Development of a system for clinical-disorder detection in the ICU

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Abstract: A system was developed that assesses the presence of defined clinical disorders occurring in the ICU. The system uses a range of variables obtained by querying the ICU's patient database management system. After processing the obtained data, an estimation is given in how far a certain disorder is likely to be present. This is communicated back in a variable to the patient database management system (which can, if necessary, used as a trigger for an alarm). The set-up allows for integration of new algorithms to a system that is in routine use through a standard interface. In this way it allows clinical experimentation with new biosignal interpretation methods and hence can speed up the dissemination of research methods into products.

INTRODUCTION

Today's intensive care unit (ICU) is equipped with a wide range of measurement systems that provide a wealth of data to the clinician. This large set of information, that contains such diverse components as numerical values obtained from patient monitors, laboratory-generated values, and nurse observations, in principle provides the means to assess the patient's physiological state. Although modern equipment, can present all this information, the step to, combine information and extract the required relevant parts from it and present the right results in time in an easily comprehensible manner proves to be difficult. Alarming systems, often operating as single-signal limit alarms, generating many false-positives are still a too common phenomenon in the ICU (e.g., [1-2]).

The first step to obtaining better results would be to process changes in one variable in the context of values of other variables; a very natural step every clinician will take when interpreting any information obtained from the patient. Other fundamental issues that play a role in the less-than-ideal performance of current alarming systems are [3]:

1. how to deal with noisy and unreliable patient data;
2. a need for new ideas in knowledge representation;
3. investigated techniques are not mature enough to find them in real clinical use;
4. lack of architectures that provide a generic platform on which domain-specific applications can easily be installed; and
5. lack of an infrastructure (from a system's point of view as well as from a protocol point of view) for easy clinical evaluation of the developed systems.

In recent years many new approaches have been tried that deal with issue 2. These include the use of Artificial Neural Networks (ANNs), Fuzzy Logic, or combinations of such techniques with rule-based systems. Despite the efforts, the uptake of advanced techniques into a real clinical setting is poor [4]. This is typically caused by issues 4 and 5 (and, as a result, issue 3) and values for false-alarm rates and low positive prediction values remain a problem.

This article reports on a first step in addressing the problems mentioned above. Next to taking into account the use of multiple data sources in building the system, the foundation is laid for an environment that allows on-line as well as off-line testing of biosignal interpretation (BSI) algorithms that can be altered easily for experimentation with new insights.

METHODS

The first installation of the Intelligent Alarm System (IAS) has been done at the Intensive Care Unit of Kuopio University Hospital (KUH), Kuopio, Finland.

The system is closely attached to the Patient Database Management System (CIMS, Datex-Ohmeda Div., Instrumentarium Corp., Helsinki, Finland) system in use at KUH. A schematic representation of the overall architecture of the measurement system in which the IAS is incorporated is depicted in Figure 1.

Signals from the patient are recorded using standard monitoring equipment (Datex-Ohmeda AS/3 monitors, Datex-Ohmeda Div., Instrumentarium Corp., Helsinki, Finland). Information present in those signals is transferred to CIMS work stations (CIMS WS). The CIMS has as its main function the support of the patient care: it records all trend data from the patient monitors, laboratory results, and information on medication and nursing actions. This information is stored in a database on the CIMS database server.

The IAS runs on a dedicated PC – running under MS-Windows NT4 (Microsoft Corp., Redmond, USA). The IAS communicates with the CIMS data base (Sybase Inc., Emeryville USA) via ODBC drivers. Data is obtained by polling the CIMS database by means of SQL queries. The system provides possibilities to use any variable that is present in the CIMS database.

The IAS polls the database for the most recent data every two minutes. Subsequently, the data is processed by BSI algorithms developed to detect possible presence of patient disorders. The outputs of the algorithms, in the form

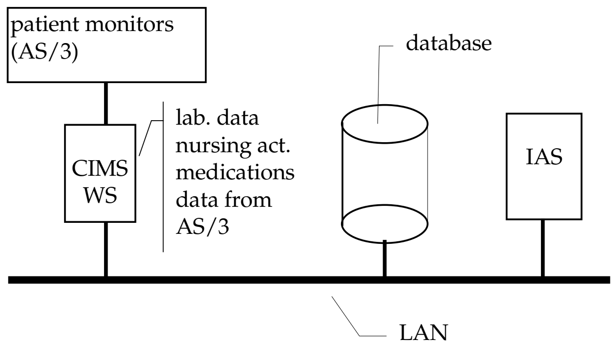

Figure 1: Schematic overview of the place of the IAS in the existing system set-up.

of an index indicating the probability of the presence of a disorder, is written back to the CIMS, again using ODBC. The CIMS work stations can read this information from the database and e.g., display it as graphical information in trend charts.

The IAS system can operate in two modes: an on-line mode and an off-line mode. During the on-line mode the system retrieves data, processes it, and sends disorder indices back to the database. In off-line mode, parameters that are used in the disorder detection algorithms (such as scaling factors, limit variables, the set of recorded variables to be used) as well as configuration parameters (e.g., identification of patients to be measured, files to be used) may be changed. Changing the first group of parameters allows the user to experiment with different algorithms by tuning their parameters.

The algorithms rely on domain knowledge provided by an international group of clinicians as well as on robust signal processing methods. Alarms have structures containing: 1) artifact detection blocks (that operate e.g., on the basis of statistical distributions of artifact-free measurements); 2) filtering blocks; 3) blocks that apply scaling functions to map all different signals onto a normalized range; and 4) methods that generate estimations of current values for those variables that are sampled at a very low frequency. Outputs of ‘chains’ of processing blocks for each variable are combined and presented as input to the clinical rules to come to sub-state indexes. These provide information on ‘attributes’ that make up a patient disorder (e.g., ‘presence of metabolic signs of tissue hypoxia’ or ‘presence of inadequate flow’). Indexes for sub states in their turn are combined to generate an index reflecting the presence of a disorder.

RESULTS

The first version of the system is installed at the ICU of KUH. Data that it uses includes trend variables and laboratory test results as defined in the ‘Clinical definitions of Disorders’ for the EU/BIOMED1 Improve project (PL921768) [5]. The disorders that are concentrated upon here are ‘cardiac failure’ and ‘sepsis evolved into high blood flow state’. BSI methods to detect these disorders were developed and validated in an earlier study [6].

In an initial test phase the technical reliability was evaluated over a recording time of over 6000 patient hours. The clinical performance was tested on 5 patients with long ICU stay (total 162 monitoring hours) and 10 post-operative cardiac patients for 200 hours. The current network-IAS combination allows for concurrent processing of data from 3 patients. The system was found to be suitable for use in an elaborate evaluation of the BSI algorithms.

A first assessment of the clinical performance of the BSI methods used in the IAS system was evaluated daily by two to three experienced intensivists. Trend curves of the probability estimations of the IAS were compared to original patient data. The episodes of all three disorders could be detected during the test period. All three experts agreed that the system could detect the disorders with high specificity and with reasonable sensitivity.

CONCLUSIONS

A multi-signal based alarming system has been developed that allows for assessing the presence of patient disorders in the ICU using BSI algorithms that can be altered easily. It provides a means to on-line run BSI methods, thus providing a testbed for trying out new ideas.

First validation of the algorithms shows that the system detects the disorders cardiac failure and sepsis evolved into high blood flow with high specificity and with acceptable sensitivity. To thoroughly asses the value of the algorithms the system is currently running in a clinical evaluation set-up recording 100 cardiac patients and 200 patients with TISS score > 40 or that have a pulmonary catheter.

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