Modular decoupling of data acquisition from analysis and visualization in acute care monitoring to facilitate evaluation and implementation of new derived parameters and visualization techniques: concept and prototype implementation

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Introduction

Traditionally, acute care patient monitoring equipment has consisted of one integrated device that performs the three key steps of data acquisition through signal conditioning and analog-to-digital con- version (A), biosignal processing and analysis (P) such as heart rate detection and ST segment analysis from electrocardiograms, and visualization/display (V) of the measured and derived data. In recent years, a number of so-called functional monitoring parameters that are computed from standard physiological measurements have shown clinical value and predictive power superior to most previously available parameters. A prime example is the pulse pressure vari- ability (PPV), which predicts luid responsiveness in patients on positive pressure ventilation1. More complex approaches to exploit- ing unused information in currently available physiological measurements are currently under development (e.g., 2). However, the evaluation and clinical application of even the simplest of these approaches is hindered by the fact that in standard clinical settings, replacement of the entire monitoring equipment is required for a new parameter to permeate into clinical practice. Although, in theory, firmware upgrades of monitoring hardware could provide such enhanced features, manufacturers are, in practice, reluctant to implement such alterations due to regulatory issues. As a consequence, PPV has only become available in recent patient monitors, more than a decade after the clinical usefulness of this parameter was recognized, indicating that the current setup of our monitoring infrastructure may hinder innovation. In contrast, a modular frame- work that transparently decouples A, P, and V steps would remove a major obstacle preventing the rapid evaluation and early, broad adoption of novel derived monitoring parameters and visualization techniques that may help to optimize treatment. Here, we describe a technical framework that may make such decoupling practical, and describe first steps towards implementation in a research setting. Methods A modular software architecture was designed that decouples the A, P, and V steps outlined above. First, server side data storage and processing (A and P steps) is separated from client side visualization (V step) in a client–server model. On the server side, an abstract model of server side data acquisition and processing was developed and implemented that allows for the deployment of arbitrary data sourcing and processing graph topologies, where nodes are elemen- tary modules consisting of data source access code (either online or offline/database based) and processing code (such as signal process- ing modules implementing, e.g., filters, and physiological analysis modules that generate derived parameter timeseries from existing parameters, such as PPV computation), and edges are signals of various dimensionality and data type. Preliminary testing of the prototype was performed to prepare for first bedside evaluations. For implementation of the server-side software infrastructure, JavaTM was used to allow for clean interface/implementation separation and facilitate maintenance and future development. On the client side, a dynamic JavaScriptTM implementation of timeseries visualization running in standard browsers supporting HTML5 (canvas tag) was chosen. For client–server communication, JSON encoded data is transmitted via HTTP.

Results

The described architecture proved to provide sufficient performance for interactive visualization and manipulation of physiological data streams in the test environment. The abstract, modular design of the server-side data access and processing infrastructure facilitates code reuse since modules for filtering, peak detection, etc., can be reused for arbitrary raw or derived signals, and simplifies development, testing, and roll-out of new analysis and data processing modules. The browser-based client visualization implementation minimizes support efforts required on the client side, with the potential of delivering a state-of-the art look and feel on both mobile and stationary devices. Since novel derived parameters are, from the perspective of the client- side visualization module, indistinguishable from other physiological timeseries, a seamless user experience is achieved.

Discussion

The described framework provides an infrastructure that has the potential to, once established in a specific clinical environment, sig- nificantly lower the threshold that has to be overcome before a novel derived monitoring parameter can be evaluated and, eventually, clini- cally applied. The seamless integration of novel analysis results into a familiar visualization environment should serve to lower the acceptance threshold of new parameters or visualization approaches among clini- cians, while simultaneously minimizing non-specific effects of an altered clinical environment on study endpoints in prospective validation studies of novel parameters or visualization techniques. The modular design and standardized interfaces facilitate well-structured development

and validation procedures in a research setting, while reducing errors through structured code reuse. Since development and live deployment can be performed within the same framework by exchanging offline for online data source nodes, significant sources of error and delay are eliminated. While the current prototype shows promise in greatly facilitating the development, evaluation, and deployment of novel derived monitoring parameters and visualization techniques in an academic environment, and may help to smooth the path to a more widespread implementation, translation of this approach to a commercial setting will require careful attention to regulatory issues. However, the combination of open interface standards and modern cryptographic techniques with a structured certification process should allow for regulatory decoupling and separate certification of A, P, and V components that would result in a plug-and-play architecture for acute care monitoring similar in flexibility to what is already com- mon in the audio signal processing market, where signal acquisition, analysis, synthesis, output, and editing seamlessly interoperate through the use of open standards. Since there is little commercial incentive to create such an open environment, with vendors often keen on marketing any minimal advance as a unique feature of their entire integrated monitoring package, widespread implementation of such a concept, while of potentially large value for both clinicians and patients, will likely require a coordinated push by users and regulatory authorities.

References

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