Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/bbe

Original Research Article

# Nephropathy forecasting in diabetic patients using a GA-based type-2 fuzzy regression model

Q1 Narges Shafaei Bajestani [a,*], Ali Vahidian Kamyad [a], Ensieh Nasli Esfahani [b], Assef Zare [c]

[a] Department of Electrical Engineering, Tehran Science and Research Branch, Islamic Azad University, Tehran, Iran
[b] Diabetes Research Center, Endocrinology and Metabolism Clinical Sciences Institute, Tehran University of Medical Sciences, Tehran, Iran
[c] Department of Electrical Engineering, Gonabad Branch, Islamic Azad University, Tehran, Iran

ARTICLE INFO

*Article history:*
Received 9 May 2016
Received in revised form
17 January 2017
Accepted 19 January 2017
Available online xxx

*Keywords:*
Type-2 fuzzy logic
Fuzzy time series
Fuzzy regression
Nephropathy
Forecasting

ABSTRACT

Choosing a proper method to predict and timely prevent the complications of diabetes could be considered a significant step toward optimally controlling the disease. Since in medical research only small sample sizes of data are available and medical data always includes high levels of uncertainty and ambiguity, a type-2 fuzzy regression model seems to be an appropriate procedure for finding the relationship between outcome and explanatory variables in medical decision-making. In this paper, a new type-2 fuzzy regression model based on type-2 fuzzy time series concepts is used to forecast nephropathy in diabetic patients. Results in two examples show model efficiency. The use of such models in diabetes clinics is proposed.





## 1. Introduction

Diabetes is among the most common and dangerous diseases of the modern world, causing huge loss of life and financial resources in many societies every year. It is a difficult and incurable, but controllable, disease. Properly controlling this disease prevents or postpones further complications. Therefore, choosing a proper method to predict and timely prevent diabetes complications could be considered a significant step toward optimally controlling the disease.

Among patients starting renal replacement therapy, diabetic nephropathy is the most prevalent cause of kidney disease, affecting 40% of type 1 and type 2 diabetic patients [1]. Due to the prevalence of nephropathy among diabetic patients, they are usually advised to go for check-ups several

* *Corresponding author at*: Department of Electrical Engineering, Tehran Science and Research Branch, Islamic Azad University, Tehran, Iran.
E-mail addresses: narges.shafaei@gmail.com, n.shafaei@srbiau.ac.ir (N.S. Bajestani).
http://dx.doi.org/10.1016/j.bbe.2017.01.003


Please cite this article in press as: Bajestani NS, et al. Nephropathy forecasting in diabetic patients using a GA-based type-2 fuzzy regression model. Biocybern Biomed Eng (2017), http://dx.doi.org/10.1016/j.bbe.2017.01.003

times a year, yet some of these check-ups are not necessary. Unnecessary check-ups are omitted from the treatment procedure for cases in which kidney complications are predicted, while more check-ups are prescribed for patients who need them. The existing research implicates the above omissions and additions as well.

To detect and follow impairment of renal function, a knowledge of glomerular filtration rate (GFR) is required to allow the correct dosage of drugs cleared by the kidneys and to use the potentially nephrotoxic radiographic contrast media [2].

In clinical research, to evaluate the severity of disease in patients, such linguistic terms like high, medium, low, etc. are used. These terms can be modeled as fuzzy sets. Moreover, the borderline between these fuzzy sets is not crisp, although they are measured in numerical scale. As an example, to define high blood glucose in diagnosing diabetic patients, a cut-off point of 140 mg/dl for two-hour plasma glucose throughout an oral glucose tolerance test is not the precise borderline. In other words, cases within the neighborhood of the borderline indicate a vague status regarding the disease [3]. For these reasons, fuzzy models have been used in medical and especially diabetes research [4–10].

Some researchers have focused on diabetic complications with fuzzy models. For instance, the study of Bin Mansour et al. presented an algorithm based on fuzzy morphology for the computer-assisted improvement of exudates in fundus images of the human retina for the diagnosis of diabetic retinopathy [11]. The study by Narasimhan et al. researched the risk classification of diabetic nephropathy using fuzzy logic [12]. Rama Devi et al. used the design methodology of a fuzzy knowledge-based system to predict the risk of diabetic nephropathy. In their paper, the manageable risk factors like hyperglycemia, insulin, ketones, lipids, obesity, blood pressure and protein/creatinine ratio were considered as independent parameters, and the stages of renal disorder became the output parameter [13].

Since in medical research only small sample sizes of data are available, and as previously mentioned, medical data always includes some levels of uncertainty and ambiguity, some researchers have used a kind of fuzzy regression model to find the relationship between outcome and explanatory variables in medical decision-making. In 2005, Bolotin modeled two examples with fuzzy regression: one associated the quality of life with BMI categories, and the other modeled the analysis of high hemoglobin HbA1c levels among diabetic patients [14]. Pourahmad et al. predicted the existence of diabetes with respect to participants' sex, age, BMI, family history, and two-hour plasma glucose [3].

There are high levels of uncertainty in diabetes data (uncertainty in measurement device, doctor decision, patient body, patient life style, etc.) which encourage the use of type-2 fuzzy logic which can handle high levels of uncertainty.

Some researchers have used type-2 fuzzy regressions as the modeling structure. Yicheng Wei and Junzo Watada built a type-2 fuzzy qualitative regression model. They implied that they used a general type-2 fuzzy number, while it seems that they used an interval type-2 fuzzy regression model. Poleshchuk and Komarov presented a regression model for interval type-2 fuzzy sets based on the least squares estimation technique [15]. Hosseinzadeh et al. presented a weighted goal programming approach to fuzzy linear regression with crisp inputs and type-2 fuzzy outputs (WGP) [16]. This model, however, only tried to close the membership functions of observed and estimated responses by closing some of their parameters. It seems that none of the studies mentioned above could adequately model the type-2 fuzzy regression; instead, they reduced their models to only some points of type-2 fuzzy numbers.

Fuzzy time series models have been applied to real life phenomena. Different fuzzy methods have been proposed to solve fuzzy time series problems. Watada applied fuzzy regression to solve the problems of fuzzy time series [17]. Song and Chissom proposed novel definitions for fuzzy time series [18]. Chen improved Song and Chissom's model [19]. Some other researchers also improved fuzzy time series models [20–22]. Fuzzy time series models have been proposed for various applications, such as enrollment, stock indexes, load forecasting, tourism demand forecasting, etc. [23–27].

Huarng and Yu proposed a framework for a type-2 fuzzy time series model to improve forecasting results [28]. Shafaei Bajestani et al. have optimized Huarng and Yu's model to forecast the Taiwan Stock Index based on optimized high-order type-2 fuzzy time series [29,30]. The GA algorithm was also used in fuzzy regression and fuzzy time series demands for optimizing models and their results [22,31–33].

The incorporation of fuzzy regression models and type-2 fuzzy time series models is named T2FRFTS, and using the benefits of both allowed the presentation in this research of a different viewpoint to type-2 fuzzy regression models that could predict GFR efficiently in two diabetic patients. In this study, our aim is to predict nephropathy due to priori of diabetic patient. It is expected that past data of GFR models could predict future GFR with good accuracy. In fact, the condition of kidneys in future referrals could be predicted using the proposed model. GFR ($t$) and GFR ($t + 1$) are the inputs and outputs of the model, respectively.

Uncertainties of measurement devices make the data recorded in the clinics have a high level of ambiguity and uncertainty. These uncertainties confirm the use of type-2 fuzzy for modeling this data. GFR has three common formulas. These three formulas are another reason for using type-2 fuzzy sets to consider the effects of all three formulas in proper ways.

It is expected that the proposed model, considering the effect of uncertainty, will be able to present a good prediction of GFR to predict nephropathy in a diabetic patient. Our motivation and final objective is to offer software which can predict diabetic complications to specialists and diabetes clinics as a large number of the world population suffers from diabetes. This prediction can help both the patients and the doctors to prevent unnecessary experiments and check-ups. Moreover, doctors can make better decisions for the type and dosage of medication they prescribe to postpone retinopathy among diabetic patients.

The rest of current paper is organized as follows. The studies relevant to this research are reviewed in Section 2. In Section 3, the proposed model is described using two examples. Finally, Section 4 presents the conclusion.



Please cite this article in press as: Bajestani NS, et al. Nephropathy forecasting in diabetic patients using a GA-based type-2 fuzzy regression model. Biocybern Biomed Eng (2017), http://dx.doi.org/10.1016/j.bbe.2017.01.003