Mobile telemedicine: robots, fish and other stories…

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Abstract: In Queensland, access to specialist and sub-specialist paediatric care outside of major metropolitan centres is very limited. We describe our approach to the design and development of two mobile telemedicine systems designed for delivering paediatric and neonatal care at a distance. We comment on our experience with the systems and issues relating to their successful implementation.

1 Introduction

The University of Queensland Centre for Online Health (COH) specialises in telemedicine research, teaching and service provision. The centre has considerable experience in delivering real-time telemedicine using video-conferencing, particularly in the area of paediatrics [Sm01,Sm04,Sm05a,Sm05b,Sm07]. For many types of consultation fixed systems work well. However there are circumstances where they work less favourably or simply do not work at all. We have developed two mobile telemedicine systems that have been engineered to meet the needs of the clinical environment in which they will be used. Both applications require a high degree of mobility and considerable customization to meet the specific clinical requirements of each setting. The two projects are known as "*Roy the Robot*" – a mobile telemedicine consultation system for the paediatric unit and "*Project NEMO*" (Neonatal Examination and Management Online) – a mobile telemedicine device for the special care nursery with a customised web-based clinician interface. Both systems have been designed to provide the ability for real-time consultations between regional hospitals and specialists in larger tertiary hospitals. Based on our experiences to date, we describe the design and evolution of these mobile systems and the related management systems that they require.

2 Background

The state of Queensland occupies around 1.7 million km^2 and has a growing population of greater than 4 million inhabitants. While the population is dispersed throughout the state specialist health services are concentrated mainly in Brisbane in the South East and to a lesser extent in Townsville 1,400 km to the North. Many hospitals in regional areas of Queensland do not have specialist clinicians on-staff. Families are often faced with traveling long distances, at great expense and inconvenience, to access specialist care. In such circumstances telemedicine consultations offer a way of projecting specialist expertise over distance. This may, in some cases, avoid the need for the patient or the specialist to travel with the potential to reduce costs and allow for earlier diagnosis and intervention. The COH has established a successful Telepaediatric Service using fixed videoconferencing systems. Since 2001, more than 4000 consultations have been conducted for patients living in rural areas of Queensland. In 2004, we investigated the feasibility of mobile telemedicine systems for use in paediatric and neonatal clinical environments.

3 Roy the Robot

In 2004, the main hospital in Gladstone, a regional town in central Queensland, was operating without a paediatrician. The challenge was to provide a mechanism for teleconsultation with specialists at the Royal Children's Hospital (RCH) in the state capital of Brisbane, 500km to the South. In addition, the aim was to integrate teleconsultation into the normal working practices of the remote paediatric unit. To do this we designed a system that could link remote patients, parents and clinicians at the bed-side with specialists at the territory hospital in a remote ward-round.

3.1 Requirements

There were five key design requirements for the telemedicine system for the remote hospital. The system should be:

a. highly mobile so that it may be easily moved to a patient's bed-side within the paediatric unit on-demand;
b. networked wirelessly;
c. child-friendly in appearance;
d. easy to use by non-technical hospital staff with minimal training;
e. capable of connecting to existing video conferencing (VC) systems.

3.2 Design

Initial sketches for the mobile telemedicine system were produced (Fig. 3.1). A "robot" theme was chosen to meet the child friendliness requirement and to conceal the video conferencing, power and communications equipment (Fig. 3.2). To provide the VC capability, the robot was equipped with a Sony PCS-1P IP-based VC system and a 51cm LCD TV. To meet the requirement for mobility, the robot was provided with wireless network connectivity via a Cisco Aironet IEEE802.11b wireless workgroup bridge. This connectivity was used to provide for both video-conferencing and for remote management. Power to all devices was provided by 1kVA Uninterruptible Power Supply (UPS) with sufficient battery capacity to run the unit for a number of hours.

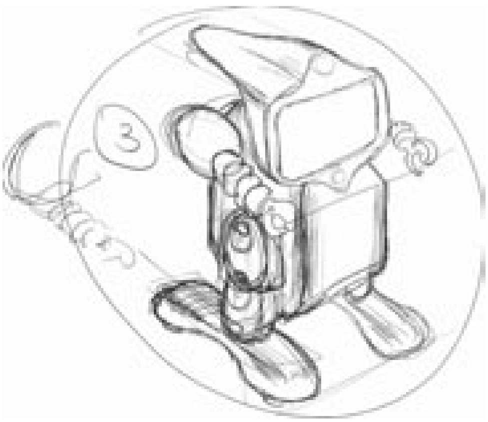

Fig. 3.1 – Prototype Design Sketch

Fig. 3.2 - Prototype

A dedicated wireless network consisting of three Cisco wireless access points was installed in the paediatric unit. This provided full wireless coverage and mobile roaming to the bedside in the wards and to doctor's rooms within the unit.

The wireless network was privately networked to a Cisco 1600 series Integrated Services Digital Network (ISDN) router which was in-turn connected to the public ISDN network via two Basic Rate Interfaces (BRI). At the RCH a studio-based Sony video conferencing system was connected via Ethernet to a Cisco 1600 series ISDN router which was also connected to the public ISDN network. The networking equipment was configured to automatically establish/close the ISDN sessions between the two routers on demand. Traffic was aggregated over the ISDN links using Point-to-Point Protocol (PPP) with a resulting effective usable bandwidth of 190kbit/s. Video-conferencing calls could be initiated by either the remote or main hospital and the underlying communications mechanisms were transparent both to the video conferencing systems and to the end users. Fig. 3.3 outlines the fixed infrastructure and equipment contained within the mobile unit.

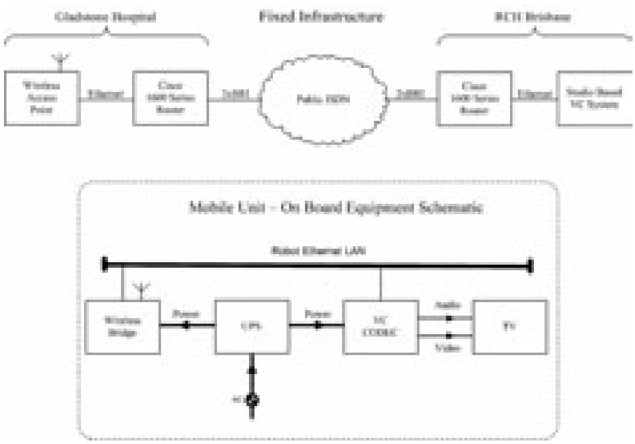

Fig. 3.3 – Prototype telepaediatric robot and related fixed infrastructure

3.3 Use

To encourage uptake of the system, ease of use was a key requirement. Use of the robot did not require the clinicians to possess any technical knowledge or skills and staff could be familiarised with the system via a brief training session. Immediately prior to sessions the robot was taken off charge and positioned where needed. To begin a consultation, the remote site was simply selected from a menu using a handset. Once the consultation was complete the robot was placed back on charge. Remote control (pan/tilt/zoom) of the camera was provided remotely by an experienced telepaediatric coordinator who was present during consultations at the RCH.

3.4 Experience

Telemedicine facilitated ward rounds, coordinated by the COH, were carried out between Gladstone Hospital and the RCH. During these sessions paediatric specialists at the RCH viewed the patient and discussed history, diagnosis and management with the family, remote nursing and medical staff. In the first six months of use 43 ward rounds were carried out with 86 consultations involving 64 patients. Clinicians and families who used the service were surveyed and satisfaction with the use of the system for consultation was very high. A range of cases was dealt with including respiratory conditions, gastroenteritis, urinary tract infections, allergic reactions and tonsillitis. The system proved to be an effective tool to allow teleconsultation in a hospital lacking a paediatric specialist [Sm05b].

We conducted a review of all patients dealt with during the first four months to examine whether there were any changes to clinical management as a result of the videoconference consultation. In about 30% of cases, there were minor changes in the preliminary diagnosis of patients. Most of these changes related to decisions related to viral and bacterial infections. In approximately two-thirds of all cases there were partial changes to clinical management as a result of the Roy the Robot link. The main changes were decisions related to antibiotic therapy and diagnostic tests. Even in cases where there were no changes to diagnosis or clinical management, the local doctors described the reassurance offered by the RCH specialists as invaluable [Sm05b].

Following the success of *Roy the Robot*, funding provided by a mining company via the RCH Foundation has allowed the development of further robots for placement in regional hospitals. In 2006, two second-generation telepaediatric robots were developed. "*Eliza Robot*" was installed in Mount Isa Hospital, 2000km from the RCH and "*Emma Robot*" was installed in Emerald Hospital 918km from the RCH. In 2007 two further robots will be developed and deployed in hospitals in North and Central Queensland. The two new robots together with *Roy the Robot* in Gladstone have been integrated into routine practice within the wider telepaediatric service operated by the COH.

3.5 From prototype to second-generation

While no technical issues were experienced with the operation of the system during the trial period the expansion of the project allowed the opportunity to revisit and improve the design based on experience.

Revised requirements:

a. Ability to power the mobile unit up/down remotely on-demand (for consultations and test calls);
b. Additional WAN capacity for VC calls;
c. A mechanism to reboot the on-board wireless bridge if connectivity to the network is lost;
d. An external video input for the connection of ultrasound systems;
e. Reduced size/weight for the mobile unit making it easier to move around;
f. A web-based remote service management system based at the RCH.

3.6 Revised Design

The prototype telepaediatric robot was placed 500km to the North of the RCH and limited technical support was available locally. The second generation robots would be placed even more remotely (900km and 2,000km from the RCH) and would also be without local technical support. In addition, operation of the robot required staff to power the robot off and on when required. Based on experience with the prototype we examined ways to add remote management capabilities to the robot. In particular, we wished to be able to turn the VC systems in the robot on and off remotely for testing and clinical work at will and without disturbing ward staff from their duties. We also wanted to automate test-calls to the unit. In order to achieve these aims we separated out two power segments within the robot – one segment ("switched power segment 1" in Fig. 3.4) was "always-on" and powered the wireless bridge. The other segment ("switched power segment 2") was switched remotely from a management console in the COH using a network connected remote power management device (Dataprobe Inc, New Jersey).

The prototype robot operated on a usable bandwidth of 190kbit/s for VC. While the system operated adequately, routine telemedicine work in the COH is usually carried out at 256kbit/s or 384kbit/s and it was desirable to increase the bandwidth available for consultations carried out using the robot systems. An additional third ISDN link was added for new sites. To accommodate the extra link the standard router was changed from a Cisco 1600 Series to a Cisco 2800 Series. Using three ISDN links and aggregating them via PPP the resulting usable bandwidth for clinical use was 288kbit/s.

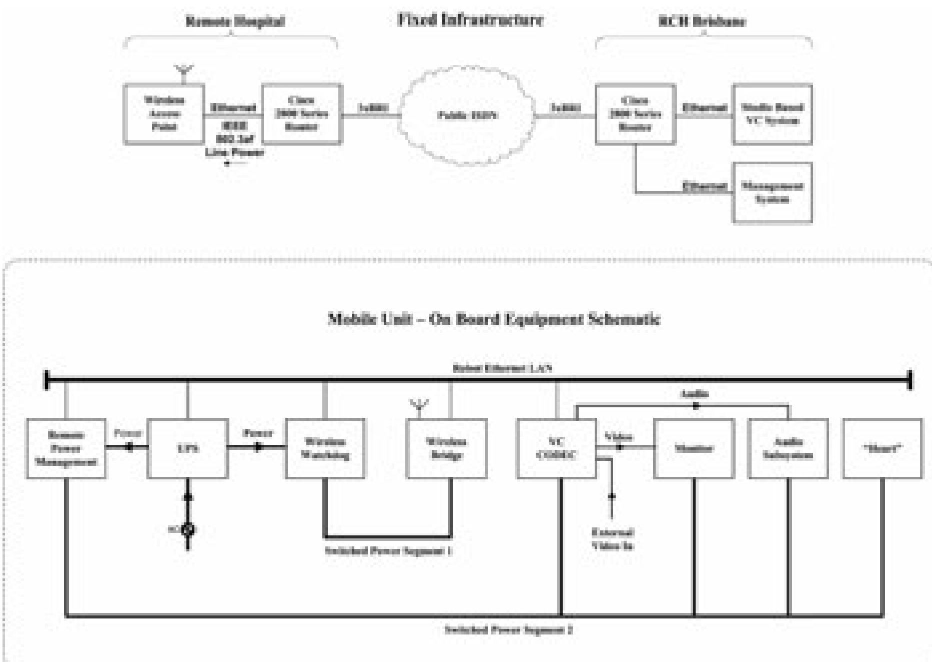

Fig. 3.4 – Second generation telepaediatric robot and related fixed infrastructure

Further experimentation was carried out to optimise the use of the bandwidth for clinical consultations and subsequently a G.728 (16kbit/s) audio codec was adopted. The video codec was set to auto-negotiate on connection with a frame rate fixed at 15fps. Additional improvements to the design were made for the second generation systems. Small form-factor industrial Ethernet equipment (Moxa Technologies Inc, California) were adopted for wireless within the mobile units and in the wards. IEEE 802.3af line power was used to provide flexibility of placement of wireless access points without the need to provide additional mains power outlets. An s-video input was provided for the attachment of external equipment such as ultrasound imaging equipment. The mobile unit shell was redesigned to produce a slimmer and less weighty unit making it easier to move around by ward staff (Fig. 3.5).

Fig. 3.5 - Second generation robot “Eliza” and staff in Mount Isa Hospital during a consultation with specialist staff in the RCH studio 2,000km away

Work has commenced on developing a service management station to allow the fleet of robots to be managed from the RCH. The management station provides a web interface with both an “engineering” view and a “service coordinators” view. Building on the success of the Roy-the-Robot project other opportunities for wireless and mobile applications became apparent. One such area was specialist care for newborn infants.

4 Project NEMO

In Queensland, specialist care for newborns is concentrated in two cities 1,400km apart. Where sick infants are born away from those centres it is necessary to retrieve them by helicopter, fixed wing aircraft or road ambulance to one of the major tertiary hospitals. This process is costly, has risks and is stressful for families.

Project NEMO - *Neonatal Examination and Management Online* – is an application designed to allow teleconsultation for the care of newborns. Specifically, the system is designed to link specialists in tertiary perinatal care centres with paediatricians in Level 2 special care nurseries.

The system comprises two components:

a. a mobile wireless system which is placed in a remote special care nursery;
b. a custom web-based clinician interface which is used by the specialist in the tertiary hospital to access and control the remote telemedicine device.

4.1 Requirements

Neonatal telemedicine presents some unique challenges: first, the patient is usually very small and second the nursery setting does not lend itself to a traditional video conferencing approach – space is often at a premium and capturing still and video images of an infant through the walls of an incubator is not straightforward. In addition, video images of the infant must be of sufficient quality to allow assessment of subtle visual cues such as facial and limb dysmorphic features and signs of respiratory distress. The assessor must be able to use the system to discern small details including endotracheal tube length markers and chest wall movements. The system must be able to capture X-ray images in some format so the assessor is able to accurately differentiate clinically important features such as endotracheal tube placement, pulmonary air leaks, heart size and abdominal gas patterns.

Specific design requirements for the neonatal telemedicine unit included:

a. a mobile wireless system which is placed in a remote special care nursery;
b. be networked wirelessly;
c. be easy to operate for staff in the remote special care nursery;
d. have a simple to use specialist clinician interface;
e. it must be able to capture still and moving images through the walls of an incubator of sufficient quality to be clinically useful;
f. it must be highly mobile and produce the least possible footprint in the remote nursery.

4.2 Design

A prototype device using a Sony SNCRZ30P network camera was constructed. The system was subjected to a number of experiments to determine technical feasibility. The experiments were initially carried out using a mannequin patient and subsequently with a live infant. Both experiments were carried out using an "Airshields" incubator and images were successfully obtained through the dual-layer plastic walls of the cot (Fig. 4.1) [Ar05].

Through a process of iterative refinement, a mobile device was produced for evaluation in a teleconsultation clinical trial (Fig. 7).

Fig. 4.1 – Prototype Mobile Device

Fig. 4.2 – Revised Mobile Device

To complement the NEMO hardware a bespoke clinician interface was developed (Fig. 4.3). The key design requirements for the software were to deliver a high degree of remote camera control while retaining a low-complexity interface suitable for a non-technical user.

Fig. 4.3 – Clinician Interface

The clinician interface runs on a dedicated PC with two monitors. The software comprises a suite of trusted java applets which run within a browser operating in 'kiosk mode'. Viewing of real-time images and camera control is carried out on the main (left) screen while captured still images are displayed on the right hand screen.

The interface provides the following features:

a. display of real-time video;
b. pan/tilt/zoom camera control;
c. selection of regions of interest within real-time images;
d. capture and display of still images (stored in PNG format to allow further manipulation as necessary without loss);
e. a library function to organise captured still images;
f. adjustment of frame rate;
g. adjustment of compression (and hence image quality);
h. monochrome/colour toggle;
i. Image equalization control to allow compensation for variable remote nursery lighting conditions and to adjust brightness/contrast when viewing X-ray images;
j. grey-scale test card to allow calibration of the still display monitor;
k. session-logging, including time/date stamping of all captured images.

The system was designed to allow the specialist to conduct an assessment of an infant at a distance. In doing so, the specialist is able to view the patient in real-time, observe the output of patient monitoring equipment and view ventilator settings as if present in person. In addition, X-ray images may be captured from a traditional light-box or from an LCD display.

Feasibility testing has been completed and a trial of clinical efficacy is currently being carried out within an intensive care nursery setting. Assuming successful completion of this phase then the system will be installed and evaluated as part of a clinical trial involving a number of special care nurseries.

5 Discussion

Two key factors have contributed to the success of both of these mobile telemedicine systems. In our experience the first was to understand the specific clinical requirements of each given setting. Based on analysis of these clinical requirements, technical design of the system could proceed. The unique clinical factors required in each setting have resulted in two very different looking systems. The robot systems needed to be mobile, wireless, able to interface with off-the-shelf VC systems and be child friendly. The resulting system therefore was based around a VC system interfacing with wireless technology and ISDN connectivity in the shape of an attractive robot. The NEMO system on the other hand, whilst also requiring mobile and wireless connectivity, has been developed with the busy and technically-full neonatal nursery environment in mind with a customised interface meeting the needs of clinicians. The resulting system has a minimal footprint and can be adjusted to be positioned with the camera view through the top of an incubator. The customised web interface provides a simple and easy to use system for remote consultation.

The second important factor has been to take a multidisciplinary approach throughout the project lifecycle from analysis through to implementation and review.

This process incorporated clinical, engineering and administrative disciplines. For clinical staff both systems needed to be easy to use and suit their needs. For coordinating staff and technical staff, both systems needed to be managed remotely as much as possible. As a result the robot systems are fully managed remotely from the RCH. Coordinating staff at the RCH are able to power up the robot, make the VC call and control the camera as needed during the consultation. At the end of the session the coordinator closes the VC call and powers the system down. Technical staff access and maintain all components of the system remotely for example changing VC codec settings, router settings, checking wireless connectivity, upgrading firmware and monitoring robot battery status. For the NEMO system, clinical input to the design of both hardware and software was very important since unlike the robot systems, with coordinated sessions, the NEMO system is used in an ad hoc manner and operation of the system relies on the clinical staff.

In summary, for both the robots and NEMO, the aim was to produce systems that were as transparent as possible allowing clinicians to focus on their clinical work without the need to learn new technical skills. From a technical perspective, the aim was to develop systems with the least complexity possible but with a high degree of remote management and some fault tolerance. From an administrative perspective, the aim was that sessions using the systems be as easy to coordinate as they would be with any fixed VC system.

6 Conclusion

The experiences outlined in this paper describe practical applications of telemedicine systems in paediatric care with particular attention to mobility. The have provided a useful link between specialists and patients in remote areas. The mobile telemedicine applications demonstrate a novel way of bringing the specialists to the patient in a convenient and clinically effective manner.

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