A Web Services Based Framework for the Transmission of Physiological Data for Local and Remote Neonatal Intensive Care

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Abstract

Premature and ill term babies born in metropolitan and regional Australia are monitored and supported by a range of medical devices within Neonatal Intensive Care Units (NICUs) or Special Care Nurseries. Information produced by these devices is in a range of formats making data transmission infrastructures complex. This paper details case study based web service framework research for the transmission of physiological data for local and remote Neonatal Intensive Care. This framework enables real-time physiological data collected from medical monitors and ventilators attached to the baby to be encoded in XML and transmitted via the use of a physiological log web service. The key contribution of this significant research is the infrastructure providing a mechanism for Neonatologists to receive information directly from a regional hospital, thereby preventing, in some cases, the immediate need to move the baby. This paper further describes the application of that architecture to a specific pilot within the NICU at Nepean Hospital, Penrith Australia.

Keywords: Web Services, XML, Health Informatics, Telemedicine, Neonatal Intensive Care Unit, Intensive Care Monitoring

1 Introduction

Approximately eighteen percent (18%) of babies born in New South Wales (NSW), Australia require special care or neonatal intensive care admission [1]. Premature babies can be up to 17 weeks early and may only weigh 450gms; they can spend 3 or 4 months in intensive care and have dozens of specific diseases before discharge. In addition, fifteen percent of neonatal intensive care admissions are transferred after delivery from smaller regional hospitals without intensive care facilities. Similar geographical conditions apply within other countries such as New Zealand, Canada and the USA where small regional hospitals are spread throughout the country.

Several medical monitoring devices monitor a baby's physiological parameters such as blood oxygen, blood pressure and heart rate. Other devices such as ventilators offer mechanical life support. All these devices have the ability to output the device readings via a serial port, however the data formats vary greatly from device to device. As such, efforts to make device data from devices attached to local or remote babies accessible for viewing through centralized NICU consultant physician viewing stations are hampered by the myriad of formats required for transmission.

Regional hospitals have equipment to provide limited NICU support within Special Care Nurseries, but without the ability for a Neonatologist to receive information from this equipment, the baby must be moved to a Referral Hospital with Neonatologist support. Given the critical requirement to maintain a consistent environment, moving a baby at this time can be life threatening. Transferred critically ill, term and pre-term babies have higher mortality rates and much higher rates of long term disability than similar babies born in hospitals with intensive care facilities [2]. A major limitation is that the attending physician at the Regional Hospital must contact a neonatal specialist via telephone, who may or may not be located at the NICU at that time, to describe the baby's symptoms and, where possible, relay any physiological information verbally. The consulting Neonatologist must then make decisions based on this verbal exchange.

It is very common for critically ill babies to have significantly abnormal variation in the measured parameters minute by minute and not all these variations are made available to the consulting Neonatologist.

Frequent transient falls in blood pressure and blood oxygen content, often with swings into the high range, may be of critical importance in survival and quality of life free of significant disability [3].

Hence the Neonatologists located at Referral Hospitals require the ability to obtain information from the monitors attached to babies. Similarly, a Neonatologist need not be located at a PC within the hospital to view local or remote patient data, but should be free to view this information through any secure Internet/Intranet connected device.

As a result, there is a need to develop a mechanism to transmit physiological device data from disparate local and remote medical devices for viewing through centralized Neonatologist devices such as PCs and personal digital assistants (PDAs). In addition, there is a need to store this data for future analysis and research.

This research aims to address the need for standardising physiological data transmission, by utilising the platform and language independence of web services and the structural independence of XML in the development of a web service based framework for the transmission, display and storage of physiological data for local and remote neonatal intensive care. A key benefit of this framework is that minimal additional technology components are required within the Regional Hospitals, thus introducing minimal technical support requirements at these locations.

This paper further describes the application of that architecture to a specific pilot within the Neonatal Intensive Care Unit at Nepean Hospital, Penrith Australia.

We begin with a brief overview of related computing and IT research for supporting intensive care units (ICUs). The e-Baby architecture is then presented and the components of that architecture that relate to this research are detailed. The Solution Manager Service (SMS) for Neonatal Clinical Management and Research is introduced. We then describe in detail the *physiological log web service* component of the SMS that is used to transmit the physiological data. The pilot developed in association with this research is then detailed. The paper concludes with an assessment of future research opportunities.

2 Related work and contribution

Telehealth is the transmission of images, voice and data via telecommunication channels. Telemedicine connects patients and health care providers improving access to quality health care particularly in rural and remote parts of NSW. Telehealth and telemedicine initiatives to provide mainstream public health care delivery across rural and metropolitan areas, have mainly focussed on video conferencing [4]. There have also been limited efforts for the electronic transmission of x-rays.

Much of the recent computing and IT related research to support intensive care units (ICUs) has focused on clinical alerts [5-8]. The information made available to these systems is limited to a small set of physiological data and/or clinical data from patients located within their ICUs. Clinician access to these systems is limited to the receipt of alerts with minimal content via email and in some cases pagers.

An integrated XML-based health care framework for a neonatal intensive care unit is described by Catley et al in [5, 9]. That research enables the capture of local real-time patient device data within a data repository located within a data collection unit (DCU). It utilises XML as a means to transfer data from a NICU data repository to clinical decision support system (CDSS). The transmission of the data from the medical devices to the DCU is not in XML. Within this research DCUs will be located within remote regional hospitals in addition to NICUs and hence a local technical architecture that does not necessitate the establishment of a database within the DCU is required.

Kreger [10] defines a web service as *an* interface that describes a collection of operations that are network-accessible through standardised XML messaging. Web Service Definition Language (WSDL) supports the implementation of web services by providing a standard XML format for describing network services as a set of endpoints operating on messages containing either document-oriented or procedure-oriented information [11].

McGregor's recent research [12-15] details the Solution Manager Service (SMS) architecture within the context of its use for business performance measurement. The SMS is an agent-based intelligent decision support system that allows organizations to collect information about their business processes in a centralized repository, and share them among authorized parties, such as supply chain partners, clients, or government agencies. A key contribution of that research is that the interaction with this IDSS, is via a set of web services. In addition, the infrastructure boasts several innovative agent based modules that support different components, providing the intelligence within this IDSS [15]. Within that research business process audit stream data is transmitted to the SMS via the use of a *log web service*. This research reapplies the principles of the SMS within the context of receiving and processing physiological stream data via a *physiological log web service*.

3 The e-baby architecture

This research is part of a wider research and development initiative, "e-Baby" [2, 16] being pioneered by Health Informatics Research, University of Western Sydney (UWS) in conjunction with Nepean Hospital's NICU. The broad aims of the e-Baby project are to:

- investigate innovative ways to address the problems of handling large volumes of patient data;

- improve communications and data capture between disparate databases and complex medical machinery via electronic linking;
- integrate and display data in a way that would facilitate the ability of clinicians to recognise new disease patterns.

The e-Baby architecture defines architectural components located at Referral Hospitals containing NICUs, Remote Hospitals with Special Care Nurseries and supports remote and Referral Hospital access by Neonatologists.

The components of the e-Baby architecture that relate to this research are detailed in Figure 1 and described below.

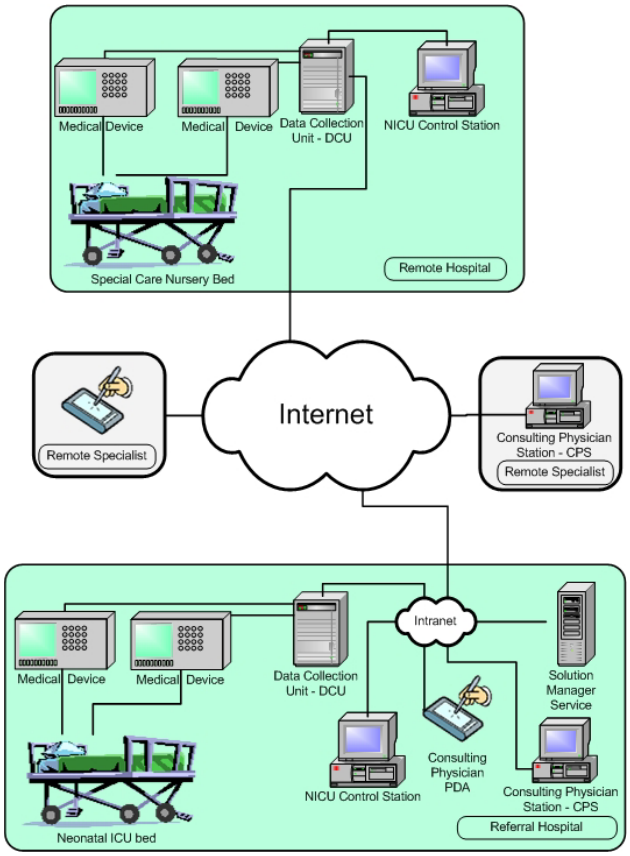

Figure 1 e-Baby Architecture

Special Care Nursery Beds are provided for baby's born in regional hospitals that require special care. Baby's born in or transferred to referral hospitals with NICU facilities that require special care are located within **Neonatal ICU beds**.

Several **Medical Devices** are attached to the baby or the humidicrib/bed containing the baby.

The **Data Collection Unit (DCU)** is situated in close proximity to the bed/humidicrib and each DCU supports two bed/humidicribs. The DCU is a fanless small-footprint PC, to minimise space requirements and noise, and is connected to bedside medical devices. It packages the incoming physiological data from the medical devices and converts the data to the required XML format before utilising the *physiological log web service* to transmit the data to the Solution Manager Service.

The **NICU Control Station** is located within the referral hospital NICU or regional hospital Special Care Nursery but at a distance from the bed/humidicribs. It provides the mechanism to control each DCU by enabling the establishment and cessation of the collection of data from the medical devices as devices are attached and detached from the baby and also provides a mechanism to control the size of the data package (10 sec or 1 minute for example) that the DCU transmits via the *physiological log web service*.

The **Solution Manager Service (SMS)** is situated in the referral hospital NICU Server room. Data collected by the DCUs is populated within the SMS via the *physiological log web service* for near real time analysis and trend detection.

The **Consulting Physician Station (CPS**) is used by the neonatologists to access the physiological data located in SMS via a set of *analyse web services* or via a direct link to the data as it is streamed through the *physiological log web service.*

4 Solution manager service for neonatal clinical management and research

The Solution Manager Service (SMS) is an Intelligent Decision Support System (IDSS) to support neonatal clinical management and research. Interaction with the solution management service is via a series of web services. The SMS contains five components:

- *Solution Builder* is a build-time component that captures metadata that is used to setup and initialize the runtime components and the *Data Management* layer.
- *Medical Alert Monitor* is a run-time component enabling Neonatalogists to define and change complex medical alert rules.
- *Event Stream Processor* provides a scalable data staging environment to continuously integrate and transform events to support complex medical alerts.
- *Analytical Processor* provides a run-time interface for retrieving near real time patient data or to perform clinical trial analysis at patient or summary levels from data located in the data warehouse or real-time data store within the data management layer.
- *Data Management* provides persistent storage of build-time metatdata and run-time physiological and clinical data stored in either the data warehouse or real-time data store.

Access to these components is via a set of *define, log, monitor* and *analyse* web services. Further high level architectural details of the complete Solution Manager Service when used within the context of neonatal clinical management and research can be found in [16]. This research details the development of one of the *log web services* known as the *physiological log web service* and the population of the physiological data within the Data Management component as shown in the diagram below.

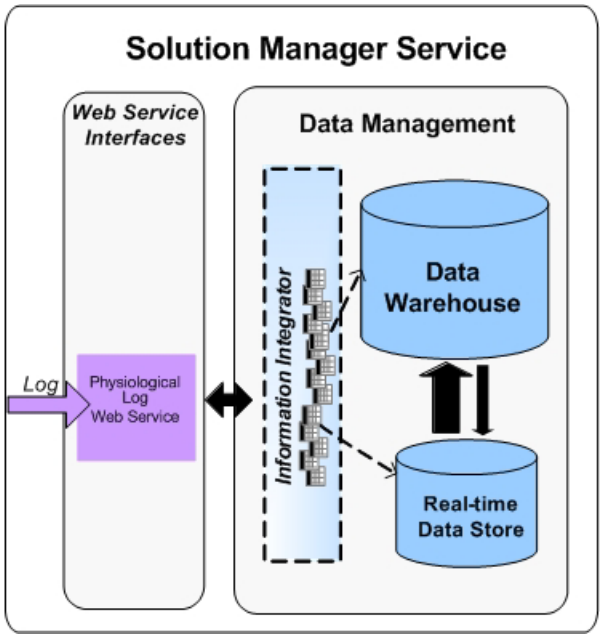

Figure 2 Physiological Log Web Service

4.1 Physiological log web service

The function of the *physiological log web service* is to enable the transmission of packets of physiological data that have been encoded in XML. To enable this the following definitions for messages and port types have been defined using WSDL.

```
<message name="ReceiveNumericDataIn">
   <part name="parameters"
         element="s0:ReceiveNumericData" />
 </message>
 <message name="ReceiveNumericDataOut">
   <part name="parameters"
         element="s0:ReceiveNumericDataResponse" />
</message>
```

The first message format is used to contain the physiological data packet ("ReceiveNumericDataIn"), the second to receive notification of successful receipt of that packet of data ("ReceiveNumericDataOut"):

The following port type is then required:

```
<portType name="numericReceivingSvcSoap">
   <operation name="ReceiveNumericData">
      <input message="s0:ReceiveNumericDataIn" />
      <output message="s0:ReceiveNumericDataOut" />
   </operation>
</portType>
```

To represent the numeric data stream in XML, data from the numeric data stream is packaged (PhysioPacket) based on a given time interval (eg one minute). Single readings produced every 1024 milliseconds (ms) are contained within one PhysioData encoding and record the time of the reading (RecordTime), the type of reading (MessageID) and the value of the reading (NumValue). Hence each PhysioPacket will contain one or more PhysioData. As some devices produce multiple readings per second, as in the case of waveform and fast waveform data which output 4 and 16 readings respectively in every 1024 milliseconds (ms) reading, each PhysioData will contain one or more NumValues. An example of the XML encoding of the device data stream required by the physiological log web service is detailed in Table 1. It represents two seconds of data from the Phillips Component Monitoring System (CMS) monitor, tracking two numeric readings (**RESP, HR**) and one waveform reading (**RESP -CW**).

5 Prototype

The *physiological log web service* and Data Management components of the Solution Manager Service have been demonstrated via a pilot development using physiological data supplied by a Dragar Ventilator and the Phillips Component Monitoring System (CMS) monitor. Both of these devices are common within NICUs and regional hospitals.

A Data Collection Unit (DCU) has been located at Nepean Hospital's NICU. Data extracted via the serial ports from both the Dragar Ventilator and the Phillips CMS monitor is forwarded to the DCU. Utilities to convert the data from both of these devices to the XML encoding required by the physiological log web service have been created. The DCU utilises the *physiological log web service* to transmit the data to the Solution Manager Service. The Data Management component has been implemented in SQL Server. When the data is received by the Solution Manager Service it is loaded into the real-time data store and data warehouse through use of the SQL Server bulk load facility.

This pilot has undergone initial clinical evaluation and assessment. Initial evaluation has enabled the capture of several days worth of data and its subsequent storage

within SQL Server. The pilot will undergo further evaluation and assessment in 2005. The results of that evaluation will be presented in future research publications.

```
<PhysioPacket>
  <PhysioData>
     <PatientID>11111</PatientID>
     <DeviceID>0099</DeviceID>
     <CollectTime>11:13:42</CollectTime>
     <MessageID>RESP</MessageID>
     <NumValue>36</NumValue>
  </PhysioData>
  <PhysioData>
     <PatientID>11111</PatientID>
     <DeviceID>0099</DeviceID>
     <CollectTime>11:13:42</CollectTime>
     <MessageID>HR</MessageID>
     <NumValue>145</NumValue>
  </PhysioData>
  <PhysioData>
     <PatientID>11111</PatientID>
     <DeviceID>0099</DeviceID>
     <CollectTime>11:13:42</CollectTime>
     <MessageID>RESP -CW</MessageID>
     <NumValue>808</NumValue>
     <NumValue>779</NumValue>
     <NumValue>757</NumValue>
     <NumValue>742</NumValue>
  </PhysioData>
  <PhysioData>
     <PatientID>11111</PatientID>
     <DeviceID>0099</DeviceID>
     <CollectTime>11:13:43</CollectTime>
     <MessageID>RESP</MessageID>
     <NumValue>40</NumValue>
  </PhysioData>
  <PhysioData>
     <PatientID>11111</PatientID>
     <DeviceID>0099</DeviceID>
     <CollectTime>11:13:43</CollectTime>
     <MessageID>HR</MessageID>
     <NumValue>146</NumValue>
  </PhysioData>
  <PhysioData>
     <PatientID>11111</PatientID>
     <DeviceID>0099</DeviceID>
     <CollectTime>11:13:43</CollectTime>
     <MessageID>RESP -CW</MessageID>
     <NumValue>732</NumValue>
     <NumValue>726</NumValue>
     <NumValue>724</NumValue>
     <NumValue>726</NumValue>
  </PhysioData>
</ PhysioPacket >
```

Table 1 Sample Physiological Stream Data Encoded in XML

6 Acknowledgements

The work presented in this paper is part of a larger, long term research effort known as “e-baby” [2], that is researching new approaches to the application of computing and information technology to support local and remote neonatal intensive care. The researchers wish to thank the staff of the Neonatal Intensive Care Unit, Nepean Hospital, Wentworth Area Health Services, NSW, for their continued support and collaboration in this research.

7 Conclusion and future work

This paper has presented a web service based framework that enables the transmission of physiological data via web services for local and remote neonatal intensive care. This paper further describes the application of that architecture to a specific pilot within the NICU at Nepean Hospital, Penrith Australia.

This research offers an innovative approach that will assist in the provision of Neonatal services to rural and regional communities. The delivery of real-time physiological data to city based Neonatologists is a significant improvement over the existing approach. A paradigm shift from 'physical consultation' to 'virtual consultation' may reduce the need to conduct high risk moves of neonates from rural and regional hospitals.

Virtual intensive care unit support is required across all ICUs. This research can be adapted for virtual paediatric and adult intensive care units.

While this research has demonstrated the ability for web services to be used for the transmission of physiological data, there are several implementation issues that will need to be addressed prior to implementation such as security, privacy and stress/load simulation and testing to assess the impact of multiple web service threads from multiple DCUs.

The size of packet sent by the DCU, which is impacted by the number of medical devices attached, the number of readings per second and the time interval covered, impacts how close to real time the physiological transmission will be.

While web services provide a platform and language independent environment to transport numeric data streams, the data streams must be encoded in XML, increasing the size of the numeric data stream considerably and thereby impacting its transmission time and the performance of the web service. Research has commenced that assesses the performance of the compression of XML documents containing physiological data streams to investigate the conditions under which the performance of a Web service can be improved through the compression of XML numeric data streams. The compressors are applied to several XML physiological data streams output by a neonatal monitoring device. A

key benefit of that research is its specific focus on numeric data streams within web services [17].

Further research has begun to enable the *physiological log web service* to transmit this data directly to neonatologists via the CPS function and use of PDAs, in addition to forwarding the data to the Solution Manager Service.

In addition, research under the title of Bush Babies Broadband [18] further extends this research by developing On-Demand Virtual Neonatal Intensive Care Unit support for regional Australia. In that research, in addition to the transmission of real-time data collected from medical monitors and ventilators attached to the baby, audiovisual streams and static physiological data such as x-ray images are transmitted to the consulting neonatologist to gain a better picture of the patient's condition than is currently available.

The Solution Manager Service as detailed in [12-15] contains an Event Stream Processor that continuously integrates and transforms events to support the monitoring of business processing service levels and business process performance management. Research has commenced to use these same principles to develop an Event Stream Processor to facilitate complex medical alerts.

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