Data Integration in CDSS for Alerts & Reminders: A Review

Sarin Shrestha
Dakota State University, sshrestha17600@pluto.dsu.edu

Surendra Sarnikar
Dakota State University, ssarnikar@outlook.com

Prem Timsina
Dakota State University, ptimsina@pluto.dsu.edu

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Sarin Shrestha  
Dakota State University  
sshrestha17600@pluto.dsu.edu

Dr. Surendra Sarnikar  
Dakota State University  
surendra.sarnikar@dsu.edu

Prem Timsina  
Dakota State University  
ptimsina@pluto.dsu.edu

ABSTRACT

Advances in sensors technology, mobile technology and information technology is leading to the development of several innovative medical devices and systems with a potential for providing higher quality of care due to better information availability and decision support. However, due to the emerging nature of the information technology environment in the healthcare sector, there is a lack of seamless integration and assimilation of the new technology into healthcare organizations' Information Technology infrastructure and processes. Clinicians often need to screen multiple monitors to access information and have to rely on multiple medical instrumentation alarms to help protect patients. Alerts are designed to make the provider aware of conditions, however frequent alarms and multiple information sources instead reduce the probability of clinicians in responding and lead to information overload and alarm fatigue. In order to address this problem, there is an urgent need to develop decision support systems with smart alarms that can integrate multivariate parameters from disparate devices, as well as the ability for advanced data analysis through the integration of medical instrumentation and electronic health records. The article presents an overview of alert & reminder generation in CDSS through the data integration and identifies issues for future research.

Keywords

Data integration, Clinical decision support, electronic health record, alarm fatigue, wearable health monitoring device

INTRODUCTION

The rapid advances in sensor, mobile and information technologies are being leveraged in the healthcare sector to develop many innovative systems and medical devices for measuring, monitoring, maintaining health and for decision support. Clinical Decision Support Systems (CDSS) that support clinical decision making by providing specific guidance based on a clinical input are now being extended to provide support based on real-time patient physiological data, as well as other new data sources such as health information exchanges, EHR's and consumer health devices. Given the emerging nature of the technology landscape in the healthcare sector, however, there is limited integration of the devices into the underlying Healthcare Information Technology infrastructure, leading to a variety of unique style of providing information, alerts, and reminders.

The clinicians view in different places and different directions to access information from multiple sensors, and monitors, and rely on medical instrumentation alarms to help protect patients. At a recent panel on Clinical Engineering and Healthcare Technology Management's Impact on Clinical Outcomes, Goldman (2012) illustrated disparate device alarms and the non-integration of data on multiple parameters for integrated decision support is a major limiting factor for effective use of technology and proper response to clinical situations. Moreover, the need to use multiple monitors and devices to access information is leading to severe information overload and alarm fatigue in healthcare providers (Ely, Osheroff, Ebell, Chambliss, Vinson, Stevermer and Pifer, 2002). The appropriate integration of medical instrumentation and EHR could restrain alarm fatigue, and ease clinicians to provide quality care. There is an urgent need to develop decision support systems with smart alarms that can integrate multivariate parameters from disparate devices, as well as the ability for data analysis to generate centralized data.

This article presents an overview of alert and reminder generation in CDSS through the data integration. The purpose of this article is to serve as a reference for researchers in this area and to provide direction for future research improvements. The article provides the novel contribution in health informatics research. The paper is organized in four sections. In the following section, we illustrate the methodology for our review. Then we present the findings, discussions and issues of literature. Finally, we conclude the article with the direction for further research.
METHODOLOGY

Because the area of research is disparate, we could not find significant articles through a systematic search; nevertheless, we adopted an iterative and exploratory approach for identifying relevant literature. To cover the wide area of literature studies, we searched several scholarly databases and indexes including PubMed, Web of Science, Google Scholar and articles cited by and cited in each of the relevant articles. We used the keywords “(Data integration OR Information integration OR Alarm fatigue OR Patient monitoring device OR Wearable sensor device) AND (electronic health OR decision support),” and scanned in the Title, Abstract and Keyword sections of articles. We included in our review articles whose primary contribution is related to the capture, integration and analysis of real time clinical data from a patient for clinical decision support. The exclusion criteria are non-English language articles, technology are not the key factor in the alert and reminder mechanism. The inclusion & exclusion criteria results in 33 articles for our final analysis.

FINDINGS, DISCUSSIONS AND ISSUES

We observed that most literature addresses the issues of integrating multiple sources of patient data for providing decision support in the healthcare environment is in two areas of research. The first is in the area of ubiquitous patient monitoring and home health monitoring, where the focus is on collecting multiple sources of real-time patient related information through the use of various sensors and providing fast response and preventive decision support. The other area of research is related to alarm fatigue which focuses on the effects of this information on the end users who have to monitor and process several streams of information related to a patient to make clinical decisions. We provide a summary of the findings and issues in each of these areas in the following sub-sections.

Health Monitoring Devices

Health monitoring devices may consist of a variety of miniature sensors that are capable of measuring significant physiological parameters like blood pressure, respiration rate, heart rate, body temperature, oxygen saturation, ECG, EMG and many more. These measurements are collected and communicated through a wireless or a wired connection to a central system that transmit the collected vital signs to the medical center. Table 1 enlists the various bio-signals and corresponding sensors.

<table>
<thead>
<tr>
<th>Monitor Bio-signal</th>
<th>Sensor</th>
<th>Monitor Bio-signal</th>
<th>Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood Pressure (BP)</td>
<td>Arm Cuff Monitor</td>
<td>Heart Rate</td>
<td>Pulse Oximeter</td>
</tr>
<tr>
<td>Respiration Rate</td>
<td>Piezoelectric Sensor</td>
<td>Electrocardiogram (ECG)</td>
<td>Chest electrodes</td>
</tr>
<tr>
<td>Body/Skin Temperature</td>
<td>Temperature Probe</td>
<td>Oxygen Saturation (SpO2)</td>
<td>Pulse Oximeter</td>
</tr>
<tr>
<td>Body Movements</td>
<td>Acceleration Sensor</td>
<td>Electromyogram (EMG)</td>
<td>Electrodes</td>
</tr>
</tbody>
</table>

Table 1: List of Bio-signal and Sensors

Varshney (2007) state requirements and applications of pervasive healthcare, wireless networking solutions that embrace pervasive health monitoring, healthcare data access, intelligent emergency management system, and telemedicine. Moreover, Sneha and Varshney (2009) proposed a framework for ubiquitous patient monitoring that involves obtaining specific vital signs, analyzing information for the presence of anomalies, and if detected, the process of transmitting is invoked and if not process of sensing is invoked. Finally information is transmitted to physician, and medical intervention is prompted. The devices and related projects in this field are summarized below in Table 2.

<table>
<thead>
<tr>
<th>SN</th>
<th>Device/Project</th>
<th>Institution/Program</th>
<th>Measurements/Monitoring</th>
<th>Medical Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>LiveNet (Sung, Marci and Pentland, 2005)</td>
<td>MIT</td>
<td>BP, ECG, EMG, SpO2, Accelerometer, Temperature, Heart flux, GSR</td>
<td>Epilepsy seizure detection, Parkinson Disease</td>
</tr>
<tr>
<td>3</td>
<td>LifeGuard (Mundt, Montgomery, Udoh, Barker, Thonier, Tellier, Ricks, Darling, Cagle, Cabrol, Stanford University &amp; NASA</td>
<td></td>
<td>ECG, Respiration rate, Heart rate, SpO2, Body Temperature, BP, Body</td>
<td>Monitoring in extreme environments (space &amp; terrestrial)</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Project Name</th>
<th>Organization/Institution</th>
<th>Sensors</th>
<th>Use Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical Remote Monitoring of clothes</td>
<td>European FP6 IST</td>
<td>ECG, Body Temperature, Respiration rate, Acceleration</td>
<td>General Health Monitoring</td>
</tr>
<tr>
<td>Wearable Health Care System</td>
<td>European FP5 IST</td>
<td>ECG, EMG, Body Temperature, Respiration, Acceleration</td>
<td>Chronic Disease and Monitoring elderly patients</td>
</tr>
<tr>
<td>MagIC</td>
<td>University of Milan, Italy</td>
<td>ECG, Respiration rate, Body Temperature</td>
<td>Elderly people/Cardiac patients for home monitoring</td>
</tr>
<tr>
<td>AUBADE</td>
<td>Department of Medical Physics, Ioannina, Greece</td>
<td>ECG, EMG, Galvanic Skin Response, Respiration Rate</td>
<td>Evaluating the emotional state of an individual at extreme stress</td>
</tr>
<tr>
<td>HeartToGo</td>
<td>University of Pittsburgh</td>
<td>ECG, Acceleration</td>
<td>Cardiovascular diseases (CVD) Detection</td>
</tr>
<tr>
<td>Real-time Wireless Physiological Monitoring System</td>
<td>Dept. of Electrical Eng., National Taiwan University</td>
<td>Blood Pressure, Heart rate, Body Temperature</td>
<td>Monitor online the physiological status of aged patients</td>
</tr>
<tr>
<td>Medical Wearable Device</td>
<td>European Community (Karma2 – IST 2001-33230)</td>
<td>SpO2, Heart Rate, Respiration Rate, Body Movement</td>
<td>Management of Home Care activities in brain-injured children</td>
</tr>
<tr>
<td>MyHeart project</td>
<td>European Commission</td>
<td>ECG, Body Movement</td>
<td>Prevention and Early diagnosis of CVD</td>
</tr>
<tr>
<td>AiQ Smart Clothing</td>
<td>AiQ Smart Clothing Inc</td>
<td>Heart rate, Respiration rate, Temperature, EED, EMG</td>
<td>General Health Monitoring</td>
</tr>
<tr>
<td>Body Tel</td>
<td>Body Tel, German</td>
<td>Blood Glucose, BP</td>
<td>Monitoring chronic illness</td>
</tr>
<tr>
<td>Moticon</td>
<td>Moticon GmbH, Munich</td>
<td>Motion sensor</td>
<td>Daily monitoring, Rehabilitation &amp; sport training analysis</td>
</tr>
<tr>
<td>IntelliVue MX40</td>
<td>Philips Electronics</td>
<td>ECG, SpO2, BP</td>
<td>Monitor ambulatory patients and patients during transport</td>
</tr>
</tbody>
</table>

**Table 2: Summary of Health Monitoring Devices and Projects**

**Use Context**

The use of health monitoring devices can be classified into two contexts: hospital related use, and home health or outdoor use. Many device like IntelliVue MX40 are designed for hospital use such as Hospital-related: Transport to Hospital (Andover, 2011). Acute care, ICU and Nursing Centers (Lin et al., 2006). Numerous devices like AMON, LiveNet are designed for home monitoring (Anliker et al., 2004; McNickle, 2012b; Sung et al., 2005; Tura et al., 2003; Weber and Porotte, 2006) as well as for outdoor activities (Katsis et al., 2006; McNickle, 2012a; McNickle, 2012c; Mundt et al., 2005) like running, or playing sports.

**Medical Purpose**

Majority of devices are used for chronic care like Cardio Vascular (Anliker et al., 2004; Di Rienzo et al., 2005; Habetha, 2006; Jin et al., 2009; Mundt et al., 2005; Weber and Porotte, 2006), Diabetes (McNickle, 2012b), Epilepsy (Sung et al., 2005) as well as neurological (Katsis et al., 2006; Sung et al., 2005; Tura et al., 2003) that require social, behavioral and emotional monitoring. Some devices are for general health (Di Rienzo et al., 2005; Lin et al., 2006; McNickle, 2012a; Weber and Porotte, 2006) that can also be used for specific medical condition.

**Data integration**

Majority of devices transferred data to the remote system with potential for integration (Di Rienzo et al., 2005; Habetha, 2006; Jin et al., 2009; Katsis et al., 2006; Lin et al., 2006; McNickle, 2012b; McNickle, 2012c; Mundt et al., 2005; Sung et al., 2005; Tura et al., 2003; Weber and Porotte, 2006). Few devices integrate data in display (Andover, 2011; Jin et al., 2009; Mundt et al., 2005). Very few devices like AMON integrates data using the algorithm in device (Anliker et al., 2004). Some research suggests adoption of smart alarms with integration in algorithm (Cvach, 2012). Only few devices like LiveNet has data integration at remote site using algorithm (Sung et al., 2005).
Decision Support: Alarms, Analysis, Patterns

The devices provide different types of decision support to the medical personnel, either in alarms or in analysis. The devices like AMON, IntelliVue MX40, BodyTel, LifeGuard, LiveNet provide alerts if the data is outside of the normal range (Andover, 2011; Anliker et al., 2004; McNickle, 2012b; Mundt et al., 2005; Sung et al., 2005). In our review, we found only AMON that provides the staged alerts (Anliker et al., 2004). The devices like AMON, AUBADE, LifeGuard provide pattern recognition across multiple parameters (Anliker et al., 2004; Katsis et al., 2006; Mundt et al., 2005); whereas, LiveNet, IntelliVue MX40 and HearToGo Project devices provide pattern recognition across single parameter (Andover, 2011; Jin et al., 2009; Sung et al., 2005; Tura et al., 2003). HearToGo project and devices like AMON, AUBADE, LiveNet, provide personalized baseline for patients (Anliker et al., 2004; Jin et al., 2009; Katsis et al., 2006; Sung et al., 2005). Devices like AMON, LiveNet, AUBADE store data and compares the history of the patient (Anliker et al., 2004; Katsis et al., 2006; Sung et al., 2005; Tura et al., 2003). The devices developed from HearToGo and MyHeart project provide diagnosis to the patient (Habetha, 2006; Jin et al., 2009). Some devices do not have decision support, they only monitor the patient (Di Rienzo et al., 2005; McNickle, 2012c; Weber and Porotte, 2006); whereas, devices like LiveNet, AUBADE, MERMOTH provide feedback potentially from the doctor (Katsis et al., 2006; Sung et al., 2005; Weber and Porotte, 2006). Hence, there exist various issues regarding the decision support.

Under our review, we also found that only Moticon has the standard communication protocol (McNickle, 2012c; Moticon, 2012) and AMON has the proprietary communication protocol (Anliker et al., 2004). Most of the devices communication protocol is unknown (Di Rienzo et al., 2005; Habetha, 2006; Jin et al., 2009; Katsis et al., 2006; Lin et al., 2006; McNickle, 2012b; Mundt et al., 2005; Sung et al., 2005; Tura et al., 2003; Weber and Porotte, 2006). Hence, we can observe the interoperability is the crucial issue. The interoperability improves the sharing and re-use of collected data between disparate healthcare devices and applications and also reduces redundant data entry. We also realized the noise was a substantial problem for measurements. The other limitation has been the large costs and inflexibility of limited monitoring modalities associated with these technologies and the impracticality for long-term use in general settings.

Alarm fatigue

The healthcare providers set alarms for a variety of medical devices in the Intensive Care Unit, acute care, and surgery room to monitor patients so that immediate attention can be provided. Actually, alarm is designed to make the clinician aware of conditions, but false alarms occur frequently that may reduce the probability of clinicians in responding which is known as the cry wolf effect (Breznitz, 1984). Alarm fatigue may occur when the numbers of alarms overwhelm providers because of false alarms or technical problem alarms, inappropriate alarm settings or inappropriate protocols for inactivation, and over utilization of physiologic monitoring. The problem of excessive alarms resulting in alarm fatigue has been reported from many years. ECRI (2011) state that alarm fatigue is the number one medical device technology hazard in 2012. Schmid, Goepfert and Kuhnt (2011) report that 359 alarms occur per cardiac surgery procedure, at 1.2 per minute and about 80% of all alarms have no beneficial effect. American College of Clinical Engineering survey more than 1300 health care professionals which illustrated that 81% agreed that nuisance alarms occur frequently, 78% agreed on disabling them that reduce trust in alarms (Drew, Califf and Funk, 2004). The frequent alarms are distracting while performing critical task that may lead a provider to disable the alarm. In 2010, a patient in Massachusetts General Hospital died after the alarm on a heart monitor was accidentally left off (Wallis, 2010). Federal investigators concluded the incident as alarm fatigue experienced by clinicians functioning among frequently beeping monitors. U.S. Food and Drug Administration (FDA) Manufacturer and User Facility Device Experience (MAUDE) database reported 566 patient deaths related to the monitoring device alarms within years of 2005-2008 (Weil, 2009).

Related Work

Blum, Kruger, Sanders, Gutierrez and Rosenberg (2009) addressed alarm related issues by implementing a computer architecture based on reactive intelligent agent technology in a critical care unit to facilitate the investigation of deterministic algorithms for the enhancement of the sensitivity of physiologic alarms. Borowski, Siebig, Wrede and Imhoff (2011) identified high false alarm rates can be lowered by separating relevant signals from noise using statistical signal extraction algorithm like adaptive online Repeated Mediation (aoRM) (Schettlinger, Fried and Gather, 2010), adaptive online Trimmed Repeated Median-Least Squares (aoTRM-LS) (Borowski, Schettlinger and Gather, 2009). Various approaches are proposed to improve alarm systems. For example, median filters can be used to eliminate noise (Mäkivirta, Koski, Kari and Sukuvaaara, 1991); a preprocessing algorithm is proposed in a trend-based alarm system to improve patient monitoring in intensive care units (Charbonnier and Gentil, 2007), a method based on control charts is developed to detect the onset of changes in systolic blood pressure for ‘advisory’ alarm during anesthesia (Kennedy, 1995). Healthcare institution can also organize creative teaching strategy such as jeopardy game to involve staff and nurse to educate about alarms (Graham and Cvach, 2010).
Joint Commission Alert recommends that healthcare organization should establish guidelines for alarm settings on alarm-equipped medical devices used for high-risk clinical conditions as well as inspect and maintain alarm-equipped medical devices to provide for accurate and appropriate alarm settings (Terrace, 2013).

Future Direction

Alarm could compromise the patient’s safety if alarms are disabled or ignored. The appropriate integration of medical instrumentation and EHR could restrain alarm fatigue. The smart medical monitors are likely to enhance patient outcomes by incorporating multifarious heterogeneous data, and reducing information overload for clinicians. The information overload and alarms generated by multiple monitors may generate circumstances that negatively impact the outcomes of patients. Smart alarms takes into account multiple parameters, signal quality, and rate of change can reduce the number of false alarms (Biot, Holzapfel, Becq, Mélot and Baconnier, 2003; Burgess, Herdman, Berg, Feaster and Hebsur, 2009; Otero, Félix, Barro and Palacios, 2009; Schmid et al., 2011). The clinicians recognize the alarm by the sound- single beep, double beep, or continuous beep, but the future research should focus on determining the most recurrent alarms, vital alarms and duplicate alarms more accurately. The documentation of alarm parameters in the medical record is also an effective way for improving alarm adjustment compliance. The significant work is needed on smart alarm technology by the manufacturer to improve alarm accuracy. There is an inadequacy of alarm notification and response protocols. In essence, a gap exists on the risk and benefit of alarm standardization across medical devices. Furthermore, the research is needed in the best way to set monitor limits to improve alarm positive predictive value, and there is also a necessity of alternate approach to the audible alarm notification when compared to human monitor watch.

CONCLUSION

In our review, we have observed that most research on CDSS in multi-data environments in the area of health monitoring devices where such data is generated, and in the area of alert fatigue, which looks at the effect of multiple data sources and associated alerts and alarms on the end users of the information. Significant amount of research has been done in the area of alert fatigue and researchers have identified several areas for improvement including lack of adequate alarm notification and response protocols, and false alarm suppression algorithms. In the area of health monitoring devices, most research focuses on data acquisition, but significant gaps remain in integrating multi-parameter data, interoperability of data, and advanced decision support and pattern recognition across multiple-data streams.

REFERENCES
