31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Service oriented architecture for the integration of clinical and physiological data for real-time event stream processing

Rishikesan Kamaleswaran, *Member IEEE*, Carolyn McGregor, *Senior Member IEEE*, and Jennifer Percival, *Member IEEE*

Abstract— **This paper proposes a framework for the integration of physiological and clinical health data within a Service-Oriented architecture framework. This integration will subsequently be used in real-time event stream processing in intelligent patient monitoring devices. Service-oriented architecture offers a unique method of integrating health data as information is collected from multiple medical devices that lack any substantial means of standardization. Employing various services to facilitate the transmission and integration of these data will result in significant improvement in both efficacy and analytical velocity of intelligent patient monitoring systems. We demonstrate this approach within the Neonatal Intensive Care setting.**

I. Introduction

NEONATAL Intensive Care Units (NICUs) boast some of the most technologically advanced machinery responsible for monitoring the babies' psychological and clinical information while others offer life support. These devices allow physicians and researchers the ability to study subtle changes within the baby as they occur in real-time. The NICU environment is extremely data intensive, thus the magnitude of data collected from these monitoring systems can be colossal and difficult to decipher by any single individual. This is evident in Miller's observation, that humans are only capable of processing seven separate variables at any given time [1].

Data collected within the NICU can be classified as either: (1) physiological data streams, in its simplest form refers to data within monitoring medical devices, such as heart rate and respiratory rate, or (2) clinical data, which are obtained by a physician's or nurse's observation and assessment and localised in a Clinical Information System (CIS). Incidentally, modern Intelligent Decision Support Systems (IDSS) [2] habitually view the entities of psychological and clinical data separately, devoid of any analysis within an integrated framework. In some cases, the entry of clinical data is transmitted to the analytic framework solely through manual entry by the use of a keyboard, or collected from hospital information systems created without the broader intention of research. This leads to the disaggregated health data being fragmented and localised within specific CIS's whose origins and design lies in supporting administrative purposes [3]. Due to the lack of an innate interoperability scheme within the current CIS, the accessibility of these data for secondary research and analysis has not been prevalent. As a result, real-time analytics frameworks have been slow to flourish because of the lack in integration of both clinical data from the disparate CIS and diverse physiological data streams. Therefore, the absence of a truly real-time analytics framework both deteriorates and elongates clinical judgment such that the optimal care cannot be performed.

That being said, the admission of a newborn into the NICU is one of the most stressful periods that a family can face, and so, any decrease in the quality of care add to the significant stress and anxiety. It is then easy to appreciate the importance placed on the potential for breakthroughs in neonatal care environment. A breakthrough nonetheless could occur through the introduction of an instantaneous and errorless IDSS framework based on real-time analytics using integrated data from all the available sources of patient data.

In particular, the essential but omitted factor for the modern IDSS frameworks is the creation of a broad architecture that is needed to integrate both physiological data streams and clinical data in real-time. In this regard, several industries such as business enterprises, banks, stock markets, weather, and even certain healthcare services such as EHR, have begun to conceptualise and develop unique solutions based on a computer paradigm known as Service-Oriented Architecture (SOA) [4]-[6]. SOA utilises several basic services as elements within a large framework based on a common infrastructure [4]. The advantage of using SOA within the framework for integrating health data lies in the nature of where the data originates. Modern medical devices are not standardised across all mediums, and have very little interoperability within the clinical environment [3].

However, even within this diversity, communication between the CIS and the medical device can be exploited. This consequently can be used within a SOA framework as multiple server interactions. For example, each medical device relies on unique drivers to facilitate the communication between its internal processing engines and the storage capabilities of external systems. By taking advantage of this interaction, the medical devices can be made to exist as SOA services thus integrating health data in

Manuscript received April 7, 2009. R. Kamaleswaran is from the Faculty of Health Sciences, C. McGregor is with the Faculty of Health Sciences/ Faculty of Business and Information Technology, J. Percival is with the Faculty of Business and Information Technology, University of Ontario Institute of Technology, 2000 Simcoe Street North, Oshawa, Ontario, L1H 7K4 Canada. Phone: 905-721-8668; Fax: 905-721-3167; rishikesan.k@gmail.com, c.mcgregor@ieee.org, jennifer.percival@uoit.ca

real-time. This breakthrough should subsequently reduce analytical time, lower mortality rates, and increase the quality of care for the baby and the family.

This paper is structured as follows; Section II introduces related work in the area of physiological and clinical data integration. Section III introduces the concept of an integrated framework for the union of physiological and clinical data. Section IV concludes with research findings.

II. Related work

The importance of integrating clinical and physiological data streams have yet to be fully exhausted within the literatures. There is a great amount of health informatics research in the area of critical care; however, there is little research on the applications of service oriented architecture to support critical care [4]. This observation holds true even within areas such as in the union of physiological and clinical data. Service oriented architecture is a unique area of research that has vast potential for the integration of these two types of distinct data. Specifically, service oriented architectures provide an environment in which multiple services run in conjunction to optimise integration for interoperability [6]. This systematic approach of using services to serve in interoperability solutions within the critical care environment is termed as service of critical care [4].

To understand the significance of service oriented architecture in medicine, one needs to understand the history of computerised expert systems, and the way in which data is transmitted within that framework. Much of data analysis today is based on Intelligent Decision Support Systems (IDSS), which differ from Decision Support Systems (DSS) largely due to its Expert Systems (ES) component [2]. ES allows IDSS to attach a level of confidence to its predictions and recommendations based on sophisticated correlations found within the analysed data. IDSS in healthcare find their early origins in the eighties within rule-based advisory systems designed with fixed rules based on clinical guidelines [2]. This high level analysis of patient health data was replaced by a newer design, which processes not just fixed low frequency physiological readings, but also began to accept manipulation of inert rule-based interpretations by a clinician's direct input [7]. This fundamental design continues to govern the basic framework of modern IDSS however, with the latest introduction of clinical data, which also happens to be directly entered by clinicians [7], [8], [10], [11].

An example of a modern service of critical care using manual data entry is found in Lin's framework [8], in which they attempt to use a web service protocol to send vital information from a patient at a critical care site to a remote specialist hospital. This study however, only looks at the transmission of physiological data with minor coverage of clinical information [8]. Although the study shows that information can be successfully transmitted, it is important to note that it is limited in such a way that only physiological data is transmitted directly and clinical data still requires manual entry from the clinicians' laptop [8].

Furthermore, this method of data analysis is reinforced in another study of IDSS designs of mechanical ventilators by Tehrani & Roum [7]. In this study, modern IDSS designs are researched and were found to contain a familiar conceptual design. Within these systems, physiological data of a patient as obtained from the patient or mechanical ventilator is collected as a separate input in comparison to the clinical data which constitutes to inputs through the clinicians' laptop [7]. This was then used to intelligently apply changes within the ventilator as needed to provide best comfort for the patient. Hence, even modern IDSS perform such that decision is semi-autonomous, and extensively requires the manual continued input of the physician to guarantee the optimum confidence in the readings.

Additionally, the lack of interoperability within CIS is a major detriment to reducing medical errors and improving quality of care. Bates et al., identify 16 major types of system failures associated with medical errors, and have found that the top 8 could be addressed through better CIS that involve high degrees of health data integrality [9]. The lack of interoperability is rooted in the diversity of proprietary systems in both clinical information systems and physiological devices [9] For example, clinical data can exist in one of many databases, such as laboratory, or pharmacy systems without any direct communication between the two [9]. Physiological data involves the coordinated effort of all medical devices connected to a neonatal infant to communicate with the central data collection equipment for processing and storage. However, these medical devices are commonly from a variety of manufacturers [10] with unique drivers for each of the device.

This lack of interoperability results in loss of a unified flow of clinical data that can be used in conjunction with IDSS for use within critical care environments. Kuperman et al. [11], documented significant decrease in the quality of clinical treatment when critical laboratory results were given to the physicians through telephone [11]. This further highlights the importance of a real-time system that is able to integrate all facets of neonatal health data, and analyse that information without delays in transcription or transmission of the required data. Recent research using multiple CIS has begun to show promise in approaching real-time analysis. Shabot et al. [12], uses wireless PDA devices as decision support tools to send physicians any critical laboratory alerts, physiological alerts, or medication alerts within a real-time environment.

With improved use of CIS within hospitals and through introductions of new standards to data encapsulation, it is now possible to integrate various clinical databases. Specifically, through the use of a rigid reference terminology such as SNOMED CT (SCT), and transmission standards like Health Level 7 (HL7) and Digital Imaging and Communication in Medicine (DICOM), the integration can be easily facilitated across all aspects of medical data [13]. SCT, provides a robust and structured representation of a large majority of terms relevant to neonatal intensive care units [14]. Comparatively, HL7 and DICOM introduce a standardised approach to the integration and transmission of several clinical and physiological data systems respectively [13]. The use of both terminology and transmission systems offers an ample opportunity to integrate data at real-time, and process the information without the delays caused by manual entry of physician or nurse.

III. INTEGRATED FRAMEWORK

The framework being introduced in this paper extends the research of the e-Baby architecture [15] by providing details of the integration of the clinical and physiological data within the event stream processor. The e-Baby architecture is an initiative to collect, store and display high frequency streams of data from multiple information systems and medical devices to facilitate intelligent analysis [15]. This architecture consists of a series of web services used to interface with an IDSS called the Solution Manager Service (SMS) shown in Fig. 1. The interest of this paper is specific to how two web services, *Physiological Log Web Service*, and the *Clinical Log Web Service* interact with the Event Stream Processor to integrate data in real-time.

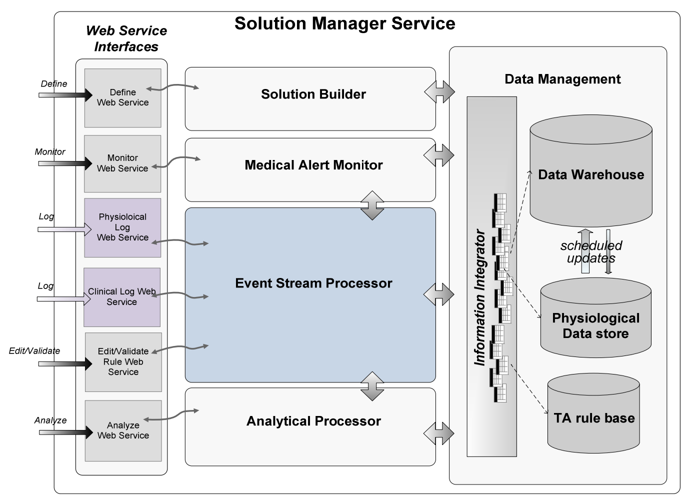

Fig.1. High level architecture of the Solution Manager Service (SMS) for intelligent data analysis and decision support for NICU

The *Clinical Log Web Service* (CLWS) transmits clinical data abstracted from hospital information systems such as James's Clinical Information Management System (CIMS) [14] for real-time analytics within ESP. The incoming data into CLWS is required to be converted from native terminology used within the hospital systems to SCT, hence enhancing interoperability and improving field consistency. Significant problems such as interoperability and consistency in clinical data are addressed through making SCT as the standard reference terminology. However, SCT concepts related to neonatology are still very much in development, despite this James notes that SCT was able to reference with more than 90% of the CIMS terms for disorders of newborn infant [14]. James's findings encourage SCT as a standard that could be used for the broad referencing of all neonatal terms used within the disparate independent hospital information systems. Furthermore, once the data has been formatted in SCT, the transmission to the SMS will occur immediately following CLWS's normalization of data within HL7 encapsulation. Subsequently the HL7 data will be picked up by the SMS for analytics.

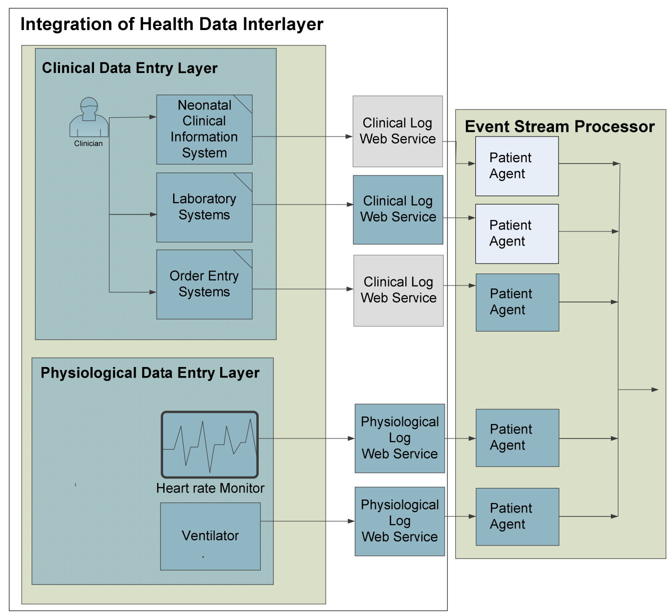

Fig.2. High level view of Clinical and Physiological integration

The *Physiological Log Web Service* (PLWS), is the gateway to the entry of all physiological data into the SMS. Data streams that have input connections to PLSW's are diverse in the sense that they monitor either (1) numeric data: one reading every 1024 milliseconds (ms), (2) wave data: four readings arrive every 32 milliseconds, or (3) fast wave: in which 16 readings arrive every 32 millisecond [16]. The physiological data is needs to be normalized from the raw data within the medical device, into XML format by the use of the Data Collection Unit (DCU) [15]. DCU will control both the size and frequency of the data sent through the PLWS to the SMS. Upon the entry of XML formatted physiological data into the SMS, they are channelled to individual and independent Patient Agents (PA) as depicted in Fig. 2. Although it may seem overwhelming, initial research has tested a 30 bed capacity with acceptable throughput. Current research is to support an 80 bed NICU using this architecture. Using a controlled mechanism for uniform data entry, the SMS is able to process these streams as they enter in real-time. This essentially allows the SMS an ability to handle data transmitted from a wide range of medical devices.

The *Event Stream Processor* (ESP) utilizes arriving data from the CLWS and PLWS and streams them to the PA, which applies rules input from clinicians. The PA's will detect the nature of the incoming data based on the format in which they appear. Clinical data will be transmitted in HL7, while physiological data remains in the transformed XML format. Once the data streams have been analysed by the PA, they are further processed by the ESP for interpretation and notification of any anomalous events triggering various alarming functionalities.

The integration of both clinical and physiological data streams as they are transmitted through their respective origins is depicted in Fig. 2. At a high level, the initial integration of these unique data occurs within the PA. Specifically, CLWS abstracts the required data from available CIS, and transforms them to SCT for optimized interoperability, and submits the data in HL7 to the PA. Likewise, PLWS transmits incoming XML formatted physiological data from DCU of various frequencies and structure to the PA directly without any additional transformations. The request for data from the systems involves the rule-based system defined by clinicians. Each PA then monitors a single stream of physiological or clinical data, allowing for a continuous integration of the diverse health data.

IV. Conclusion

This paper has presented a framework utilising web services built on a Service Oriented Architecture, to integrate two very different types of health data. Modern IDSS have been slow to take advantage of the unique associations of both clinical data and physiological data, however this paper discusses a way to integrate both data for real-time patient monitoring within an IDSS. The IDSS extended in this research is the Solution Manager Service (SMS) which has been developed by McGregor, 2005 [15]. Web services form the interface to SMS, hence eliminating problems faced by other IDSS in integrating diverse transmissions from a variety of medical devices. We have demonstrated this framework within the context of Neonatal Intensive Care. This research forms part of our future research directions to utilise the SOA approach to create a service of critical care model for use initially within NICUs and further onto other ICUs. This approach is required to enable the use of data from multiple sites for the clinical research on data captured during this stage. Future IDSS will need to adapt similar integration methodologies within an ever growing diverse medical environment, as new more advanced medical devices are introduces within the neonatal environment.

Acknowledgements

This research is funded by McGregor's Canada Research Chair in Health Informatics.

References

[1] Miller G. The magical number seven, plus or minus two: Some limits on our capacity for processing information. Psychol Rev;63(8):1-97.

[2] Foster D, McGregor C, El-Masri S. A survey of agent-based intelligent decision support systems to support clinical management and research. In: Proceedings of the first international workshop on multi-agent systems for medicine, computational biology, and bioinformatics; 2005. p. 16-35.

[3] Blendon, R. J., Schoen, C., DesRoches, C., Osborn, R., & Zapert, K. (2003). Common concerns amid diverse systems: Health care experiences in five countries. Health Affairs, 22(3), 106-121.

[4] McGregor, C, & Eklund, JM, 2008, "Real-time Service Oriented Architecture to Support Remote Critical Care: Trends and Challenges", First IEEE Int.Workshop On Real-Time Service-Oriented Architecture and Applications (RTSOAA 2008), Finland, July, 08, 1199-1204

[5] Lawler, JP, Howell-Barber, H. Service-Oriented Architecture: SOA Strategy, Methodology, and Technology. Auerbach Pub; 2007

[6] Papazoglou M. Service-oriented computing: Concepts, characteristics and directions. In: Web Information Systems Engineering, 2003. WISE 2003. Proceedings of the Fourth International Conference on; 2003. p. 3-12.

[7] Tehrani, Fleur T and Roum, James H. Intelligent decision support systems for mechanical ventilation. Artificial Intelligence in Medicine. 2008, Vol. 44, pp. 171—182.

[8] Lin YH, Jan IC, Ko PCI, Chen YY, Wong JM, Jan GJ. A wireless PDA-based physiological monitoring system for patient transport. IEEE Transactions on information technology in biomedicine. 2004;8(4):439-47.

[9] Bates DW, Cohen M, Leape LL, Overhage JM, Shabot MM, Sheridan T. Reducing the frequency of errors in medicine using information technology. Journal of the American Medical Informatics Association. 2001;8(4):299-308.

[10] James B. E-health: Steps on the road to interoperability. Health Aff. 2005

[11] Kuperman GJ, Boyle D, Jha A, Rittenberg E, Ma'Luf N, Tanasijevic MJ, Teich JM, Winkelman J, Bates DW. How promptly are inpatients treated for critical laboratory results? Journal of the American Medical Informatics Association. 1998;5(1):112-9.

[12] Shabot MM, LoBue M. Real-time wireless decision support alerts on a Palmtop PDA. In: Proceedings of the Annual Symposium on Computer Application in Medical Care; 1995American Medical Informatics Association; 1995. p. 174.

[13] Eklund JM, McGregor C, Smith KP. A method for physiological data transmission and archiving to support the service of critical care using DICOM and HL7. In: Engineering in Medicine and Biology Society, 2008. EMBS 2008. 30th Annual International Conference of the IEEE 2008. p. 1486-9.

[14] James, AG. SNOMED CT® as the Clinical Terminology for Representation of the Clinical Care of the Newborn Infant: A Capstone Project. Oregon Health & Science University; 2007

[15] McGregor C. e-baby web services to support local and remote neonatal intensive care. HIC 2005 and HINZ 2005: Proceedings:344.

[16] Stacey M, McGregor C, Tracy M. An architecture for multi-dimensional temporal abstraction and its application to support neonatal intensive care. In: Engineering in Medicine and Biology Society, 2007. EMBS 2007. 29th Annual International Conference of the IEEE [Internet]; 20072007. p. 3752-6.