Editorial: Special Issue on Critical Care Engineering

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The aim of this special issue on Critical Care Engineering is to provide a representation of the new trends of engineering involved in critical care. The main focus is on the state of the art in the various areas covered, with an indication of the current developments taking place and the problems and challenges that remain to be addressed.

This issue is logically divided into four main areas: (a) critical patient care, (b) improvement of critical care quality, (c) critical care information systems, and (d) critical care facilities. Seventeen papers were selected through our routine rigorous double-blind external peer review by qualified experts. Due to the capacity limitation, some papers have already appeared earlier in the last issue (Volume 1, No. 3). All papers are briefly introduced below:

Critical Patient Care

Hemodynamic instability is one of the most critical events that require effective and prompt intervention in the intensive care unit (ICU), and cause longer ICU stay. Early prediction of hemodynamic instability would allow intervention to prevent organ injury associated with low perfusion events in the ICU. Current automated alert mechanisms typically generate an alert when one or more physiological parameters cross predetermined thresholds. Unfortunately, often by the time these alerts are triggered, the patient is already in an unstable state. The paper, “Hemodynamic Instability Prediction Through Continuous Multiparameter Monitoring in ICU” by Cao et al., addresses hemodynamic instability prediction with *minute-by-minute* segments of vital sign data. The prediction algorithms are based on features that are robust to missing data, a common reality in ICU. The purpose is to predict the events early enough for proactive management, resulting in reduced occurrences of hemodynamic instability.

Patients in critical care, trauma, or other situations involving reduced lung function may be treated with oxygen to avoid hypoxia. However, under certain conditions and long term exposure, oxygen is toxic to the lungs. The paper entitled “Instrumented Indentation of Lung Reveals Significant Short Term Alteration in Mechanical Behavior with 100% Oxygen”, by Silva et al. (published in Vol. 1, No. 3), reports results of mechanical tests to investigate possible changes in lung function in terms of stiffness, non-linear mechanical response, and induced alveolar deformation, when exposed to 100% oxygen in the short term.

Syringe infusion pumps used in ICU may malfunction in terms of undesirable bolus delivery on release of line occlusion, dosage fluctuation due to pump height change, and fluid reflux within the multiple pump installations, causing negative physiological impacts in patients. The paper entitled "A new approach in the design of high-risk infusion technology", by Murphy and Wilcox (published in Vol. 1, No. 3), examines the performance of a typical ICU syringe infusion pump and identifies mechanical compliance, inherent in commercial designs, as a source of flow errors. This was supported by experiments that tested the performance of a prototype pump system with low mechanical compliance, and demonstrated a shorter start-up delay and significantly reduced flow error due to height change compared to the conventional design.

Continuous monitoring of vital signs is crucial for premature infants in neonatal intensive care unit (NICU). The paper entitled "Design of an Integrated Sensor Platform for Vital Sign Monitoring of Newborn Infants at Neonatal Intensive Care Unit", by Chen et al., presents the design work of a vital sign monitoring platform, Smart Jacket, integrated with non-invasive sensors for neonatal monitoring in NICUs. The Smart Jacket was designed based on a unique integration of medical science, industrial design, sensor technology and electrical engineering, to provide reliable health monitoring as well as a comfortable clinical setting for both neonatal care and parent-child interaction. Textile sensors, a reflectance pulse oximeter, and a wearable temperature sensor are embedded in the Smart Jacket for monitoring electrocardiogram (ECG), blood oxygen saturation and body temperature, respectively. The design was achieved through an iterative process of user research, concept generation, technology integration, prototype implementation, experimental testing and user feedback.

Ambient technologies and advanced internet services provide new opportunities for distributed information systems where users can access, treat, and manage 'information resources' in order to support their activities. The paper, "A Service-Based Perspective on Neonatal Critical Care", by Grönvall et al., describes the development of monitoring technologies from a service-based perspective for neonatal intensive care as a setting for pervasive computing. The system contains a browser that supports the creation of loosely-coupled services to allow non-service developers (such as NICU staff) to work with a distributed computational network, reconfiguring it and changing connections among running software entities, thus adapting the equipment to the requirements of individual newborns. An incubator prototype was developed to integrate dedicated technologies (Biosensors Belt and the Mattress) with the current NICU equipment, in conjunction with a User Interface, the "Assembly Browser", that allows NICU staff to discover the available services and devices, to access and monitor data, and to create, manage, and visualize assemblies.

Improvement of Critical Care Quality

More than a third of ICU patients require mechanical ventilation due to respiratory failure. However, extended duration of intubation leads to a higher risk of Ventilator-Associated Pneumonia (VAP), a potentially deadly condition associated with increase in costs, length of stay, and over 50% of all antibiotic use in the ICU. The paper entitled "The Use of Scan Statistics and Control Charts in Assessing Ventilator-Associated Pneumonia Quality Control Programs", by Nathanson and Higgins, presents some new rare-event-monitoring statistical methods that can be used for a VAP quality control program. Scan statistics is a method introduced to investigate statistically unusual clusters of events, such as VAP, over time, that may indicate a breakdown in quality. Another method is a g-type statistical process control chart that can indicate a significant improvement in quality by prospectively observing unusually long periods of time between events. Examples are provided using data taken from an ICU at a large tertiary care, teaching hospital.

Severity assessment of patients' conditions by healthcare professionals is an important task, as it determines the subsequent course of patient care. The paper entitled "Inter-Observer Agreement Among Medical Professionals in Critical Care of Neonates and Children", by Osnat et al. (published in Vol. 1 No. 3), investigates the inter-observer agreement among physicians and nurses in assessing the potential severity of Almost Adverse Events (AAEs) observed in ICUs. The statistical analysis demonstrated relatively low levels of agreement among raters in ICUs, and significantly better agreement among nurses than among physicians. Significant disagreements in assessing the severity of AAEs suggest discrepancies in how staff members perceive and eventually treat the patient. Low levels of agreement are attributable to the nature of work and characteristics of ICU. Inter-observer agreement may be improved by establishing a detailed written consensus of definitions and examples of different levels of severity of AAEs.

In improving the patient care quality in resuscitation units, knowledge is required about how the various activities and processes within the units can impact the management of patient care. The paper entitled "The Use of Observation and Interview Methods for Assessing Issues in Patient Care in the Resuscitation Unit of a Level-1 Trauma Center", by Sharit et al. (published in Vol. 1 No. 1), presents a detailed description of the methodology for collecting and analyzing observational data to identify and assess a broad array of issues and concerns within the highly complex critical care setting in a large level-1 trauma center, as well as a summary of the results of the observations.

Critical Care Information Systems

A challenge in switching from paper to electronic records in ICUs has been the subtle but important variation in the conditions and requirements for individual ICUs. Although clinical information systems that can be customized by Information Technology consultants are available, the customization processes are usually costly and often do not allow clinical personnel to fully adapt and adopt the information system into their work. The paper entitled "Practitioner-Customizable Clinical Information Systems: a Case Study to Ground Further Research and Development Opportunities", by Morrison et al. (published in our last issue, Vol. 1, No. 3), reviews the use of a practitioner-customizable clinical information system in an ICU, which allows trained ICU personnel to customize most or all aspects of the system with which they and their colleagues interact. The paper examines the tools, practices, and organizational issues that influenced the customization of the system, for further research and development of this emerging technology.

As vast quantities of physiological data are continuously generated and discarded, the ICU remains to be one of the most potentially data-rich, yet information-poor environments in modern healthcare. The paper, “SIMON: A Decade of Physiological Data Research and Development in Trauma Intensive Care”, by Norris et al. (published in Vol. 1, No. 3), details SIMON (Signal Interpretation and MONitoring), a system that continuously collects and processes bedside medical data, including heart rate, blood pressures, oxygen saturations, cardiac function variables, intracranial and cerebral perfusion pressures, and ECG waveforms, in a trauma ICU. This system not only provides a large repository of physiological data supporting research analyses, but facilitates data display, reports, and alerts that potentially enhance clinical decision-making.

In an ICU, the overwhelming quantity of gathered information and the highly specialized language used by clinicians make it challenging to achieve a fluent flow of health information, although it is critical for health communication and decision making. The paper, “Supporting Communication and Decision Making in Finnish Intensive Care with Language Technology” by Suominen and Salakoski, describes development of computational methods for analyzing and generating natural, human language to support the flow of textual information in ICU. The focus is on building overviews of textual health records in ICU with respect to topics specified by the user. The topical search methods are based on supervised multi-label classification and regression, as well as supervised and unsupervised multi-class classification.

ICUs are complex, data-intense environments as dozens of systemic parameters related to multiple, changing and interacting complex physiological subsystems are monitored to enable clinical personnel to detect subtle changes in patient’s physiology and to implement appropriate interventions promptly. The paper entitled “Data Acquisition and Complex Systems Analysis in Critical Care: Developing the Intensive Care Unit of the Future”, by Jacono et al. (published in Vol. 1, No. 3), summarizes the current state of data acquisition in ICU and identify limitations that must be overcome in order to achieve the goal of real-time processing of biological signals to capture subtleties identifying early warning signals hidden in physiologic patterns. The paper also outlines an approach to analyzing biological waveform data based on animal models, and proposes guidelines for the development, testing and implementation of integrated software and hardware solutions that will facilitate the novel application of complex systems approaches to biological waveform data with the goal of risk assessment.

Temporal dimension plays an essential role in analyzing the evolution of patient’s health condition in ICU. The paper, “Applications of Temporal Reasoning to Intensive Care Units” by Juarez et al., presents a review of development of temporal reasoning methods and software tools that help physicians to better understand the patient’s temporal evolution. Issues to exploit the temporal dimension of ICU data were described from the Artificial Intelligence perspective. The paper reviews (1) the traditional management of time in medical information systems, (2) the representation of time for reasoning purposes, (3) mechanisms to implement temporal similarity, (4) the acquisition of temporal medical knowledge, and (5) temporal knowledge discovery.

Critical care involves employment of complex medical instruments to monitor, report and record patient conditions. Manually recording health information into an electronic system is a time-consuming process prone to error. For some instruments, automatic transmission of data may be possible via proprietary mechanisms provided by manufacturers; however, interoperability among interfaces is necessary to achieve a uniform access point to all patient data. The paper, "Interoperable Medical Instrument Networking and Access System with Security Considerations for Critical Care" by Gurkan and Merchant, proposes an interoperable networking of all critical care bedside instruments, that enables patient monitoring, data archiving and secure access without the need of manual entry. A security overview and network architectural considerations for this medical instrument networking in critical care are presented in this work.

Critical Care Facilities

Physical environment of ICU directly affects the performance of ICU staff. Staff and patient safety in ICU can be compromised if insufficient space is provided, or if the layout and ergonomic design of workspace restrict activities and contribute to adverse events. The paper entitled "Two Case Studies Using Mock-Ups for Planning Adult and Neonatal Intensive Care Facilities", by Hignett et al. (published in Vol. 1, No. 3) describes a 5-step protocol to determine functional space requirements for clinical activities in Cardiac ICU and NICU. Functional space experiments were conducted to determine the spatial requirements defined as the minimum-sized rectangle to encompass the Link Analysis that analyzes movements between individuals and components in a system using observable or measurable data to record and represent the nature and frequency of the links.

Transmission of infections is a major concern in healthcare facilities, and a major source of hospital acquired infection is airborne infection. Heating Ventilation and Air Conditioning (HVAC) system design plays an important role in airborne infection, as it determines the possibility of cross contamination through air particulate dispersion. The paper "Airborne Contamination Control through Directed Airflow in the Exam Room: A Pilot Study Using a Membrane Diffuser" by Pati et al. examines a clean room technology that has been successfully used in technology and pharmaceutical industries, to control airborne contamination in an examination room. It included both performance tests in a mock-up room and a simulation study using Computational Fluid Dynamics analysis.

Through various supportive functions, families of ICU patients can make important contributions to care decisions and make clinical personnel's efforts more effective and efficient. The paper entitled "Environmental Design for Patient Families in Intensive Care Units", by Rashid (published in Vol. 1, No. 3), introduces "healing environment of care" as a model for family integration with patient care in ICUs, and proposes design recommendations for creating a healing environment of care that promotes family integration in ICUs, supported by research evidence on the effects of environmental design on ICU patients' families. In developing effective models for family integration, it is necessary to understand family needs, experience and behavioral responses.

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