A KNOWLEDGE ACQUISITION EDITOR FOR FUZZY-CONTROLLED WEANING IN INTENSIVE CARE UNITS (KBWEdit)

Schuh[1] Ch., Koller[1] W., Kolb[2] M.,
Hiesmayr[2] M., Adlassnig[1] K.-P.

[1] Department of Medical Computer Sciences, University of Vienna Medical School, Spitalgasse 23, A-1090 Vienna, Austria,

[2] Department of Cardiothoracic Anaesthesia and Intensive Care Medicine, University of Vienna Medical School, Währinger Gürtel 18-20, A-1090 Vienna, Austria

e-mail: christian.schuh@univie.ac.at

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).

Keywords: Knowledge acquisition component, fuzzy knowledge-based control, intelligent monitoring.

Objective:

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 [10]. 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 in intensive care units (ICUs), is represented by a so-called knowledge-based editor (KBWEdit), which helps intensive professionals to generate crisp- and fuzzy knowledge bases.

Methods:

The crisp- and fuzzy knowledge bases generated by the editor KBWEdit 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 knowledge bases as well as various experimental versions are implemented as plug-in knowledge bases for the FuzzyKBWean frame program [7].
The editor's liberal user interface design allows adjustment for different ventilation modes.

Ventilatory management

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].

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 (Table 1).

- $FiO_2 < 60$ (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)

Table 1: Careful handling of the lung.

In addition, the patient also has to be treated carefully 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 physiological properties of the lungs are derived from the measurement of pressures (inspiratory pressure and expiratory pressure) and the volume of an individual breath.

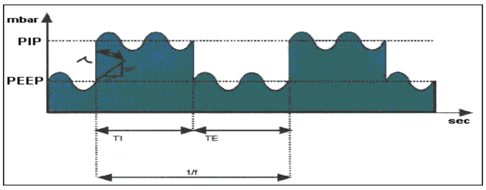

Figure 2: BIPAP ventilation mode.

The ventilatory management uses a ventilator (Evita, Dräger, Lübeck, Germany) in BIPAP mode. 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: Positive Inspiratory Pressure (PIP), Positive End Expiratory Pressure (PEEP) 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 FuzzyKBWean are proposals to adjust these five parameters (Figure 2).

Knowledge bases

The fuzzy-based knowledge base of a fuzzy knowledge-based controller has to consist of a data base and a rule base [6]. 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 parallel to a set of If/Then control rules, Figure 3 illustrates the declared value of SpO_2 and a rule example. 3) defuzzification: the fuzzy outputs are combined to yield discrete values for the respirator adjustments. FuzzyKBWean uses the Sugeno controller method for the defuzzification [3].

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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% "
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Figure 3: A declared SpO_2 value and a crisp knowledge base rule.

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 $EtCO_2$. A sample of membership functions for ventilating (EtCO2_vent) and weaning (EtCO2_wean) a patient is shown in Figure 4.

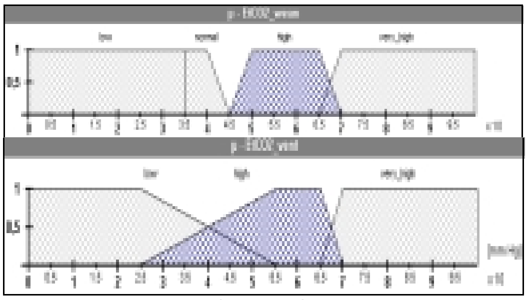

Figure 4: Membership function for EtCO2_vent and EtCO2_wean

Results:

The knowledge acquisition tool KBWEdit has been developed as a 32 bit application with Delphi® 4.0 running on Windows95/98® or Windows-2000® platforms. 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 FuzzyKBWean.

Finally, at the end of forming a knowledge base the editor generates a compiled (scanned and parsed) version of the knowledge base (Figure 5). This executable version of the knowledge base's ‘source code‘ is used as an interface for the computer-assisted expert system.

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.

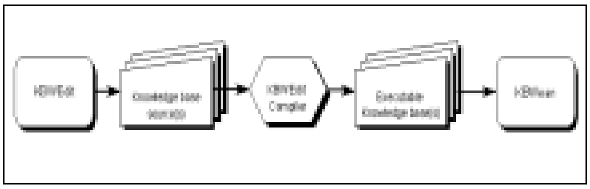

Figure 5: Knowledge base compilation process

The rules of the knowledge bases can easily be generated due to a huge set of predefined operators. These are based on logical, arithmetical, comparison 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 is especially designed to interact with the Interbase® database.

Figure 6 shows the KBWEdit application generating an oxygenation rule.

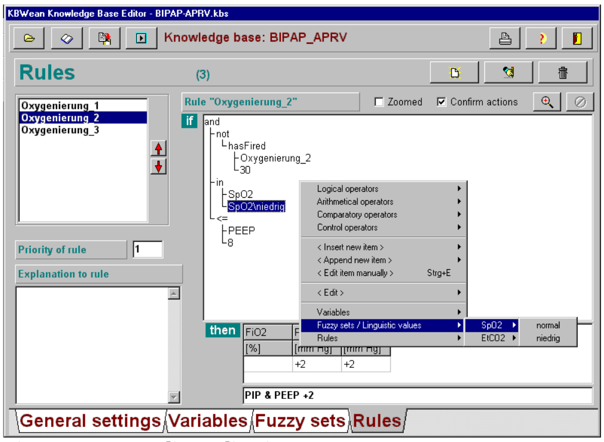

Figure 6: KBWEdit application

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

Conclusion

The gained results confirm the applicability of KBWEdit to formalize 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.

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