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A hybrid fuzzy-ontology based intelligent system to determine level of severity and treatment recommendation for Benign Prostatic Hyperplasia

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ABSTRACT

This paper deals with application of fuzzy intelligent systems in diagnosing severity level and recommending appropriate therapies for patients having Benign Prostatic Hyperplasia. Such an intelligent system can have remarkable impacts on correct diagnosis of the disease and reducing risk of mortality. This system captures various factors from the patients using two modules. The first module determines severity level of the Benign Prostatic Hyperplasia and the second module, which is a decision making unit, obtains output of the first module accompanied by some external knowledge and makes an appropriate treatment decision based on its ontology model and a fuzzy type-1 system. In order to validate efficiency and accuracy of the developed system, a case study is conducted by 44 participants. Then the results are compared with the recommendations of a panel of experts on the experimental data. Then precision and accuracy of the results were investigated based on a statistical analysis.

1. Introduction

Prostate gland is a male organ. This gland may be involved by benign or malignant neoplasms. One of the most prevalent neoplasms among benign category is Benign Prostatic Hyperplasia (BPH). BPH is a considerable health problem to aging men through its associated signs, symptoms, and complications. Although it is not life-threatening, but it can have negative impacts on a patient's quality of life (QOL), as evidenced in community and clinic-based studies [1,2].

BPH is a progressive condition characterized by prostate enlargement accompanied by lower urinary tract symptoms (LUTS) [3,4]. It arises in the per-urethral and transition zones of the prostatic gland and represents an inescapable phenomenon for the aging male population [5]. Although it is uncommon before age 40, approximately 50% of men are involved in BPH-related symptoms at age 50. Incidence of BPH increases by 10% per decade and reaches 80% at approximately 80 year of age [6,7]. An estimated 75% of men with ages more than 50 have symptoms arising from BPH, and 20–30% of men reaching 80 and over 80 years old require surgical intervention for the management of BPH [3,4].

In real world, on one hand, patients having BPH symptoms belong to different social and cultural categories and on the other hand, having access to high level medical experts to determine the level of progression of the disorder may be limited due to weakness of the medical system of the region. This is a great motivation for researchers to develop intelli-

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gent systems such as expert systems to get various signs of the patient and determine level of the disease severity in an intelligent manner.

The first medical expert system which uses symbolic knowledge in a rule-based format, MYCIN, was developed in early 1970s [17]. Adlassnig [32,33] described CADIAG II. Then its successors CADIAG III and CADIAG IV [34], utilized the concepts of fuzzy sets in order to deal with inherent uncertainties in medical knowledge.

Application of intelligent system techniques in the field of prostate disorders is a nice research area. Petrovic et al. [8] have presented a novel case based reasoning (CBR) approach to generate dose plans for prostate cancer patients. In this approach, experience of oncologists in treating previous patients is captured and a dose in two phases is recommended using a modified Dempster–Shafer theory to fuse the dose plans suggested by the most similar cases retrieved from the case base.

Application of fuzzy expert systems in predicting pathological stages of prostate cancer has been investigated in Ref. [9]. In this paper utilizing uncertain variables and approximate reasoning, a fuzzy rule-based system is developed.

Fuzzy sets have been widely used in medical signal processing applications especially in the field of prostatic disorders. In Ref. [10], the concept of ignorance function is defined and used to determine the best threshold in transrectal prostate ultrasound images. Most of efficient classification methods are based on neuro-fuzzy classification (NEFCLASS). In Ref. [11], a new approach based on NEFCLASS to classify prostate cancer is presented. This approach has several features including batch learning, automatic cross validation, and automatic determination of the rule-base size. Since symptoms of BPH and prostate cancer are very similar, medical data related to both categories are obtained to test the system. In a similar study, a neuro-fuzzy system has been developed to predict the presence of prostate cancer [12].

Fuzzy sets and systems have also been used in other medical fields. For example fuzzy clustering has been used in designing efficient in homogeneity compensation models [35], brain MR image segmentation [36], Carotid artery image segmentation [37], analysis of thyroid diseases [38], and heart disease recognition systems [39].

Neural networks are widely used in medical diagnosis during the last two decades. Artificial Neural Networks (ANN) has been utilized in prognosis of prostate cancer in Ref. [13]. In Ref. [13], an ANN is devised that yields a prognostic result indicating whether patients have cancer or not using some of the related medical data. In another research, prostate boundary is detected in ultrasound images using biologically-inspired spiking neural networks. One of the main difficulties in prostate related therapies is insufficient accuracy in decision making based on ultrasound images. In order to solve this problem, Pulse-coupled neural networks (PCNNs) which are capable of extracting edges and segments from images are utilized [14].

Although all these studies have widely used AI techniques in prostatic disorders, but there are still some limitations. First, nearly all these studies focus on prostate cancer while BPH is much more prevalent among men so it is necessary to develop intelligent systems to deal with such an illness. Second, the literature lacks a hybrid intelligent system to be able to reproduce the real decision making processes performed by urologists to be understood by non-technical audiences such as physicians. As a result, since the expert's knowledge in the medical context is mostly linguistic, application of fuzzy logic accompanied by ontologies to represent the semantic structure of the expert's knowledge seems to be necessary. Moreover, there cannot be found a hybrid system to diagnose the BPH level and to recommend appropriate treatment, simultaneously.

In this paper, a hybrid fuzzy intelligent system consisting of two modules is represented. The first module receives several signs from the patient and determines the level of BPH severity on the basis of a rule-base framework. Then, the second module completes the process of therapeutic decision-making based on the output of the first module and several other input parameters. Eventually, ontologies are used to represent the semantic structure of the expert's knowledge and provide a comprehensive formulation of the generated outcomes. This formulation is in the form of a fuzzy rule-based system and decides what the appropriate treatment for the patient is. This system is designed to be applicable in medical environments where the users are less familiar with the technical terms in the literature.

The rest of the paper is organized as follows. In Section 2, a brief introduction to fuzzy logic and ontology modeling is presented. Structure of the developed system and different modules of the system are thoroughly described in Section 3. An experiment which is conducted to evaluate the system and validate its results is given in Section 4. Conclusion remarks and future research issues are represented in Section 5.

2. Background

The proposed system relies on two knowledge representation techniques including ontologies and fuzzy logic. Fuzzy logic was first introduced by Zadeh [21] in order to handle vague concepts. Using fuzzy logic, one can make inference through rule bases using fuzzy variables which are in the form if *if-then* rules [22]. In the following ontology modeling technique is outlined briefly.

2.1. *Ontology modeling*

Ontology is a knowledge representation method with a philosophical concept as "the branch of metaphysics" which has been widely used in science and technology. From computer specialist's perspective, ontology means a vocabulary and a set of terms and relations that define, with the needed accuracy, a set of entities enabling the definition of classes, hierarchies, and other relations among them [25,26].

Ontology tries to describe and represent a knowledge domain. Therefore, ontology of a domain is a form of computer-acceptable representation of knowledge about a part of an abstract or real world. Generally, an ontology model Ω can be represented in the form of a set C of concepts and a finite family of ontological models M_k, $k = 1, 2, \ldots K$ defined as relationships described on selected subsets of C. The relationships may be of various kinds such as named roles or binary