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Main Menu

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ABSTRACT

The process of weaning a patient with respiratory insufficiency from mechanical ventilation is complex and requires expertise obtained by long clinical practice. Using the human expertise for computer-assisted weaning in an adequate manner is a common problem for such applications. The knowledge acquisition component we developed is designed to formalize knowledge in an easier way. It helps intensive professionals to generate crisp and fuzzy knowledge bases for computer-assisted weaning in intensive care units (ICUs). At the end of forming a knowledge base the component generates a compiled version of the knowledge base which represents an interface for the computer-assisted expert system. The present aim is to find the optimal knowledge base design to improve the computer-assisted weaning process in future.

KEYWORDS: Knowledge acquisition; crisp and fuzzy knowledge-based control; KBWEdit; decision making.

INTRODUCTION

Patients who require mechanical ventilation during operation, where they are deeply sedated, must slowly be weaned from mechanical ventilation after the operation to the point where they breathe spontaneously. At this point the patients can be extubated, i.e., the tube, placed in the trachea to ensure the proper ventilation, is removed [11]. The aim of an improved weaning process would be to make the transition from controlled ventilation to total independency (extubation) as smooth and short as possible.

The procedure for weaning a patient is complex and requires expertise obtained by long clinical practice. Using the expertise for computer-assisted weaning in an adequate manner is a common problem for such applications [1, 2, 5, 8].

The knowledge acquisition component we developed is designed to formalize knowledge in an easier way. This knowledge acquisition tool, which is used for computer-assisted weaning of patients after cardiac surgery in intensive care units (ICUs), is represented by a so-called knowledge-based weaning editor (KBWEdit) which helps intensive professionals to generate crisp- and fuzzy knowledge bases. The reason for dealing with two knowledge bases is to find the optimal knowledge base approach for the crisp- and fuzzy-based methodologies in the field of weaning.

Finally, at the end of forming a knowledge base the editor generates a compiled (scanned and parsed) version of the knowledge base. This executable version of the knowledge base's 'source code' is used as an interface for the computer-assisted expert system Knowledge-Based Weaning (KBWean) [7].

METHODS

Crisp and fuzzy knowledge bases generated by the editor consist of variables, values, and rules. The variables represent the physiological parameters and the respirator settings. The values are described by way of fuzzy sets and linguistic terms. The editor's liberal user interface design allows adjustment for different ventilation modes.

Our application centers on building knowledge bases for patients which are weaned by the BIPhasic Airway Pressure Ventilation (BIPAP) mode, since the mode allows a very smooth and gradual change from controlled to spontaneous breathing [4, 9].

Ventilatory management

During mechanical ventilation as well as during weaning the goal is to achieve optimal values of the arterial O_2-partial pressure (pO_2) and the arterial CO_2-partial pressure (pCO_2). These optimal values have to be achieved with careful handling of the lung.

Careful handling of the lung:

- $FiO_2 < 60$ (else oxygen - toxicity)
- low inspiratory pressures $P_I < 35$ (else barotrauma)
- small shearforces equivalent to small tidal volumes (else volume trauma)
- prevent atelectasis formation (else shearforces at reopening)

In addition the patient also has to be carefully handled to avoid cardiac failure and respiratory muscle fatigue. Both of these conditions have to be observed if the heart rate or the respiratory rate increase. The value pO_2 states whether the oxygenation is sufficient or not. pO_2 is not continuously available because taking a blood sample would be necessary. Thus O_2-saturation (SpO_2) provided by pulsoximetry is more convenient, because SpO_2 is permanently available. pCO_2 states whether alveolar ventilation is sufficient or not. Similarly, the end-tidal CO_2 ($EtCO_2$) is permanently available but at the disadvantage of being only an indirect measure of pCO_2. Thus, the main physiological input parameters of the weaning system are SpO_2 and $EtCO_2$.

The ventilatory drive is evaluated based on the measurement of the ventilatory rate (Vrate).

The ventilatory management uses a ventilator (Evita, Dräger, Lübeck, Germany) in pressure controlled mode (BIPAP). This mode allows spontaneous inspiration during the whole respiratory cycle and thus allows a very smooth and gradual change from controlled to spontaneous breathing. Ventilatory adjustments are based on two pressure levels: Inspiratory Pressure (P_I), Expiratory Pressure (P_E) and on two durations, Inspiration Time (t_I) and Expiration Time (t_E), as well as on the fraction of Inspired O_2 (F_IO_2). Within this mode five parameters can be adjusted. The output of the expert system are proposals to adjust these five parameters (Figure 1).

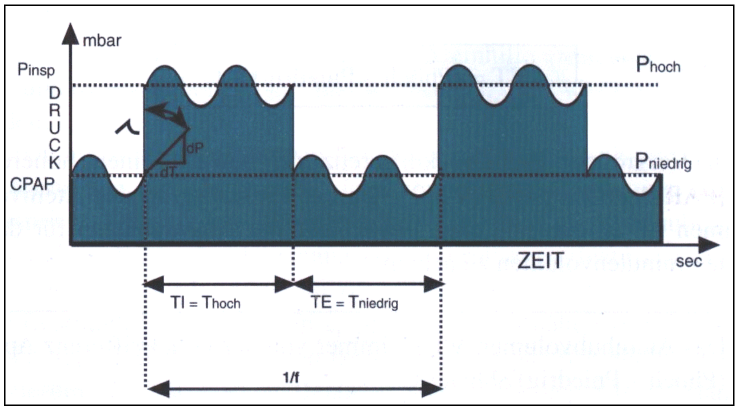
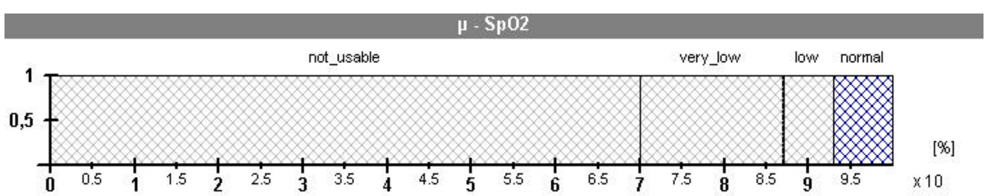


Figure 1: BIPAP ventilation mode

Crisp- and Fuzzy knowledge base

The crisp-based knowledge base uses categorized data which is combined in If/Then rules with comparative, logical, arithmetic and control operators. The values (constants) of the crisp knowledge base are intervals by the associated variable is declared. Figure 2 illustrates the declared value of SpO_2 and a rule example.



Rule OXY_3
if [SpO2 in SpO2_normal] and not [FiO2 in FiO2_normal] and
[PEEP in PEEP_normal or PEEP in PEEP_low]
then "[OXY_3] FIO2 -10% "

Figure 2: A declared SpO_2 value and a crisp knowledge base rule.

The fuzzy-based knowledge base of a fuzzy knowledge-based controller has to consist of a data base and a rule base [3, 6, 10]. The fuzzy inference process is performed by three steps: 1) fuzzification: input variables are assigned degrees of membership in the predefined variable classes, 2) rules: the inputs are applied in parallel to a set of If/Then control rules, 3) defuzzification: the fuzzy outputs are combined to yield discrete values for the respirator adjustments.

The first step in the fuzzification process is to determine the parameters O_2 and CO_2. The determination of parameter O_2 is based on the parameters SpO_2 and pO_2, CO_2 is determined by the parameters pCO_2 and $EtCO_2$ (as mentioned above). A sample of membership functions for ventilating (EtCO2_vent) and weaning (EtCO2_wean) a patient, is shown in Figure 3.

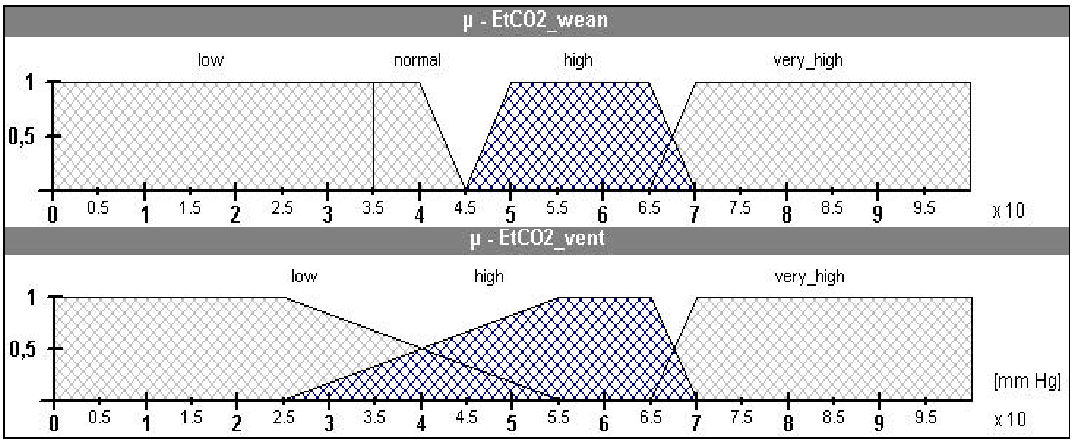


Figure 3: Membership function for EtCO2_vent and EtCO2_wean

RESULTS:

With the developed knowledge acquisition tool KBWEdit crisp and fuzzy knowledge bases can be formalized with hardly any restriction. Still, formalizing knowledge bases has to be syntax-guided in order to make knowledge bases usable for the expert system, in our special case for the expert system KBWean. Finally, at the end of forming a knowledge base the editor generates a compiled (scanned and parsed) version of the knowledge base. This executable version of the knowledge base's 'source code' is used as an interface for the computer-assisted expert system (Figure 4).

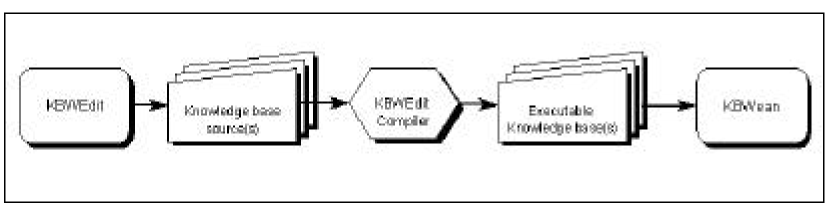


Figure 4: Knowledge base compilation process

These concept allows to create various experimental versions of the knowledge bases. Further, the interface can easily be modified for the use of other computer-assisted weaning applications in future.

The rules of the knowledge bases can easily be generated due to a huge set of predefined operators. These are based on logical, arithmetical, comparatory and control operators. With the latter information is provided as concerns the completion of realized rules. For this reason all data involved in the weaning process have to be stored in a database. KBWEdit, and KBWean, respectively, are especially designed to interact with the Interbase® database.

Figure 5 shows the KBWEdit application generating an oxygenation rule.

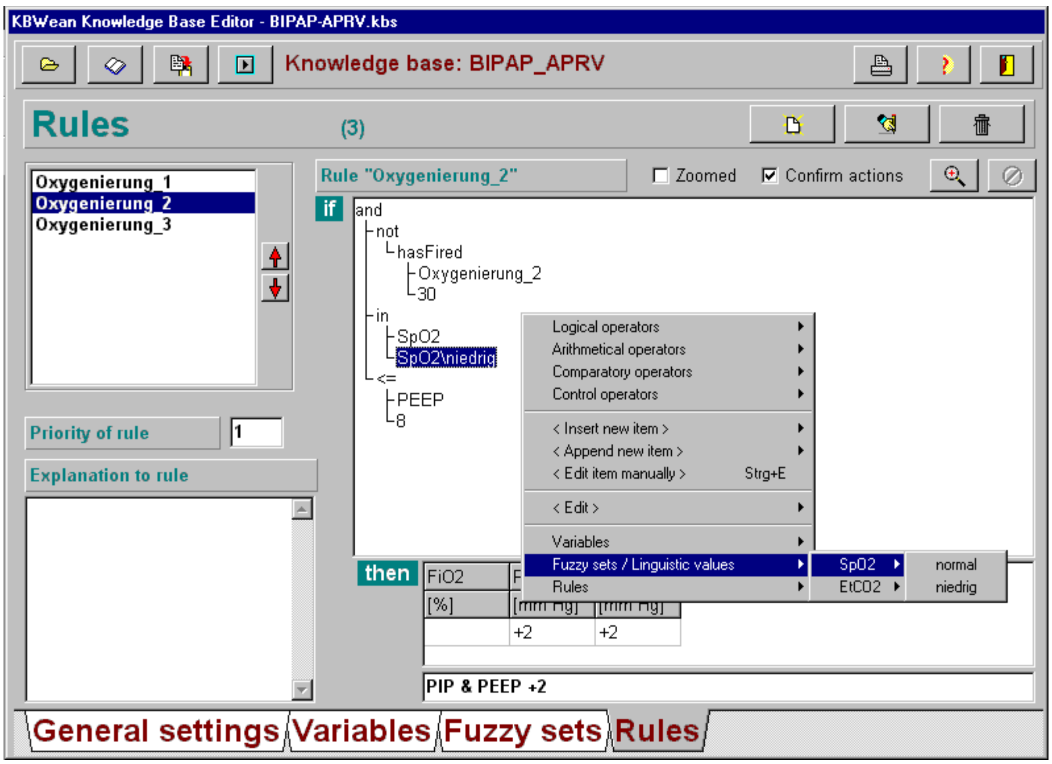


Figure 5: KBWEdit application

The system is used at an ICU for post-operative cardiac patients at the Vienna General Hospital. The advantage of the KBWEdit its easy application and the generation of more specific knowledge bases which allows a smoother treatment of weaning patients.

A source of error are still missing or ‘noisy data’ which cannot yet be handled by the knowledge base design.

Technical Specifications:

Hardware Environment: 8 bedside PCs, Pentium 166 with 32 MB Ram, Intelligent Digiboard, and Light-Pen. All PCs are connected to a server, using the hospital’s token-ring-network.

Software Environment: Operating System Windows-NT®4.0, PDMS PICIS CHART+ (Paris-Barcelona), Delphi® 2.0 Client/Server Suite. The KBWEdit as a component of KBWean is a 32 bit application, and uses a Interbase® database for data storage.

CONCLUSION:

The gained results confirm the applicability of KBWEdit to represent medical knowledge, making the weaning process transparent and comprehensible. The system is widely approved of by intensive professionals, who spare no effort to tune its applicability. With their assistance and expertise we aim at finding the optimal knowledge base design to improve the weaning process in future.

The ultimate aim is to generate an ideal knowledge base for a closed-loop system, which can be integrated into the ventilator. This would finally allow exact and continuous setting adjustments and thus guarantee an optimal weaning process.

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