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Modelagem do Comportamento Hemodinâmico de um Paciente Virtual Cirúrgico baseado em Sistema Especialista Fuzzy.

Hemodynamic behavior modeling of a Virtual Surgical Patient based on a Fuzzy Expert System.

Modelado de comportamiento hemodinámico de un paciente quirúrgico virtual basado en un Sistema Esperto Fuzzy.

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ABSTRACT: The Virtual Reality (VR) allows its users to experience a sense of being immersed in synthetic 3D scenarios generated by computer graphics. The so-called Virtual Environments (VEs) based on RV can be applied to medical education, enabling: repetitive training and the development of psychomotor skills in surgical procedures without compromising real patients. Surgical simulators that feature Dynamic Virtual Patients (VPs), that is, reacts physiologically to interventions and medical decisions made during the training. These systems present more realism while it offers the possibility of varying clinical cases. This work has as main objective to discuss important issues of modeling the hemodynamic performance of a VP, specifically to simulate blood pressure values (both sistolic and diastolic variables). The model of a VP is presented as result as well as is presented an architecture for its integration to simulators based on VR.
Key-words: Patient Simulation, Computer Simulation, Fuzzy Logic, Anesthesiology.

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I INTRODUCTION

Virtual Reality (VR) technology is an inter and multidisciplinary branch of human knowledge, which allows the simulation of various events in three-dimensional graphic environments, that are denominated Virtual Environments (VEs)[1]. Some of the main features of VEs are: responsiveness to user actions in real time; interactivity; acuteness of users' cognition making them feel immersed in an alternate reality (immersion principle); use of electronic devices for unconventional human-machine interaction (e.g., data gloves, haptic devices), among others[2]. In the context of health education, medicine is certainly one of the most areas benefited with the advent of this technology. The VR-based simulators for medicine (or medical simulators), enable cost reduction of training process, using more interactive teaching techniques, and decreased use of animal subjects and bodies, favoring the ethical aspects involved in the training of new professionals[2,3].

At first, a graphical simulation consists of a mathematical and physical model of natural phenomena, as well as the interactions between different events. In this sense, VR makes it possible to simulate one or more physiological systems (e.g. lymphatic, respiratory, cardiopulmonary, etc.) of Virtual Patients (VPs)[4]. The VPs simulations are applied with different goals: surgical monitoring of vital signs, training in meeting emergencies5, physiological reactions to test new drugs, development of diagnostics, training, in surgical decision making, clinical randomization, simulation of extreme medical conditions allowing students to gain experience, VP parameterization based on data from real patients, among others. In general, the PVs have the characteristic of responsiveness, i.e. they are able to adequately respond to different stimuli (external or internal) to their own physiology, such as medical interventions. These VEs are also known as Dynamic Virtual Patient (DVP) simulators, or Virtual Patients (PVs) with pathophysiology or responsive dynamics[4].

In this context, different Decision Models (DMs) or techniques of Artificial Intelligence (AI)[1,3,5] can be applied on these physiological systems modeling[4]. However, before the definition of the DM to be used, it is necessary to answer some important questions: what is the nature of the data involved (e.g. vital signs)? How to treat them? The studied variables feature (or not) aspects of inaccuracy and/or measurement uncertainty? What are the surgical events to which the model will be subordinate? What level of interaction (correlation) with the other physiological systems of the patient? Throughout the process of design of this study, it was observed that for the simulation of the physiology of a VP, a large number of involved variables (e.g. vital signs), presents an inherently imprecise nature. Thus, for this work, we opted for the use of the theory of fuzzy logic proposed by Lotfi Zadeh[6], which states that where there is subjectivity in the knowledge base, its representation can be made logically.

This work aims to present a proposal for modeling the hemodynamic performance of a surgical

VP (under non-invasive monitoring) through a methodological development research. The variables initially studied are: systolic blood pressure (SBP) and diastolic blood pressure (DBP). Monitoring of blood pressure is the most common method of monitoring of the cardiovascular system, and such variables represent the potential energy to tissue perfusion, that is, the eventual supplying blood to tissue[7]. The proposed model is based on a fuzzy Expert System (ES)[1,6] with the actual data being consulted (qualitative and quantitative) based in the medical literature about the fluctuations of hemodynamic parameters of surgical patients in different conditions of normal or high blood pressure.

II THEORETICAL FOUNDATION

2.1 Blood Pressure Monitoring of the Surgical Patient

The key elements of the surgical monitoring include observation and surveillance, observation data through devices, analysis and institution of corrective measures, for each specified case. The objective monitoring provides the best intraoperative conditions and detect abnormalities early so that corrective measures are employed before happens serious and irreversible damage[9]. The monitors are used for safer patient who undergoes surgery easier to read different vital signs such as blood pressure, heart rate, oxygen saturation levels, respiratory rate, body temperature, among others[8]. Indications, risks and benefits related to the use of electronic and invasive monitoring and non-invasive should be evaluated according to each patient individually. These decisions should be made taking into consideration the patient's condition, the type of surgery and the risk of complications associated with invasive monitoring. However, the propagation of monitoring devices does not reduce the need for clinical parameters (inspection, observation, auscultation, palpation)[8].

Arterial blood pressure is the pressure thrust created by the pumping action of the heart, usually, arterial blood pressure reflects the ventricular pressure[10]. The systolic pressure is the highest blood pressure measured during a cardiac cycle for the artery's pressure after the blood has been ejected by the left ventricle systole. In the other hand, the diastolic pressure is the lower blood pressure measured during a cardiac cycle, equivalent to the pressure in the artery during ventricular relaxation when there is no more blood being ejected by the left ventricle[11]. According to the Brazilian guidelines stipulated by the Hypertension Brazilian Society of Cardiology[12], different classes are used for classification of blood pressure of a patient (Table I). Blood pressure monitoring is required during all anesthetic procedures and can be considered as the most common method of monitoring of the cardiovascular system[7]. The available techniques of non-invasive blood pressure monitoring are appropriate for most surgical cases and the most modern operating rooms are equipped with automated blood pressure analyzers.

Table I. Blood pressure classes according to the Brazilian guidelines of hypertension.

Classification	**SBP (*mmHg*)**	**DBP (*mmHg*)**
Optimun	< 120	< 80
Normal	< 130	< 85
Limitrophe	130 - 139	85 - 89
Hypertension - stage 1	140 - 159	90 - 99
Hypertension - stage 2	160 - 179	100 - 109
Hypertension - stage 3	≥ 180	≥ 110
Isolated systolic hypertension	≥ 140	< 90

Credits: IV Brazilian guidelines stipulated by hypertension Brazilian Society of Cardiology.

The indications for invasive blood pressure monitoring include intraoperative use of induced hypotension, continuous assessment of blood pressure in patients with severe organ damage or undergoing high risk surgical procedures when non-invasive methods are inadequate[9]. In this context of human knowledge modeling, the Expert Systems (ES) are inserted. According to Moraes and Machado[1], the architecture formed by the base of expert knowledge (in this case, the medical knowledge) and an inference system is called the “Expert System” (ES). The ESs are those systems that utilize the knowledge of a human specialist in a particular specific domain, to answer important questions and solve problems in this field. In these systems, they can be used for modeling knowledge, classical logic and/or fuzzy logic, this being encoded into logical rules, where each rule of an ES relates to a variable of interest. The most basic rules are like *“IF <condition satisfied> THEN <conclusion>”*. From the rules and the facts represented in expert knowledge, new facts (conclusions) are obtained by an inference process[1].

The fuzzy logic theory proposed by Zadeh[6], allows translation of inaccurate and vague (as qualitative data) into numerical values which are generally described in natural language, and translated into rules of easy manipulation by computer, making computer systems better able to treat such data. Thus, the fuzzy logic makes it possible to model the subjectivity involved in human experience in a computerized control[1,2]. Fuzzy Logic differs from the classical logic systems in its mapping of true and false values. In classical logic, the “true value” can only assume two values: “true” or “false” (1 or 0), while in the fuzzy logic the “true value” of a proposition can assume different levels of belonging in the unit interval [0,1]. Mathematically, the definition follows:

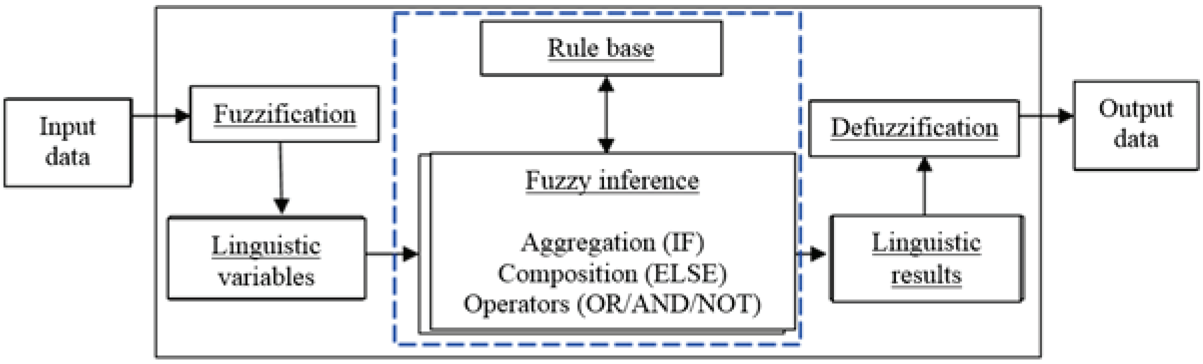
Definition 1. Take U as universal set, where all elements are denoted by x. Also, a fuzzy set A in U is given by:

$A = \{x, \mu A\ (x)\},\ x \in U.$

Where $\mu A\ (x)$ is called the membership function or gradation of pertinence of an x element in a fuzzy set A and $\mu A\!: U \rightarrow [0;1]$. The value 0, in this sense, means that the x element belongs absolutely to A and a value 1 means that x absolutely does not belong to A. In this context, this is an analogous interpretation to classical logic[1].

The theory of fuzzy sets revisits various medical and epidemiological concepts, expanding the occurrence of new insights. According to Massad[13], for a long time, the medical community has treated the concepts of health and disease as opposing conditions. However, in the fuzzy reasoning approach these conditions are ante-complementary rather than contradictory. That is, one given individual can be classified at the same time as healthy and non-healthy, at different intensity levels[14]. Mamdani[15] proposed a form of inference to systems based on fuzzy rules based on special operators for fuzzy adaptive control, which are: *t-norm* ("minimum" value of a fuzzy set) and *t-conorm* ("maximum" value of a fuzzy set). Currently, this form is often used to model systems based on rules, even if the application is not in adaptive control. Such architecture can be seen in Figure 1; It was presented by Santos *et al.*[16]:

Figure 1. A generic Fuzzy Expert System architecture



Credits: Adapted from Santos *et al.*[16]

a) Fuzzification Process: In this case, the numerical values of the input variables are transformed into linguistic terms. For each variable, it is defined their different functions of relevance. Consecutively, for each class of PSA are defined different degrees of relevance for each possible value of PSA in the sample space (Ω)[13-15].

b) Expert Knowledge Base (Rules): This is the most important part, because that is where the decision rules are implemented. The information about the rules and variables, can be obtained in different ways, such as: based on the real experience of experts; based on studies in the area and reference guides[13-16].

c) Inference Interface: Processing of the fuzzy input data, along with the rules (propositions) in order to infer the output fuzzy sets by applying to the operator involvement. Throughout the implication of the findings obtained (fuzzy output variables) is performed[13-15].

d) Defuzzification Process: Transforms the fuzzy set output, previously entered on accurate data again. Performs a scaling, so as to match the normalized values coming from the preceding step, which are the values of the real discourse universes of the variables[13-15].

III METHODOLOGY

The survey encompassed four steps and began with a bibliographic survey about studies that discussed the physiological behavior of different clinical pictures in surgical procedures, as well as DMs used in computational systems for simulation of such procedures. Thus, the initial step was to understand the needs found in the development of these methodologies, deepening domain searches through the survey of similar studies, and as the DMs are being used in VR simulators, for physiological simulation[1,2]. From the results found in the literature search were delimited a study scope by setting the variables to be used in the VP model. Such a model was used, in a third step, to specify a problem case in order to show the relevance of the VP's model usage. As the study is not analyzing empirically no phenomenon, this text presents a methodological research development[3] and not as an exploratory and descriptive study. After the initial phase of design, we used the fuzzy systems modeling software called *inFuzzy*[17] for ES modeling (variables) and some initial rules.

The literature review of the work was carried out with the aid of the portal CAPES[2] and the Google Scholar search engine, with searches done in several scientific publications databases, such as: *IEEE Xplore*, *Elsevier*, *PubMed*, *SpringerLink*, *Scielo*, *ACM Digital Library*, *CiteSeerX*, among others. The keywords used in the search were: Surgical Simulation, Virtual Patient Hemodynamic Simulation, Cardiovascular, Surgical Monitoring Variation, Hypertension, Virtual Reality. The same words in Portuguese were used. Altogether 436 titles were found at first (March 2015) and 769 titles in a second search (April 2013), from which we selected 25 reference works.

As selection criteria, studies involving the use of VR as an education and training support tool for health and/or that used DMs in their modeling as well as medical studies were included. We seek to analyze important requirements of VPs in VEs and relating to each other, such as: the simulation objectives; b) physiological details of VP model; c) used DMs; d) variables involved. Based on the steps listed previously, it is intended to provide examples of the model decision rules where the variables involved assume different conditions, simulating thus, different clinical conditions.

IV RESULTS

4.1 State of Art of Virtual Patients

According to Dev *et al.*[18], such virtual physiologies models may have a "static" or dynamic behavior. In the first case, simpler models simulate only a clinical condition in particular (current state of the patient). In the second case, the evolution of the state of the patient is accompanied in time, either with or without assistance from the student. However, in general, these models have the characteristic of responsiveness, i.e. they are able to react appropriately to different external or internal stimuli from the physiology of the VP itself. The external stimuli include medical interventions (clinics, surgical or pharmacological) and/or unexpected events that could interfere with the patient's state, and the inmates refer to physiological reactions (adverse or not) of the model[18]. In this topic, some virtual patients and simulators that resemble the proposal of this work will be presented.

The first one, is the *CliniSpace*[19], which is a healthcare environment simulator and it simulates virtual patients with pathophysiology dynamics, that is, that are able to respond to a range of medicines and procedures. The *Virtual ED Patient*[18] is a model of simulated VP for scenarios of emergency medicine. For the modeling of this VP is used as the classical logic, being monitored four vital signs (e.g. blood pressure, heart and breathing rates, oxygenation) for representation of their state. The above mentioned systems are fed with quantitative data coming from the medical literature[18,19]. The simulators *UVIMO*[16] and the *TOUCH*[20], in turn, simulate just one case. In the first case is simulated a diabetic patient suffering a myocardial infarction, based on a fuzzy ES. In the second case, it modeled a VP based on classical logic, with a head injury. The *3DiTeams*[21] and the Orthopedic Surgery simulators[22] stand out under the collaborative simulators that allow distance training[23, 24]. In the first case is simulated a room of military operations and has a physiological simulation module, with main focus on training of team interaction skills. In the second case, is used a Decision Tree[5] as the DM applied for the game's computational logic, where the strategies for managing blood loss of the VP's model are generalized, throughout the orthopedic surgery. Some examples of the systems presented here are in Figure 2.

Figure 2. Examples of VR simulators with VP models: *CliniSpace* to left, UVIMO in the Center and the *3DiTeams* right.

Table II. Comparative table between the VR simulators with VPs.

VR simulators	Objective:	DM	Vital signs or monitored variables	Variability of the Cases
CliniSpace [18]	Pathophysiology Dynamics	Classical logic	Bleeding rate, among other vital signs	Multiple cases
Virtual ED Patient [19]	Emergency medicine	Classical logic	Blood oxygenation, blood pressure, heart rate and breathing, bleeding rate.	Multiple cases
UVIMO[16]	Emergency medicine	ES based on fuzzy logic	Oxygen saturation, temperature, oxygen level, SBP, DBP	Diabetic suffering myocardial infarction
3DiTeams[22]	Teams training in military operations	Physiological motor	Blood oxygenation, temperature, blood pressure, heart rate and breathing, bleeding rate, pulse pressure.	Multiple cases
Orthopedic surgeries [21]	Psychomotor training in orthopedic surgeries	Decision Tree	Blood volume, heart rate, rate of bleeding, time of the procedure	Different classes of blood loss
TOUCH[20]	Emergency medicine	Classical logic	Elapsed time, blood pressure	Trauma Cranial

As a noted, among the studied simulators, they have different objectives (e.g. training teams, emergency medicine, and dynamic pathophysiology. It was also verified that all make use of classical logic as DM, e.g. in the Orthopedic Surgery Simulator[21] in which such a model encodes a decision tree. The UVIMO[16] system is the only one which make use of fuzzy logic. One of the monitored variables are: oxygen saturation, heart rate and breathing, bleeding, time rate, systolic (SBP) and diastolic blood pressure (DBP), blood volume and oxygen saturation. As for the possibilities of variation of simulated cases, we highlight the following simulators: *CliniSpace*, *ED Virtual Patient* and *3DiTeams*. These systems allow the simulation of multiple cases, and the others just simulate a single case condition.

4.2 Proposal of a PV Model based on *Fuzzy* Logic

The model divided in four steps to consider: 1) requirements elicitation; 2) definition of fuzzy *variables;* 3) creation of inference system (rule base); 4) merger proposal of VP in a VR Simulator.

4.2.1 Requirements Survey

According to the best practices of development of medical simulators and reference guides in VR, it is recommended the definition of all requirements prior to the stage of collection and modeling of the medical expert knowledge in question[2].

For the planning and modeling of a virtual physiology phases, it becomes important the presence of a multidisciplinary team, with medical, computer scientists, mathematicians and/or statistician professionals, among others. Thus, the knowledge experts can be incorporated into the simulation more coherently with the reality of the observed phenomena[16]. At first, it is necessary to define the scope of simulation, once the completely reliable physiological representation of a surgical patient becomes impractical. This occurs since the prediction of all possible states that one (or more) physiological systems can come to take are virtually infinite, as well as the relationship between the other systems[19]. In addition, detailed physiological levels are possible (e.g. biochemical, cellular, organic) and beyond the purely physiological events (those internal to the VP), there are also those of external nature, from the environment, as for example, surgical interventions that rely on human decisions.

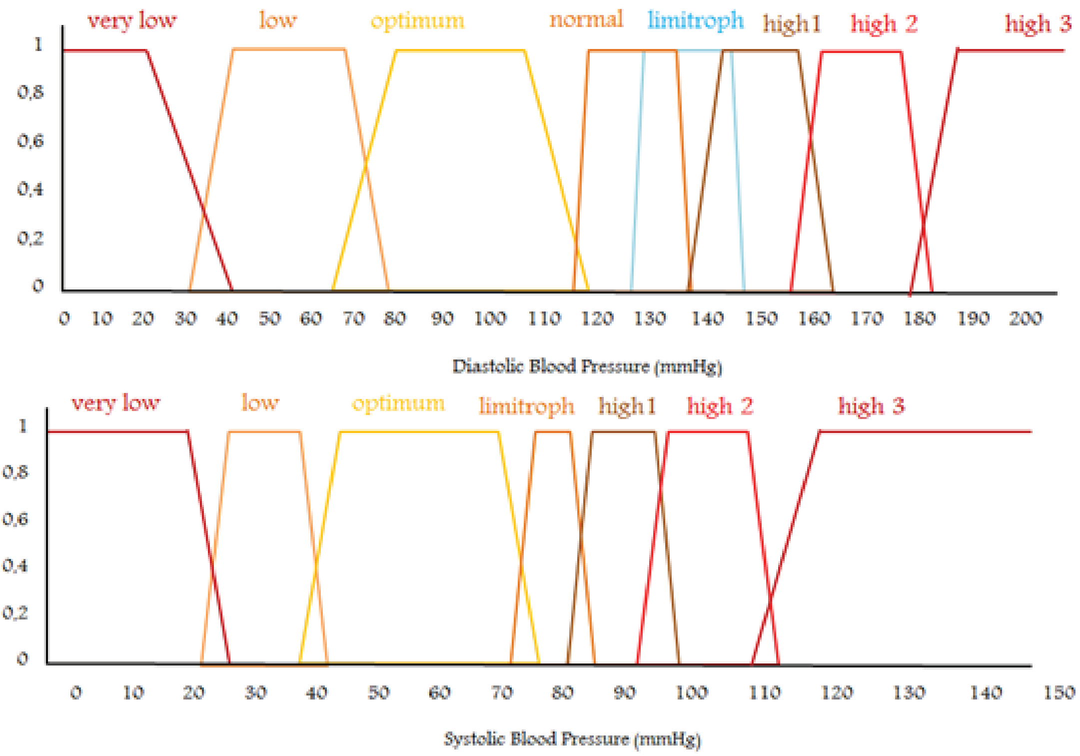
As noted, for modeling a VP, all possible events (external or internal) of desired simulation must be per-established. In this sense, the scope defined for this work was the initial flotation behavior simulation of two important hemodynamic parameters (SBP and DBP) throughout the anesthetic induction. The data obtained were based on actual medical studies[7,25]. As alternative study variable, is also analyzed the blood volume (blood volume) in extreme cases of bleeding or loss of blood plasma (hypo/hypovolemic shocks), for example.

4.2.2 Definition of Models Variables

The development process of an ES based on fuzzy logic initially part of the modeling of fuzzy numbers (or pertinence functions) for each variable involved in the study[16]. To this end, it is necessary to check which linguistic terms will be used and what fuzzy numbers are most appropriate to numerically define them[16]. The fuzzy numbers play an important role in the modeling of fuzzy systems, because they allow the quantification of qualitative predicates (or linguistic terms) and mathematically process them in the fuzzification process, described above. The Figure 3 shows the VP's input variables (SBP and DBP).

The following terms have been defined for each linguistic function of relevance: "*too low*", "*low*", "*optimun*", "*normal*", "*limitroph*", "*high 1*", "*high 2*", "*high 3*". For each studied variable, three types of fuzzy numbers (left slope, right slope and trapezoids) represent these functions. As you can see, the definition of the classes was based on the categories laid down by the Brazilian Hypertension Guidelines displaced in table 1, with the exception of the functions "*too low*" and "*low*", being its relevance values stipulated based on other medical studies[7,25]. Other important variables that relate somehow to the pressure values can also be mapped into fuzzy functions, if these present aspects of inaccuracy.

Figure 3. Relevance functions defined for variables of systolic blood pressure (SBP) and diastolic blood pressure (DBP).



Thus, it becomes possible to check different levels of assertiveness in some medical procedures during induction and monitoring of the VP. As an example:

- *SBP and DBP:* Are the main input variables of the model, as presented earlier.

- *Infusion Drugs:* The degree of assertiveness of this procedure is given based on the reference parameters such as infusion rate, induction type (intravenous and inhalation) to each clinical case, the medicine dosage used, etc. We could, for example, set the following pertinence functions for such {incorrect, regular, correct procedure}.

- *Pressure State:* ES fuzzy output variable that defines the current state of the patient according to their blood pressure levels.

- *Patient State:* output variable fuzzy ES, which defines the current state of the patient, according to the relationship between the other physiological variables defined by the ES. Initially, it was included in the study only the variable of blood volume for greater understanding of the proposed DM. As an example, the following pertinence functions can be defined for such variable { "*very unstable*", "*unstable*", "*stable*" }.

- *Blood volume:* Fuzzy variable which represents the different levels of the patient's blood volume.

- Other variables that do not have an imprecise nature and which belong to the domain of classical logic, that is, they can only take a value in the set {*"true"*, *"false"*}. Usually these variables are used for monitoring the occurrence of various events, such as:

- *Hypovolemic Shock, Hemostasis:* Coding when there is occurrence of blood volume shock events (loss of blood volume and/or plasma) and achieve hemostasis (bleeding control), respectively.

- *Bailey Plan:* The occurrence of anesthesia Bailey is given when the anesthesiologist checks for physiological changes such as the centralization of the eyeball, miosis and pupillary areflexia to a light stimulus. The adjustment to this plan allows continued operation.

4.2.3 Establishment of Inference System (Base Rules)

As seen earlier, the system of inference is based by the chaining of rules, which store the medical knowledge. For example, for the VR simulator to verify that the VP is already properly anesthetized (under anesthesia Bailey), based on pre-established pertinence functions, the following rules presented can be used by the ES:

IF "*Drug infusion is correct* **AND** "Bailey *plan is true*" **THEN** "*Anesthetic plan* is correct "

IF *"SBP is high 3"* **AND** "DBP *is limitroph"* **THEN** "*Pressure State is high 3*"

IF "*Pressure State is high 3*" **AND** "*blood volume < 20%"* **THEN** "*Blood volume shock is true*"

As seen from the rules, it creates a logical connection system that makes decisions according to the surgical interventions already performed. Another example of situation outside the VP physiological model, is checking the student's decision in relation to an unexpected hemorrhage situations. For this purpose, it can be defined a data vector containing *k* -boolean options (with correct and incorrect values), so that the PV can react as the user's decision from a hemorrhage treatment (represented by the value *treatment [x]*)*:*

treatment [k] ← { crystalloid, Colloid, CO_2*, Blood transfusion, ... k }*

IF "*blood volume shock is real*" **AND** "*treatment [x] is true*" **AND** "*hemostasis is true*"
THEN "*Blood volume shock is false*"

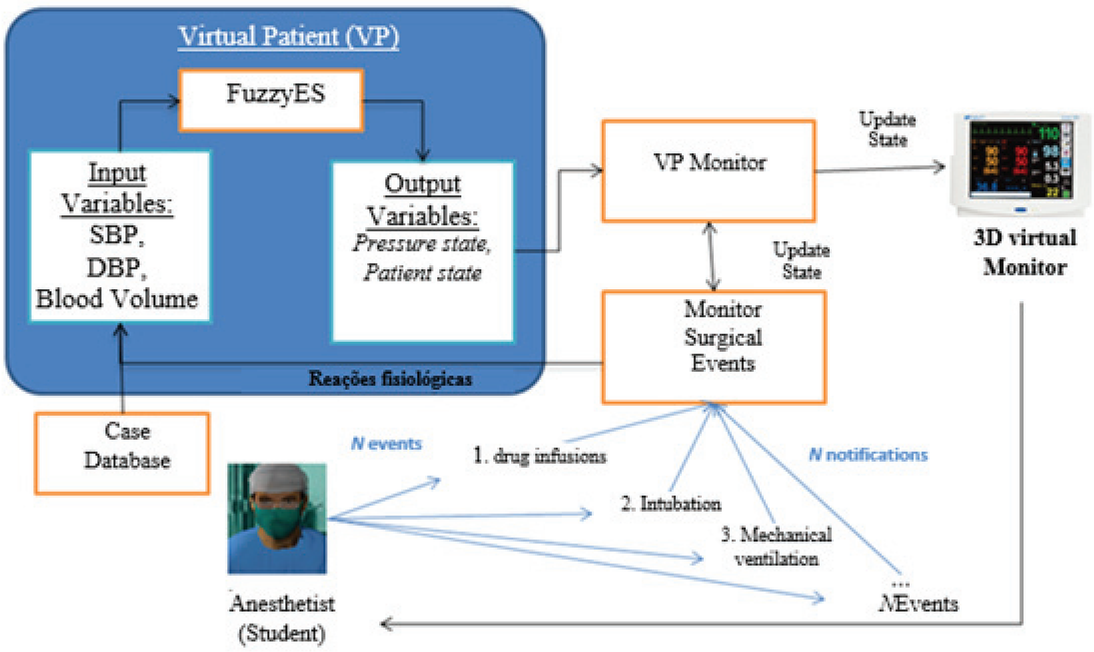
IF "*Blood volume shock is false*" **AND** "*blood volume is normal*" **AND** "*Pressure State is normal*" **THEN** "*Patient State is stable*"

An important issue to note is that for the DM there is a clear distinction between the events that occur internally or externally to VP, and therefore influence its behavior. This occurs because the input variables of the model are encoded in the same way, regardless of the causes of its origin (stimuli). Based on the findings obtained from the premises, the ES performs the defuzzification process of linguistic terms (or fuzzy output variables), simulating the physiological reactions of the patient.

4.2.4 Adaptation of Simulators for Use of the VP

For future incorporation of the proposed VP model in a generic VR simulator, it will be required some modifications to the architecture of *software*, for example, the insertion of some features, which will be listed in this section. As a case study, we initiated the development of some of them in the Simulator for Surgical Education Collaborative (*SimCEC*)[24,26]. The *SimCEC* is a collaborative virtual environment that allows the training and evaluation of a group of students in basic surgical procedures. The proposed architecture is shown below (Figure 4):

Figure 4. Proposal for VR Simulator architecture for incorporating the VP model.



Source: Developed by authors (2015).

a) Surgical Event Monitor: Responsible for detecting the occurrence of all events, such as surgical anesthetic induction, intubation, among others. This module receives new notifications of each occurrence of surgical procedures performed by students in the Simulator. At the same time, requests are issued (or update state) to "*VP Monitor Module*" of the physiological state of the VP for verification of its hemodynamic fluctuations.

b) VP *Monitor Module:* Performs monitoring of physiological reactions of the patient, based on the occurrence (or not) of new surgical events (events external to the VP). That is, this module performs the monitoring of numerical data fuzzy output ES of the VP, obtained by the process of defuzzification described above. After the display of such data is performed in the 3D virtual object that represents the anesthetic monitoring display of the patient, to display the values of SBP / DBP obtained.

c) Cases database: This is a database containing values of different variables numerous clinical cases. These can be randomly generated, or be obtained from actual epidemiological databases.

d) VP (ES fuzzy): This is the physiological model previously presented. The model is powered by the "*Cases database"* at the beginning of the simulation, where a case is randomly generated or choosed by the students, who wish to act on certain type of patient. In addition to this case, the VP receives as input data, the physiological changes planned for each vital sign according to surgical interventions which are notified to the *"Surgical Events Monitor"*.

V CONCLUSIONS

It is notorious, the increasingly growing usage of VR simulators focused on skills training in health procedures in recent decades. However, the simulators are in great demand for education, although developed with little attention to the planning stage and the medical curriculum[1,2]. Even so, the use of the VR systems has expanded and been recommended by various organs related to medical education as an auxiliary tool in the teaching and learning processes. Observing such important issues, a series of requirements have been raised in the medical literature and computer science (especially VR) on the benchmarks for the development of a physiological model. Observing the nature of measurement inaccuracy of most hemodynamic variables, we propose the use of fuzzy logic[6]. The VP model proposed is physiologically dynamic, i.e. it is sensitive to interventions carried out by students who learn to interact with the VR environments. Initially, they were included in the study of the cardiovascular system variables SBP and DBP. We take as a reference the classes proposed by the Brazilian guidelines of hypertension[12].

The main contributions of this work are: 1- Survey of the state of the art and comparative analysis of medical simulators containing VPs; 2 Comparative analysis of Decision Methods (DMs) used in these systems; 3- Modeling a fuzzy ES for simulation of hemodynamic physiology of a VP; and 4- Definition of a software architecture for incorporating VP conceived in medical simulators.

The advantage of using fuzzy ES in this case is caused by the fact that the patient can respond hemodynamically to pressure fluctuations, based on its uncertain values. As noted, the approach of fuzzy logic, allows the occurrence of important insights into the medical field, such as revisiting concepts previously regarded as antagonistic as sickness and health, the traditional classification method. However, the real-world phenomena exhibit intrinsically aspects of subjectivity and uncertainty. It is important to bring here the limitations of the proposal.

The modeling was performed of the fuzzy variables input and ES output and the definition of inference system (rule base), on the basis of expert knowledge from the literature. Once modeled the fuzzy ES, it was proposed a generic software architecture for incorporating such a model of VP in Medical Simulators. Thus, it is possible that this model is generic and can be used by one or more simulators, just by developers of medical simulators, defining a database containing the variables to be simulated. This database, can be fed from actual data, or data from medical literature.

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