Process modeling and assisted diagnosis in spinal recovery

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Abstract - The diagnosis and treatment of lumbar spine pathology represents a complex process involving many and diverse parameters that should be investigated and processed. In order to properly approach the computer-assisted treatment and diagnosis this paper presents a model of the process using BPMN and also a UML model for implementation. The data is supplied directly from the keyboard or from the Zebris equipment. The parameters investigated are: demographic data, disability status (4 degrees), daily activity expressed in calories (24 possibilities), Zebris mobility degree (minimum/maximum – 6 values), and Zebris position rate (expressed as an angle).

The inference engine of the presented method is created using fuzzy inference system. The data collected from the patients and the Zebris equipment is transformed in linguistic variables and the appropriate fuzzy inference rules are constructed. The consequences of the rules encode the actions that should be taken.

Relating the values of the investigated parameters, screening values for each measurement can be established. Future work will result in prediction of recovery rate and also developing educational tools related to recovery domain.

I. INTRODUCTION

The aims of the study are to identify and correlate in a symmetrical way three key elements in the management of low back pain: diagnosis, treatment and prevention [1]. The ultimate goal is to implement an expert system to manage these disease stages.

As the computer-aided diagnostic (CAD) has already become a part of the clinical work we propose to implement CAD system to interpret the mentioned clinical data. The computer output is considered as a “second opinion” in the diagnostic process. CAD systems are based on some kind of inference system. Fuzzy inference systems are used with success to determine if a patient suffers of typhoid fever [2]. Another CAD system based on fuzzy inference is use to identify the presence of neuromuscular disorder [3]. Yet another system based on the same principle is used to predict the possibility of the appearance of multiple sclerosis [4]. We propose to implement a fuzzy inference system in a CAD process to determine if a patient will need or not a surgical intervention to correct spinal deformations.

II. DESCRIPTION OF THE PROCESS

When a patient comes to the doctor, clinical and personal data is registered. Further, the patient is diagnosed; he responds to a questionnaire and the calories related to daily activity are computed with the formulas presented in Figure 1. Finally his spinal parameters are measured with Zebris. After performing all these steps a decision is taken: some patients will undergo surgery and others will follow the conservative medical and rehabilitation therapy.

The part of data flow for the proposed solution is presented in Figure 1. When the application starts, the doctor fills in the patient demographic data: first and last name, age, gender, living area (urban or rural), occupation (engineer, doctor, etc.) and presumptive diagnosis. The last one will be followed by a more extended and then confirmed. The treatment to be followed can be surgical or conservative (rehabilitation and medication).

Four types of data will be investigated for each patient: demographic data, disability status (4 degrees), daily activity expressed in calories (24 possibilities), Zebris mobility degree (minimum/maximum – 6 values), and Zebris position rate (expressed as an angle).

The disability status is determined from patient’s answers to 10 questions. The resulted score sum is the investigated parameter. Each question is scored from 0 to 5 points considering the difficulty in carrying out the daily activities. Depending on the final score we determine the patient’s disability to perform certain activities and the final score falls within a described interval. If the investigated parameter is between 0-10 points then there is a minimum disability; if the result is between 10-20 points there is a mild disability; if the result is between 20-30 points there is a moderate disability; if the result is between 30-40 points there is a severe disability, and if the result is between 40-50 points then bed rest is needed. Our questionnaire is adapted after the Oswestry scale and Quebec scale [5], [6]. The daily activity parameter refers to the calories needed by the patient to perform his daily living activities. It is computed using the formula given by WHO (World...
Along with age muscle tissue diminishes in favor of fat and internal organs decrease in size and activity. This natural phenomenon is more pronounced at people who had no physical activity throughout life. Calories are influenced by daily activities. In order to maintain a healthy weight there is a need for a more precise calories control. They can influence our health and can cause a number of inconveniences.

There are convincing epidemiologic data to support the role of increased physical activity and exercise with reduced risks of various chronic diseases, including cardiovascular disease, low back pain, degeneration, certain cancers, type 2 diabetes mellitus and osteoporosis. Better understandings of the biologic mechanisms that link sedentary lifestyle to poor health are needed to refine and support physical activity guidelines [8].

The data related to daily activities categories:
- reduced physical activity: $M=1.56$, $W=1.56$;
- average physical activity: $M=1.78$, $W=1.64$;
- increased physical activity: $M=2.10$, $W=1.82$, where $M$ is man and $W$ is woman.

The Zebris Mobility facility measures the minimum and maximum values reflecting the mobility of the spinal cord when the patient performs flexion-extension, rotation and laterality. The results from these measurements are six values that will reflect the degree of mobility associated with the patient.

Biomechanical parameters:
- $PB_{OP}$ 1 - is a parameter that quantifies the difference between the maximum amplitudes of the lumbar spine before and after surgery of a patient moving flexion. Maximum amplitude is obtained by averaging the instantaneous maximum angular values recorded in this type of movement. The determination of the angle is performed preoperatively (preop) and postoperative (post-op) at 3 months. $PB_{OP}1 = \bar{\beta}_f(\text{postop}) - \bar{\beta}_f(\text{preop})[\%]$
- $PB_{OP}$ 2 - is a parameter that quantifies the difference between the maximum amplitudes of the lumbar spine before and after surgery of a patient moving extension. $PB_{OP}2 = \bar{\beta}_e(\text{postop}) - \bar{\beta}_e(\text{preop})[\%]$
- $PB_{OP}$ 3 - is a parameter that quantifies the difference between the maximum amplitudes of the lumbar spine before and after surgery of a patient in rotation. $PB_{OP}3 = \bar{\beta}_r(\text{postop}) - \bar{\beta}_r(\text{preop})[\%]$
- $PB_{OP}$ 4 - is a parameter that quantifies the difference between the maximum amplitudes of the lumbar spine before and after surgery of a patient in lateral excursion. $PB_{OP}4 = \bar{\beta}_l(\text{postop}) - \bar{\beta}_l(\text{preop})[\%]$
- $PB_{OP}$ 5 - is a parameter that quantifies the difference between postural angle of the spine before and after surgery. This angle is determined fully upright. $PB_{OP}5 = \bar{\alpha}(\text{postop}) - \bar{\alpha}(\text{preop})[\%]$
- $PB_{TR}$ 1 – quantify the difference between the maximum amplitudes of the lumbar spine before and after nonsurgical treatment of a patient's moving flexion. Maximum amplitude is obtained as in the previous case. The determination of the angular measurements are done before treatment values (pretrt) and after of therapy (posttrt) at 3 months. $PB_{TR}1 = \bar{\beta}_f(\text{posttrt}) - \bar{\beta}_f(\text{pretrt})[\%]$
- $PB_{TR}$ 2 – quantify the difference between the maximum amplitudes of the lumbar spine before and after nonsurgical treatment of a patient's moving extension. $PB_{TR}2 = \bar{\beta}_e(\text{posttrt}) - \bar{\beta}_e(\text{pretrt})[\%]$
- $PB_{TR}$ 3 – quantify the difference between the maximum amplitudes of the lumbar spine before and after nonsurgical treatment of a patient moving extension $PB_{TR}3 = \bar{\beta}_r(\text{posttrt}) - \bar{\beta}_r(\text{pretrt})[\%]$
- $PB_{TR}$ 4 – quantify the difference between the maximum amplitudes of the lumbar spine before and after nonsurgical treatment of a patient in lateral excursion. $PB_{TR}4 = \bar{\beta}_l(\text{posttrt}) - \bar{\beta}_l(\text{pretrt})[\%]$
- $PB_{TR}$ 5 - is a parameter that quantifies the difference between postural angle of the spine before and after treatment. This angle is determined fully upright. $PB_{TR}5 = \bar{\alpha}(\text{posttrt}) - \bar{\alpha}(\text{pretrt})[\%]$
The definition of the physiological meaning of the biomechanical parameters presented in figure 2 is:
- $PB_{SF1} \leq 0$ - loss of mobility due to surgery;
- $PB_{SF1} > 0$ - improving mobility following surgery;
- $PB_{SF5} < 0$ - postural recovery;
- $PB_{SF5} \geq 0$ - features gait;
- $PB_{TR1} \leq 0$ - loss of mobility due to nonsurgical treatment;
- $PB_{TR1} > 0$ - improving mobility following nonsurgical treatment;
- $PB_{TR5} < 0$ - postural recovery;
- $PB_{TR5} \geq 0$ - enhancing or maintaining posture.

The Zebris Position parameter measures the deviation of the spine from the normal position as a certain angle. After modeling the process, the resulted application is SpinalTreat. Based on this application, patient data is processed. By interrelating the effect of the four presented parameters, normal or abnormal screening domains will be reported. The prediction of future injury development will be proposed.

### III. THE BPMN MODEL

The definition of the Business Process Modeling and Notation (BPMN) after [9] is “a graphical notation that describes the logic of steps in a business process”. Also, this graphical notation is designed to coordinate the sequences of processes and messages that flow between participants in different activities. BPMN is used to communicate with a wide variety of information to a wide variety of audiences [10] and it is recommended as:
- an internationally accepted process modeling standard
- being independent of any process modeling methodology

- creating a standardized bridge which reduces the gap between business processes and their implementation
- enabling to model processes in a unified and standardized way so that everyone in an organization can understand each other.

Figure 3 presents the workflow of the actions in a recuperation center.

The software used is Bisagy Modeler. Figure 3 presents the actions of the doctor, patient and the application (SpinalTreat).

In this model the doctor will act when a patient comes for a visit and personal data is registered. After that, the patient is diagnosed, he responds to a questionnaire, the calories related to daily activity are computed and finally his spinal parameters are measured with Zebris. After performing all these steps a decision is taken, then is given a prediction.

### IV. THE UML MODEL

The present work is using Unified Modeling Language (UML) to model the real workflow in Recovery Center from an IT perspective.

UML is a standardized general-purpose modeling language used in object-oriented software engineering field. The OMG (Object Management Group) created and manage this standard and becomes the industry standard for modeling software-intensive systems [11].

Figure 4 presents a use case where a doctor adds different data about the patient (demographic data, calories, spinal parameters).

Figure 4. Use case for doctor adding patient data
V. THE INFERENCE SYSTEM

Fuzzy logic extends the classical Boolean logic by introducing a degree of uncertainty. The fuzzy logic maps a numerical to a linguistic value \([Zad65]\). This mapping is done using fuzzy membership functions which indicates a degree of appurtenance to a fuzzy set. A degree of 1 indicates a full membership to the fuzzy set and a degree of 0 indicates that the element is not part of the fuzzy set.

To represent the imprecision and vagueness of the entities and relationships the theory of the fuzzy sets are employed. If \(U\) is considered as a fuzzy set, then \(A\) is considered as a fuzzy subset, then there is a function, called membership function, \(\mu_A\), which:

\[
\mu_A(U) = \left[0,1\right]
\]

\[
A = \{x: \mu_A(x)\} \subseteq U
\]

\[A\] is a fuzzy subset if there is a \(U\) such that \(A\) is a fuzzy subset of \(U\). (2)

Several fuzzy sets of the same kind form a linguistic variable. In our case we use the linguistic variables as presented in figure 5:

- For the demographic data: age (children , teen, young, mature and elder ) , sex (female, male), occupation (engineer, doctor);
- For the medical data: disability status (minimum, moderate, severe, disability, bed_rest), Zebris_data (High, Middle, Low) for each numerical parameter (PB_{op1} … PB_{op5} and for the PB_{tr1} … PB_{tr5}), daily activity (24 fuzzy sets)

![Figure 5 The fuzzification of the disability status](image)

The linguistic variables are used to create the fuzzy inference rules. These rules are very similar to the natural language communication. They can be compared with instructions coming from one person to another. In their general form they have an antecedent and a consequence separated by the "THEN" statement. The antecedent is a conjunction of several fuzzy terms (using the statement IS) and several logical operators (AND, OR, NOT) between them.

The general form for the fuzzy inference rule is: “IF \(LV_1 IS FS_1 AND LV_2 IS FS_2 AND LV_3 IS FS_3\) THEN \(R_1 IS FS_4\)”.

The antecedents of the rules are the collected clinical data and the consequent of the rules is a suggestion to perform or not to perform a surgery to correct the position of the spinal cord.

The computational form of a fuzzy rule is the following:

\[IF \text{Age IS Teen And Sex IS Female AND Occupation IS Student AND Disability IS Moderate AND BP_{tr1} IS High AND BP_{op2} IS High AND BP_{op3} IS High AND BP_{op4} IS High AND BP_{op5} IS High AND DayAct IS Intens THEN Recommendation IS NoOperation.}\]

It is mandatory for the inference rules to cover all the possible situations to eliminate the possibility on unstated results.

VI. SPINALTREAT APPLICATION

SpinalTreat is a web-based application developed in Visual Studio .NET 2012 using ASP.NET and C#, using Sql Server 2012.

The application is developed after the model described in Section II, where the doctor can add patient demographic data, add different parameters based on which a prediction is given. Also, the doctor will have the possibility to perform different statistics.

![SpinalTreat interface example](image)

The SpinalTreat is work in progress and Figure 6 presents an interface where the doctor adds patient demographic data.

VII. RESULTS

The paper presents the models supporting a clear and complete development for a complex implementation of an application that assists spinal investigations for diagnosis and treatment.

Starting from a current problem in medicine that affects more and more patients and concerns physicians, spinal recovery, we developed a model and applied fuzzy theory for building the application SpinalTreat in order to obtain a performing tool for analyzing and predicting injured patient’s evolution.

VIII. CONCLUSIONS

The implementation of predictive software with the help of SpinalTreat system is necessary for tracking the patient and for prognosis disease progression as early as possible. The system is needed both for physician and patient for the best possible evidence in terms of daily activities and in terms of disease progression.

The novelty of this software is the ease of information storage related to patients and the feature to early identify complicated diseases or evolution of the disease, which direct us to make a decision on the next step in treating the pathology.

The software application allows physician to diagnose many more pathologies starting from a single diagnosis. It helps us to follow patients at 2 weeks, 6 months and one
year and to compare easily the results. SpinalTreat is necessary both for daily use and in terms of research.

REFERENCES

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