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DESIGN OF A FUZZY MEDICAL EXPERT SYSTEM FOR CONSULTING PROSTATE DISEASES

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ABSTRACT: *The incidence of prostate-related diseases is increasing in the community. To assist physicians dealing with prostate diseases and reducing pressure on central hospitals, Medical Expert System in diagnosis and consulting is becoming an effective solution. This paper presents the design of a medical expert system using fuzzy logic rules for giving advice or preliminary diagnosis conclusions via friendly-designed graphic user interfaces.*

Key words: *Medical expert system, consulting, prostate diseases, fuzzy logic.*

Acronyms: *Information Technology (IT), Artificial Intelligence (AI), Internet of Things (IoT), Expert System (ES), Medical Expert System (MES), Graphic User Interfaces (GUI).*

I. INTRODUCTION

IT is becoming an indispensable part of our modern life. In addition to the visible applications in electronic devices used daily, IT is still being developed with other achievements aiming to enhance the quality of service in the community. The outstanding steps of IT in this era are AI, IoT, Big Data, are applied in high-tech devices. Being a part of AI, Expert System (ES) emerges as a smart solution in solving expert issues or supporting decision making in specific situations. ES acts as a human-like reasoning machine with an expert-reasoning-imitated set of conclusions to achieve reasonable conclusions for different requirements of users. It takes some advantages concerning convenience, remote use and being appropriate for many areas in the same computer space. Medical Expert System (MES) is one kind of ESs imitating knowledge of physician experts to deal with pathological problems. For this reason, MES has a high potential to be widely applied in many aspects of health care.

According to [1], a large number of countries do not have programs or guidelines to enhance early identification of common cancers at the primary care level. For example, less than 50% of surveyed countries have clinical pathways to facilitate the early diagnosis of prostate cancer in primary care. Vietnam is a developing country where MES for early diagnosis has not been widely developed because academic researches and applications on MES are very limited. Therefore, MES has not effectively contributed to the Vietnam health care system. For this reason, it is said that MES needs to be strongly promoted to meet the increasing social demand in health care systems and to solve the existing overload problem in central hospitals, thereby contribute to reducing the incidence of disease in the community.

Defined in [2], the prostate is a small gland about the size of a walnut and is a part of the male reproductive system. It is located under the bladder, near nerves, blood vessels and muscles that control erections and bladder function. These muscles include the pelvic floor muscles, a hammock-like layer of muscles at the base of the pelvis. The main function of the prostate is to secrete a fluid that nourishes and protects sperm. During ejaculation, the prostate will squeeze this fluid into the urethra, then it is expelled with semen. Commonly, the older the age is, the bigger the prostate becomes, called prostate hypertrophy. This is a normal physiological phenomenon of body aging. However, some pathological features such as urinary urgency, frequent urination, weak urination, urinating several times in less than 2 hours, difficulty urinating, painful urination are worthwhile signs because it may be a manifestation of prostate-related diseases. Causes can come from inside the body, from the outside environment or from daily living habits. Depending on the severity and nature of the diseases, the treatment may vary by patients. Without careful monitoring or improper treatment, patients may experience severe complications such as bladder stones, recurrent urinary infections, chronic urinary retention, impaired renal functions and possibly lead to kidney failure.

Although there are significant impacts on daily life such as various life-threatening complications, prostate diseases are still not paid enough attention. In most cases, patients go to hospitals and medical facilities when severe symptoms appeared. In some cases, patients even buy medicine for self-treatment without any guidance from a doctor. For outpatients, difficulties may come from objective factors such as geographical distance to health care locations, or subjective factors like hesitating to let relatives know their disease. These reasons prevent them from supplying sufficient information for diagnosis process. With features of a male disease, the approach is to make the patients feel comfortable, thereby giving their symptoms accurately to make valid diagnosis conclusions.

In the tendency to improve the quality of services and bring benefits to patients, associated with the technology and experience of specialized doctors, the Medical Expert Systems for prostate diseases are becoming a suitable solution for the time being, which helps to solve the difficulties in diagnosing and treating patients even when face-to-face visits are impractical. In addition, with high accuracy, simple operation and fast processing time, the Medical Expert Systems also support hospitals and medical facilities to regulate patients, provide specific and clear instructions to help patients arrive at the right destinations in the treatment facility. It is becoming an essential measure to create virtual hospitals and serve patients in the most optimized and effective way.

According to [3], in the particular area of logic, several approaches have been devised to deal with the referred uncertainty and ambiguousness: multivalued logics, evidential reasoning, Bayesian inference, fuzzy sets and fuzzy logic inference. In some cases, uncertainty arises due to assumptions that hold in most cases except for a handful of exceptions. Non-monotonic logics deal with those situations. In the field of MES design, fuzzy logic becomes a good solution due to its flexibility. Furthermore, fuzzy MES can explain to the user how to reach the conclusions concerning pathological classification and diagnosis [4].

This paper focuses on the design of a knowledge base and reasoning function based on fuzzy logic to classify features of prostate diseases. The structure of this paper is divided into four sections. Firstly, the specialist knowledge of prostate diseases for building the computer knowledge base is briefly introduced; Secondly, the basic design of the fuzzy medical expert system is presented; Then the design of the deductive mechanism is analyzed; Finally, the graphic user interfaces (GUI) are illustrated for consulting typical pathological cases concerning prostate disease.

II. SPECIALIST KNOWLEDGE OF PROSTATE DISEASES

According to [5], prostatitis describes a combination of infectious diseases (acute and chronic bacterial prostatitis), chronic pelvic pain syndrome (CPPS) or asymptomatic prostatitis. The classification of prostatitis includes:

- *Category I:* Acute bacterial prostatitis (ABP) which is associated with severe prostatitis symptoms, systematic infection and acute bacterial urinary tract infection (UTI).
- *Category II:* Chronic bacterial prostatitis (CBP) which is caused by chronic bacterial infection of the prostate with or without prostatitis symptoms and usually with recurrent UTIs caused by the same bacterial strain.
- *Category III:* Chronic prostatitis/chronic pelvic pain syndrome which is characterized by chronic pelvic pain symptoms and possibly voiding symptoms in the absence of UTI.
- *Category IV:* Asymptomatic inflammatory prostatitis (AIP) which is characterized by prostate inflammation in the absence of genitourinary tract symptoms.

Another common disease with a high prevalence is prostate fibroids. According to the results of some studies in Vietnam, 65-70% of men aged 45-75 suffer from prostate-related diseases and the higher the age, the greater the incidence, in which prostate fibroids ranked second in urinary-related diseases (after urinary stone). At the age of 50, the incidence rate is 50%. This number increases to 70% for the 70, and more than 90% for the over 80. The impacts of this disease make 58% of men limit fluid consumption before leaving home, 40% limit participation in crowded events, 62% avoid places without toilets. Most of them cannot stay in the car continuously for more than 2 hours or take part in outdoor sports activities and avoid drinking water before going to sleep. Common manifestations on patients are fever, painful urination, dripping urine, weak urine flow, hematuria and fatigue.

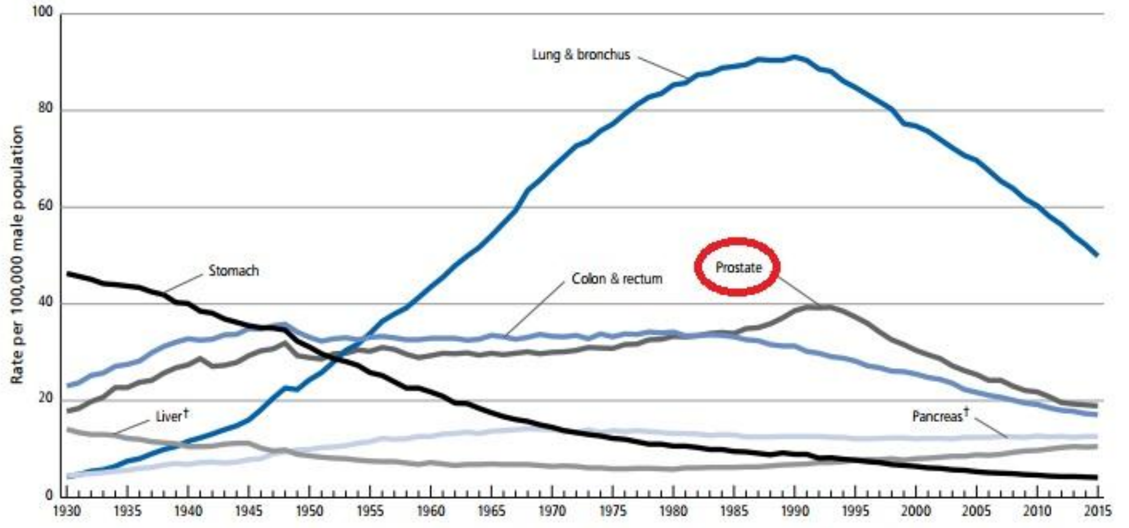


Figure 1. The proportion of prostate cancer compared to other cancers [6]

"In men, lung cancer ranks first and prostate cancer second in incidence in both developed and developing countries" [7]. As the report in [8], after screening 408 subjects during the CaP (Prostate Cancer) program in Vietnam, the result showed that prostate biopsies were carried out on 87 men (21.3%) based on Prostate-Specific Antigen (PSA) values and Digital Rectal Examination (DRE) results. Ten of these biopsied men (2.5%) were diagnosed with prostate cancer, mostly with Gleason's scores of 5 to 7 and in an early clinical stage. As shown in Figure 1, prostate cancer ranked second in comparison to other cancers in the USA. This disease is malignant, can spread to other organs and be fatal. The causes are undetermined. Studies and researches show some combinations of factors can contribute to prostate cancer such as family history, hormones, diet and environment. Symptoms are painful urination or burning feeling when urinating, blood in the urine or semen, trouble with erection, painful ejaculation and less semen. According to the Singapore Cancer Committee, prostate cancer is the third most common cancer in men. In fact, the incidence of prostate cancer has increased steadily over the past 30 years. However, prostate cancer can be cured if detected early but will be fatal if diagnosed late or not treated effectively.

According to Hospital of Ho Chi Minh City University of Medicine and Pharmacy, prostate cancer ranked 12th in popularity and the incidence of infected people has increased over time at hospitals across Vietnam. Ph.D. Duc Hoang Nguyen, Head of the Urology Department, said that the hospital receives 2 to 3 patients every day for prostate examination, of which 70% are diagnosed being cancer in the late stages, which means conducting surgery is almost futile. However, prostate cancer at an early stage has no special symptoms. Most patients have some common signs of urinary tract disorders such as difficulty urinating, frequent urinating, nocturnal urinating, etc. Prostate cancer can only be detected based on annual PSA tests.

From all of the index and data mentioned above, it can be seen that the level of interest in the prostate-related diseases is not high. In addition, the concern and fear of visiting medical facilities of patients is also an obstacle in early symptoms detection. Therefore, smart computer programs follow the doctor's knowledge to apply in remote diagnostics is becoming the right solution to solve this current problem. The physician's knowledge is transferred into appropriate rules in MES's program. The expert system presented below is an example of this application.

III. DESIGN OF FUZZY-BASED MES

The fundamentals and characteristics of heuristic inferences over uncertain information for ES are clearly introduced in [9]. The general structure of a medical expert system, shown in Figure 2, contains:

- Computer hardware
- Software program
- Medical knowledge base

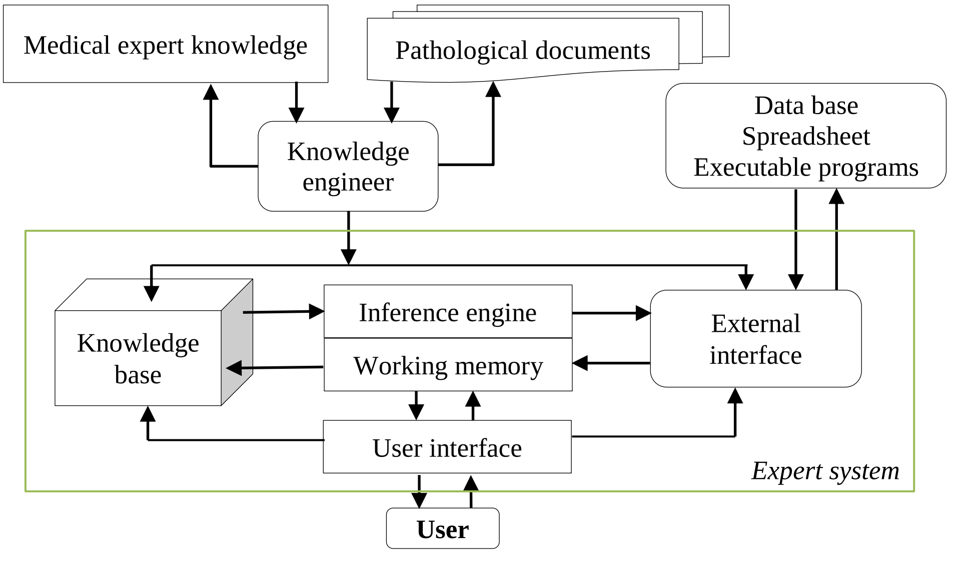


Figure 2. General structure of MES

The main part of MES is the software program and data in the knowledge base. The software program is the part of expressing expert knowledge in the form of rules that can be understood by a computer. It contains:

- *Knowledge base:* includes knowledge units called rules (or 'production memory'), organized as a database. In a knowledge base, there are two types of knowledge as assertion knowledge and operating knowledge.
- *Inference engine:* a tool, a program or a processor creates reasoning by deciding which rules will satisfy events, objects; prioritize satisfied rules, and enforce the highest priority rules.

Developed from the study of inference rules based on certainty factors in [10], this research improves the human-imitated reasoning by adding fuzzy logic rules into the knowledge base and the inference engine of the Medical Expert System (Fuzzy-based MES) to deal with uncertainty factors. The program of this MES is named PD_Diagnosis. Its structure is performed below.

The four basic modules of the fuzzy-based MES for diagnosis namely Fuzzifier, Pathological Rules, Inference Engine, and De-fuzzifier are shown in Figure 3.

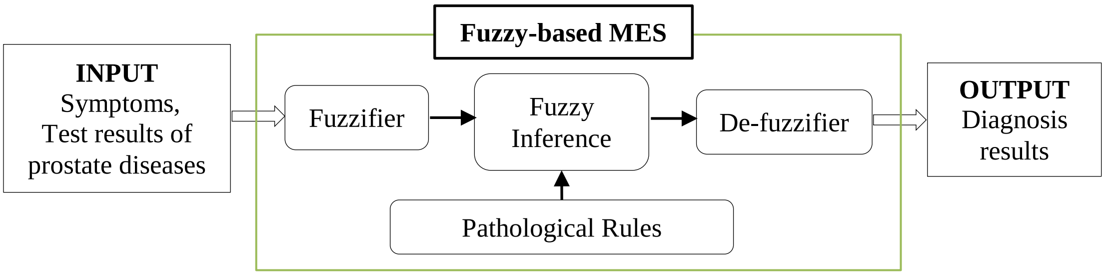


Figure 3. Block diagram of the fuzzy-based MES for Prostate diagnosis

The input data of the system are the symptoms and test results of a patient. In the module Fuzzifier, input data is fuzzified into fuzzy sets for classifying diseases before being provided for the module Inference Engine, where the data are compared to the given rules. The module Rules represented by the physician expert knowledge to produce the fuzzy result set. In the next step, module De-fuzzifier turns the fuzzy results into crisp results, and an output decision for the diagnosis will be made based on it.

A sample fuzzy logic rule in the module Rules has three basic following forms:

$$\text{IF } A \text{ THEN } X \quad (1)$$

$$\text{IF } A \text{ AND B THEN } X \quad (2)$$

$$\text{IF } A \text{ OR B THEN } X \quad (3)$$

where

- A and B are crisp values defined under physician's knowledge of prostate diseases;
- X is a crisp value represented for a conclusion of the expert.

The bottom nodes can convert general rules into simple rules (with appropriate weights) as follows:

$$\text{IF } A \text{ AND } B \text{ THEN } X \text{ OR } Y \Leftrightarrow \begin{cases} \text{IF } A \text{ AND } B \text{ THEN } X \\ \text{IF } A \text{ AND } B \text{ THEN } Y \end{cases} \quad (4)$$

All prostate diseases are shown in the knowledge tree (Figure 4). The first layer shows four main diseases by classifying its unique features from each other. The following layers diagnose the specific selected disease with input data from patients. This paper will focus on 'Classification' and 'Prostate cancer' layer. Both layers use the Fuzzy logic toolbox for fuzzifying and de-fuzzifying input data before making output decision. With four input symptoms, the Classification layer will make a decision for the user to continue in which specific disease for the following process.

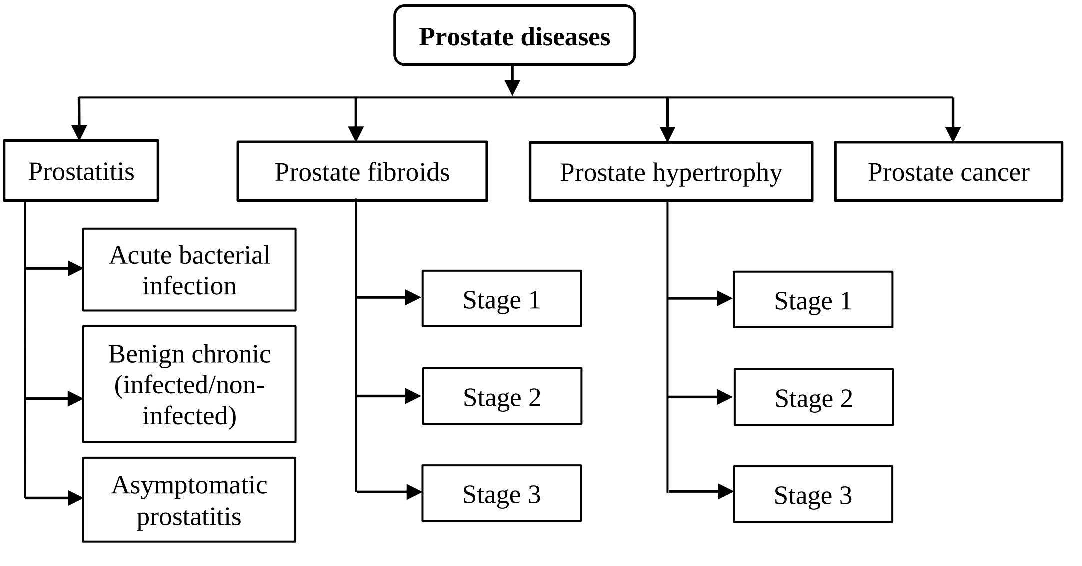


Figure 4. Classification for all prostate diseases

Figure 5 shows steps that are carried out in the 'Prostate cancer' layer, where clinical diagnosis and definitive diagnosis are used as input data for diagnosing. The clinical diagnosis is executed based on the external symptoms concerning fever, pain and features of urination. The clinical symptoms are provided from patient data and prescreened by a physician in hospitals or health care facilities. The definitive diagnosis is completed in a laboratory of bacteriologic examination involving urine and PSA tests, which are performed in higher level hospitals.

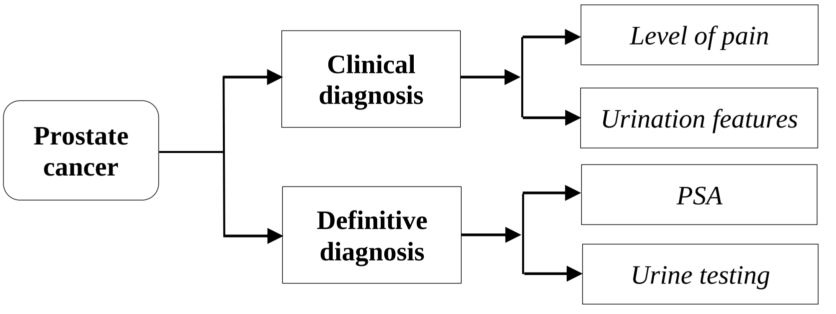


Figure 5. Search tree for prostate cancer diagnosis

According to [11], prostate-specific antigen, or PSA, is a protein produced by normal, as well as malignant, cells of the prostate gland. The PSA test measures the level of PSA in a man's blood. For this test, a blood sample is sent to a laboratory for analysis. The results are usually reported as nanograms of PSA per milliliter (ng/mL) of blood. The PSA index plays a prominent role in diagnosing prostate diseases. The blood level of PSA is varied according to the age and caused by various reasons, especially prostate cancer. The data of normal PSA level in ages and the percentage of prostate cancer patients with various total PSA level is shown in table 1 and table 2 relatively.

Table 1. The average PSA level in different age groups

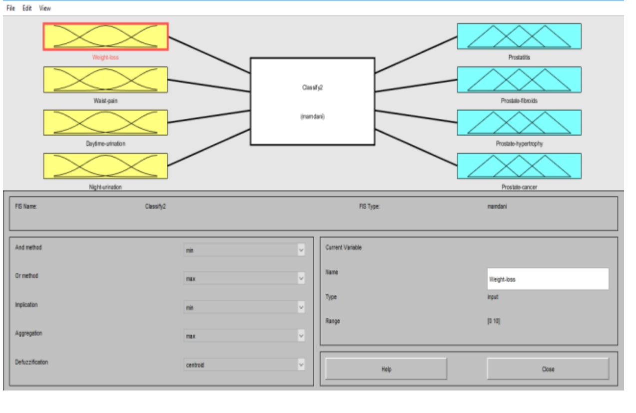
Age	Normal PSA level (ng/ml)
40 – 49	≤ 2.5
50 – 59	≤ 3.5
60 – 69	≤ 4.5
70 – 79	≤ 6.5

Table 2. The relationship between total PSA level and prostate cancer rate

Total PSA level (ng/ml)	Proportion of prostate cancer (%)
0 – 2.4	Rare
2.5 – 4.0	12 - 23
4.1 – 10.0	25
> 10.0	> 50

IV. THE MECHANISM OF FUZZY LOGICAL REASONING

Medical diagnosis usually involves careful examinations to check the presence and strength of some features relevant to a suspected disease in order to decide whether the patient suffers from that disease or not. By this reason, the fuzzy inference system of PD_Diagnosis is divided into two layers: Classification and Specific Diseases. For the Classification layer, there are 4 inputs and 4 outputs as demonstrated in Figure 6. The inputs are Weight loss, Level of waist pain, Daytime urination and Night urination. The outputs corresponding to 4 mains specific prostate diseases. The following example shows the index of prostate cancer.



Input/Output	Levels	Geometric shape	Interval
Weight-loss	Few Moderate Many	trapmf trapmf trapmf	[0 0 1.5 3] [2 3.5 6 8] [7 9 10 12]
Waist-pain	Mild Moderate Extreme	trapmf trapmf trapmf	[0 0 1 3] [2 3 7 8] [7 9 10 12]
Daytime-urination	Few Moderate Many	trapmf trapmf trapmf	[0 0 1 3] [1.5 3 5 7] [6 7 10 12]
Night-urination	Few Moderate Many	trapmf trapmf trapmf	[0 0 1 3] [1.5 3 5 7] [6 7 10 12]
Prostatitis	Low High	trapmf trapmf	[0 0 0.1 0.4] [0.3 0.5 1 2]
Prostate-fibroids	Low High	trapmf trapmf	[0 0 0.1 0.4] [0.3 0.5 1 2]
Prostate-hypertrophy	Low High	trapmf trapmf	[0 0 0.1 0.4] [0.3 0.5 1 2]
Prostate-cancer	Low High	trapmf trapmf	[0 0 0.1 0.4] [0.3 0.5 1 2]

Figure 6. Fuzzy inference system and membership functions for the Classification layer

The sample relationships among inputs and output are illustrated in Figure 7. After that, the final step carried out in the inference process is defuzzification.

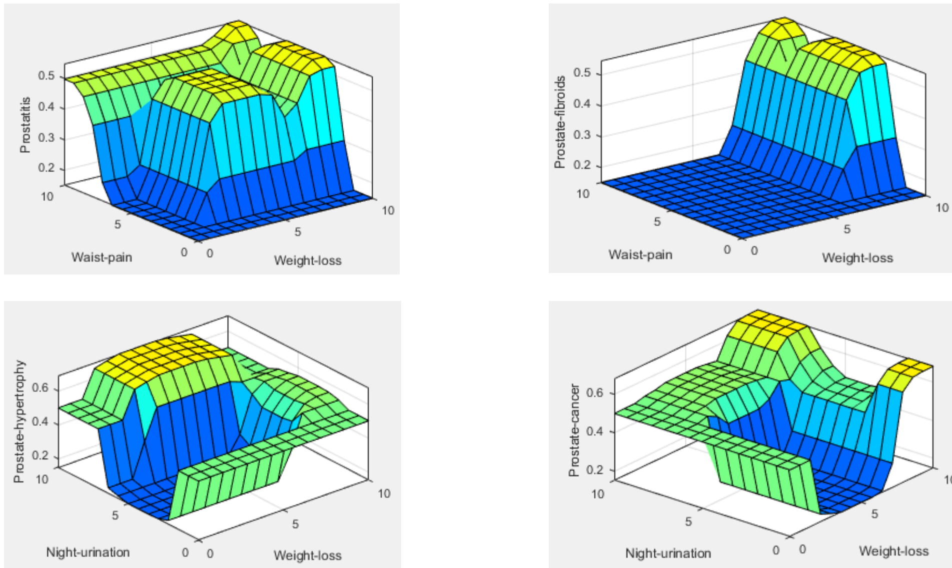


Figure 7. Relationships among output result and input data

After the Classification layer, the output results are shown with the index of 4 main diseases. User will continue to choose a disease base on these calculated percentages. In Specific diseases layers, the same fuzzy inference system is used with more inputs for only 1 output. For prostate cancer example, there are 6 inputs namely Body temperature, Physical strength, Difficulty in urinating, Feature of urination, Urination pain and Ejaculation pain. The output is the possibility patients come down with prostate cancer.

There are 4 steps in the performance of the inference engine in PD_Diagnosis:

- Step 1: Classification: Evaluate patient’s first 4 symptoms to find out which disease that the patient has the highest chance to get. The rate for each disease is shown in a chart and then, the user will choose a specific disease for further diagnosis.
- Step 2: Clinical diagnosis: Calculate the chance that the patient has the chosen disease (μ_D). If μ_D is greater than a certain number ε, then go to step 3. If not, go straight to step 4.
- Step 3: Definitive diagnosis: The system requires 2 samples from Urination test and PSA test. PD_Diagnosis utilizes those inputs in combination with symptoms in step 2 to recalculate μ_D.
- Step 4: Conclusion: Using the results of step 2 and 3 to give the final result.

V. GRAPHIC USER INTERFACES

The whole program is written in Matlab, one of the most popular programming software for biomedical engineers. The program is organized the same as the structure shown in Figure 3. The PD_Diagnosis MES has 5 layers of user interface: Beginning layer; Classification layer; Clinical diagnosis layer; Definitive diagnosis layer and Diagnostic Conclusion layer.

The beginning interface is displayed in Figure 8. The interface gives instructive information about all diseases are contained in this program including Prostatitis, Prostate fibroids, Prostate hypertrophy and Prostate cancer.

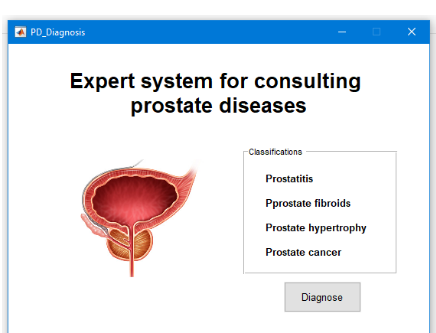
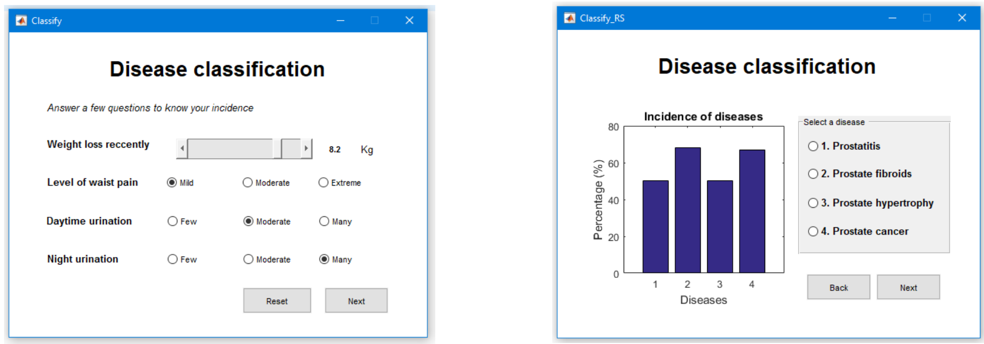


Figure 8. The first user interface of *PD_Dianosis*

When the user clicks on the ‘Diagnose’ button in the beginning interface, the interface of Disease Classification pops up as shown in Figure 9a. Four questions are displayed to get inputs before proceeding to the next steps of the diagnosing process. The answers will be recorded for the last conclusion.



a) b)

Figure 9. The Classify interface and the resulting interface for the Classification layer

After clicking the ‘Next’ button, a sample result for the Classification layer is shown in Figure 9b. The percentages for 4 main disease cases are calculated to show users the incidence. Select one specific disease and choose ‘Next’ to continue the clinical diagnosis.

The next layer is Clinical Diagnosis. Six typical symptoms of Prostate cancer mentioned above will be listed in this interface. Each symptom is shown in a separated interface as shown in Figure 10a.

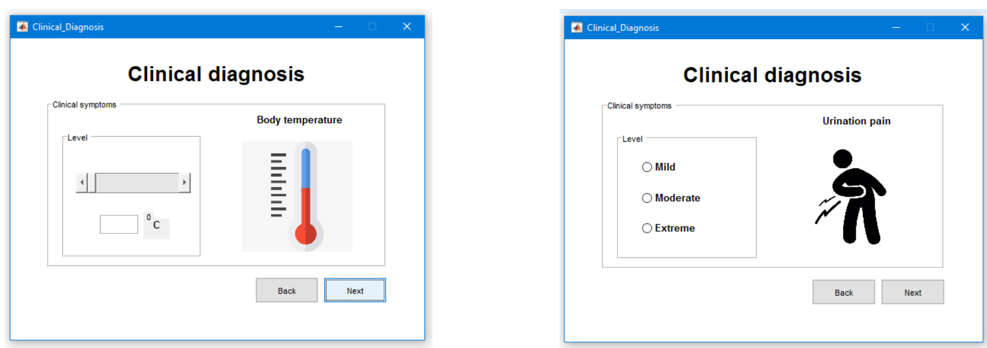


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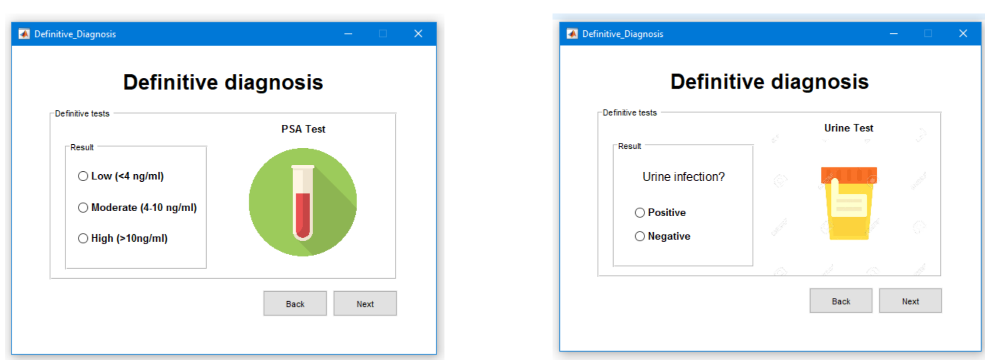
Figure 10. User interfaces for clinical diagnosis

After choosing the ‘Next’ button in Figure 10b for the last clinical symptom, the system will combine all the answers with previous calculations from the Classification step and evaluate the possibility that the patient has prostate cancer (μ). If μ is not greater than ε then PD_Diagnosis will show the Diagnostic Conclusion interface. In contrast, the definitive diagnosis is recommended.



a) b)

Figure 11. User interfaces for definitive diagnosis

Figure 11a displays the GUI of definitive diagnosis on PSA level test. Figure 11b displays the user interface of definitive diagnosis on the urine test. If μ is greater than ε, this interface will show up to ask for user’s test results.

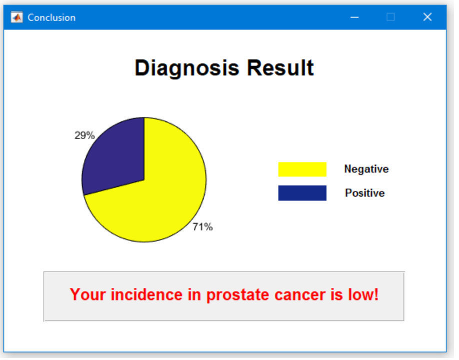


Figure 12. User interface for consulting result

At the last step, the result is shown in the Conclusion interface as Figure 12. The percentages of incidence for the chosen diseases are demonstrated in a pie chart with the conclusion as a diagnosis result.

VI. CONCLUSION

The paper presents the design of MES with the knowledge base and the reasoning processes based on the fuzzy logic to consult prostate diseases. In addition, many GUIs are designed to provide input data for the MES related to pathological symptoms and test results. The outputs of MES are advice to patients on the preliminary treatment of prostate disease.

In the next phase, a rule generator will be developed to create IF-THEN rules automatically based on the symptoms and conclusions in the medical record. After that, the MES will be operated in hospitals to evaluate the quality of the designed system.

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THIẾT KẾ HỆ CHUYÊN GIA Y TẾ DỰA TRÊN LOGIC MỜ ĐỂ TƯ VẤN VỀ CÁC BỆNH TUYẾN TIỀN LIỆT

Mai Ngọc Anh, Phạm Duy Dương

TÓM TẮT. *Tỷ lệ mắc các bệnh liên quan đến tuyến tiền liệt ngày càng tăng cao trong cộng đồng. Để hỗ trợ các bác sĩ đối phó với các bệnh về tuyến tiền liệt và giảm áp lực quá tải cho các bệnh viện tuyến trung ương, nghiên cứu này đề xuất một Hệ chuyên gia Y tế hỗ trợ chẩn đoán và tư vấn về bệnh nhằm cung cấp một giải pháp hiệu quả cho bài toán quá tải bệnh viện. Mô hình Hệ chuyên gia y tế này sử dụng các quy tắc logic mờ để đưa ra lời khuyên hoặc kết luận mang tính chẩn đoán sơ bộ. Hiệu quả hoạt động của Hệ chuyên gia y tế này được đánh giá trên dữ liệu bệnh nhân được lấy từ một số cơ sở chăm sóc sức khỏe ở Việt Nam.*