Design of an Advanced Telemedicine System for Emergency Care

Jane Li
CSIRO
Jane.Li@csiro.au

Laurie Wilson
CSIRO
Laurie.Wilson@csiro.au

Stuart Stapleton
SWAHS
StapleS@wahs.nsw.gov.au

Patrick Cregan
SWAHS
Patrick_Cregan@onaustralia.com.au

ABSTRACT
In this paper we describe the design process of the Virtual Critical Care Unit (ViCCU\textsuperscript{®}) – an advanced telemedicine system developed by CSIRO in conjunction with Sydney West Area Health Service. The system allows an emergency care specialist in a major referral hospital to remotely lead a team in a small rural hospital during the treatment of critically ill patients. It enables transmission of high quality audio/video information and has a seamless interface to the complex clinical working environment. The technical design team took an iterative participatory design approach towards the system design. The combination of expert user evaluations and scenario-based user testing methods ensured users’ needs were designed into the system and verified. Our experience indicates that the success of this telemedicine system relied largely on a participatory design approach, appropriate evaluation methodologies and working closely with users to build a system which was integrated into the emergency clinical work practice.

Author Keywords
Emergency care, telemedicine, participatory design, usability, scenario-based testing, evaluation.

INTRODUCTION
In Australia, the level of specialist expertise in emergency departments is usually less in rural hospitals where the specialist advice is obtained by telephone or through patient transfer to a major referral hospital. Geographic obstacles impede transporting a patient to tertiary hospitals in a timely manner, imposing extra costs. This situation is typified in Sydney West Area Health Service (SWAHS), whose hospitals cover north-western Sydney and nearby rural areas. One of the small hospitals in this group is the Blue Mountains District Anzac Memorial Hospital (Katoomba Hospital) which supplies emergency services to several Blue Mountains towns, but frequently requires specialist advice from its referral hospital, Nepean Hospital.

Telemedicine uses information and communication technologies to transfer medical information for the delivery of clinical and educational services (Norris, 2002). It has been used to assist in trauma patient care in the emergency department (Berg et al., 2003; Brebner et al., 2002). However, emergency medicine is still regarded as an emerging telemedicine application due to the combination of recent introduction of application and limited research (Krupinski et al., 2002).

The Centre for Networking Technologies for the Information Economy (CeNTIE) in the CSIRO ICT Centre has demonstrated its “telepresence” technology in several applications on gigabit networks. A medical Focus Group run by CeNTIE identified the need to trial the provision of emergency services between Katoomba Hospital and Nepean Hospital using a telemedicine solution, leading to the creation of an advanced telemedicine system - Virtual Critical Care Unit (ViCCU\textsuperscript{®}), developed through collaboration between CeNTIE and SWAHS. ViCCU\textsuperscript{®} has since completed a clinical trial in the emergency departments of the two hospitals.

In this paper we discuss first related work in the telemedicine design field, then the ViCCU\textsuperscript{®} design and development process, the methodologies that were employed, and critical system design success factors.

RELATED WORK
The success of any telemedicine system depends on not only technology but also a careful consideration of the human-computer interaction entailed in the new technology (Bashshur & Kathan, 1999), with a focus not only on media quality but also usability and human elements from a socio-technical perspective (LeRouge, Garfield & Hevner, 2002).

Studies of design and evaluation methods in telemedicine system usability include Lathan, S ebrechts, Newman and Doarn who reported that the designers should have considerable knowledge of the users’ tasks and receive continual feedback from medical experts throughout the development process (Lathan et al., 1999). Tang et al reported using expert heuristic evaluation to effectively and efficiently improve the usability of a digital emergency medial services system equipped on an ambulance (Tang, Johnson, Tingall & Zhang, 2006). A Cognitive task analysis approach was studied by Kushniruk and the methods they found most useful were the heuristic evaluation and the cognitive walkthrough (Kushniruk, & Patel, 2004). These researchers concluded that a combined expert heuristic evaluation/user testing methodology could provide benefit in the developmental of a telemedicine program. From the CSCW perspective, Kaplan and Fitzpatrick proposed a locales framework to design support for remote intensive-care telemedicine (Kaplan & Fitzpatrick, 1997). Also Weerakkody and Ray emphasised awareness as an important factors in dynamic group collaborative work environments in health care facilities (Weerakkody & Ray, 2003).
DEVELOPMENT PROCESS
ViCCU® was not a technically driven project. The technical team made field observation visits to get an in-depth understanding of the time-critical, team-driven working environment. The technical reference team consisted of CSIRO technical design team and the hospital IT manager. The clinical reference team comprised medical (various specialities) and nursing staff from both hospitals.

We took an iterative prototyping and user-participant design approach in the development life cycle (Figure 1). We also utilized the expert evaluation and scenario-based analysis methods towards the system design. The iterations during a one year period included design, evaluation and redesign processes of a concept system, initial prototype, updated prototype and final system. The iterative nature of these activities and the effect of user input throughout development ensured that the system was closely integrated into clinical pathways.

Users’ needs and solutions
It became clear that the complex activities of the emergency department could not be supported by a conventional image-based or simple video conferencing telemedicine system:

- Emergency medical care is delivered by highly trained individuals working in groups function as teams working simultaneously (Williams, Rose & Simon, 1999);
- Coordination and communication are critical throughout the emergency response engagement (Kristensen, Kyung & Palen, 2006); 80% of the time team members are engaged in communications events and some are multitasking. A large amount of information transactions (90%) between team members involves informal communication (Coiera & Tombs, 1998);
- Multi-source information is required in a timely manner by the specialist.

After analysing users’ environments and needs, the technical specification focussed on the following aspects:

- High quality audio interaction between two sites, since most communication was by voice, and particular important for communications from the Katoomba Hospital where multiple workers operated in a poor acoustic environment.
- Simultaneous multiple channels of high quality real-time video. For the specialist it required: room overview, patient overview, close-up view of patient which can be maintained during procedures, and continuous transmission of vital signs
- Ease-of-use, especially at the Katoomba end, since the emergency department clinicians were highly patient-focussed
- The use of a mobile trolley at the peripheral hospital to allow the system to be shared among beds
- Low latency for natural and immediate responses to questions and answers
- High reliability with minimum on-site technical support to permit unscheduled use.

The iterative design ultimately led to a final system that is displayed in Figures 2 and 3. A mobile trolley was designed to be located at the end of the patient bed at the emergency department at Katoomba Hospital. At Nepean Hospital a workstation enabled the specialist to receive multiple streams of real-time information from Katoomba Hospital and interact with the Katoomba team members.

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**Figure 1. System design process**

**Figure 2. The system configuration at Katoomba Hospital**

**Figure 3. The system configuration at Nepean Hospital**

*Quality of media information – design for collaboration and communication*

For a remote specialist to correctly assess and treat an emergency patient, multiple sources of information are required in a timely manner. It is a team-driven environment requiring low latency for natural and immediate responses to questions and answers. High media quality was one of the features of the ViCCU® system and it was achieved by using DV (Digital Video) over IP (Internet Protocol) technology. The two hospitals were connected by a Gigabit Ethernet-based network.
The ViCCU® system provided multiple channels of high quality real-time video to the Nepean specialist to enable quick understanding of the patient situation and resuscitation progress: room overview, patient overview, a portable camera close-up view, the patient vital signs, the paper document and medical film images (Figure 2). The emergency department is a noisy environment and the Katoomba team members’ conversations needed to be heard clearly by the Nepean specialist. Therefore a high quality microphone with good direction sensitivity and echo cancellation was chosen and carefully placed.

**Usability design – Design for the task and ease-of-use**
Ease-of-use and task-specific design were fundamental requirements in this clinical setting. The technology needed to allow doctors and nurses to focus on patient care rather than being distracted by attending the system. This was particularly important at Katoomba Hospital since the team were totally patient-focussed. Some user-driven design features in Katoomba Hospital:

- The system was always-on and the Katoomba staff did not need to adjust any of the equipment in order to use it.
- A mobile trolley was designed to house the majority of the equipment at Katoomba Hospital to minimize impact on the working environment.
- The trolley was placed at the end of the patient bed, where the local team leader usually stood. Facing the Katoomba team, a screen displayed a life-size view of the Nepean specialist’s face.

The Nepean specialist acted as virtual team leader of the Katoomba team, requiring highly natural interaction with them:

- The specialist was able to see multiple channel of real-time information transmitted from Katoomba Hospital on 3 monitors. One PC monitor provided patient vital signs information and selection of views to be displayed on two TV monitors (Figure 3).
- The vital signs were displayed in the same format as shown at Katoomba Hospital.
- The Nepean specialist was also able to remotely control the focus, aperture and zoom of the document camera for film-based medical images.

Due to the unscheduled nature of consultations in the emergency department there was no onsite technical support. A simple reset procedure was designed to facilitate fixing technical problems without CSIRO technical support.

**Evaluation during the design process**
Prototype evaluations were performed at different stages of the one-year design and development process.

**Expert inspection**
The concept system was set up in the CeNTIE laboratory and clinical experts had an initial test, leading to a detailed specification design; Hospital-based tests facilitated the development of a clinically-acceptable applications system, so a test using the first initial system model was performed at Nepean Hospital for two weeks and feedback from the key clinicians was taken into account in the system re-design.

Different layouts of the equipment and sizes/positions of the screens were reviewed during these processes. A slow update rate high-resolution document camera was initially used for medical images, but during user evaluation (using a panel of four senior clinicians from SWAHS) it was rejected due to the poor interactivity.

**User testing with scenarios**
Using the second initial system model we performed a two-week trial at the two hospitals using critical care scenarios and simulators. All of the emergency specialists at Nepean hospital, three obstetricians, about twenty nurses, three midwives participated in the test. Feedback was obtained by:

- Direct observations in these sessions, with sessions video taped
- Interviews with doctors and nurses involved
- Questionnaires filled out by doctors and nurses involved
- Discussions with the key clinicians

The users’ feedback identified improvements required to support the roles and interactions. It also contributed to some changes of requirements and solutions, such as the need for a life-sized view of the specialist (Grayson & Coventry, 1998), as it contributed to a sense of “presence” in the interaction without conveying diagnostic information.

**DISCUSSION**
Unlike most previous telemedicine systems, ViCCU® was explicitly purpose-designed, allowing an emergency specialist in a major referral hospital to “virtually” join a clinical team in a peripheral hospital. A high quality system and a proper development approach are essential to build a telemedicine system in this context.

**Consideration of usability and ergonomics**
In health care, there were examples of human factors and usability principles affecting patient safety and quality of care, for examples in the emergency department settings (Wears & Perry, 2002). Human factors engineering (technology, functionality, workflow, structure) is gradually becoming regarded as one of the criteria to evaluate the effects of telemedicine application (Gagnon & Scott, 2005). Usability and ergonomic design principles have been applied to our system design. For example, allowing users to concentrate on the work rather than figuring out the operation; system functionality provides information in a format which is easy to use and trust.

**Iterative participatory design**
Participatory design has been adopted in various telemedicine projects (Brisben, Lockerd & Lathan, 2004; Atack, Luke & Sanderson, 2004). We practised three participatory design principles in the ViCCU® design.
process: early focus on users and tasks, empirical measurement and iterative design.

**Scenario-based user testing**
Scenario-based testing plays an important role in design of computer-supported collaborative work (CSCW) (Weerakkody & Ray, 2003). This is a group collaborative environment and we need to analyse the requirements and solutions for specific roles and interactions (Kaplan & Fitzpatrick, 1997). We found that clinical users were unable to make a judgement about the system until they had a hands-on experience.

**Combination of expert inspection and user testing methods**
Expert users’ review and evaluation has been used as an effective way to uncover interface design problems, and it has been used by researchers to assess and improve system usability in telemedicine (Kushniruk & Patel, 2004). In the ViCCU® design process we incorporated expert evaluation with user testing methods and have demonstrated resultant benefits in the final design.

**CONCLUSION**
The Virtual Critical Care Unit (ViCCU®) is an advanced telemedicine system that has been designed and used in emergency medicine. We have demonstrated the importance of an appropriate design methodology in this application. Iterative participatory design ensured users remained central to the design. Considering usability and ergonomics contributed to ease-of-use and reliability. The combination of expert evaluations and scenario-based user testing ensured users’ needs in a complex clinical setting were designed into the system and verified. The design of a telemedicine system should not only take advantage of technology advances but also adopt appropriate design and evaluation methodologies and work closely with users to make sure the system is built around work practices.

**ACKNOWLEDGMENTS**
We would like to thank contributors to the design of this project: Tony Adriaansen, Keith Bengston, Steve Broadhurst, Rosemary Hollowell, Mike Hogan, Neil Killeen, Alex Krumm-Heller, Rong-Yu Qiao, Alex Murdoch, and Bob Shields from CSIRO, Cate Salter and Graham Taylor from Sydney West Area Health Service.

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