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Open Source Software: A Key Component of E-Health in Developing Nations

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ABSTRACT

The global burden of disease falls most heavily on people in developing countries. Few resources for healthcare, geographical and infrastructure issues, lack of trained staff, language and cultural diversity and political instability all affect the ability of health providers to support effective and efficient healthcare. Health information systems are a key aspect of improving healthcare, but existing systems are often expensive and unsuitable. Open source software appears to be a promising avenue for quickly and cheaply introducing health information systems that are appropriate for developing nations. This article describes some aspects of open source e-health software that are particularly relevant to developing nations, issues and problems that may arise and suggests some future areas for research and action. Suggestions for critical success factors are included. Much of the discussion will be related to a case study of a training and e-health project, currently running in the Himalayan kingdom of Bhutan.

Keywords: economic development; e-health; obstetrics; open source movement; perinatal medicine

ORGANIZATION OF THIS ARTICLE

This article is organized around a number of sections. The introduction outlines the rationale of the article and deals with some aspects of open source software (OSS) that make it attractive for software development in the health domain for low-income countries. The methodology section then introduces the framework of assessment that is being used. The majority of this article describes a case study of a project run by the authors in Bhutan

in the obstetric domain. Critical success factors for such a project are then analyzed and some conclusions are drawn. The discussion covers some of the issues that have arisen from this experience, and articulates some lessons learned.

INTRODUCTION

This project deals with the intersection of a number of domains, as shown in Figure 1.

E-Health

E-health has become a popular term for the transformation of healthcare that has occurred through the use of electronic communications, in a conscious imitation of "e-business." E-health encompasses more than the traditional electronic health record. It involves the use of information and communications technologies in the widest sense, including telemedicine, Web-based health and mobile devices for healthcare. A definition has been proposed, after comprehensive analysis, in Pagliari et al. (2005):

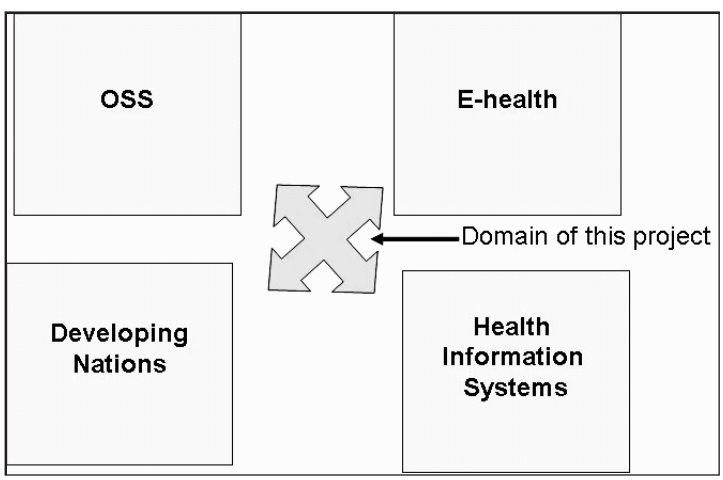
E-health is an emerging field of medical informatics, referring to the organization and delivery of health services and information using the Internet and related technologies. In a broader sense, the term characterizes not only a technical development, but also a new way of working, an attitude, and a commitment for networked, global thinking, to improve healthcare locally, regionally, and worldwide by using information and communication technology.

This definition is actually adapted from a previous one in an editorial which discussed the scope of "e-health" (Eysenbach, 2001). The globalized and networked aspects are particularly important in our case study—the emphasis is on communication and collaboration rather than distance

Health Information Systems

Health information systems (HIS) often have three main objectives: to improve patient care, improve management and form part of a quality improvement program. However, these objectives—as described by Littlejohns, Wyatt and Garvican (2003),

Figure 1. Research domains



are not always achieved. As part of a HIS implementation there are often major changes to workflow and practice, large expenditures on hardware including computing and communications, and system integration, as well as software development, training and implementation. Failures occur in HIS development often due to a lack of understanding of the complexity of the project (Littlejohns et al., 2003). Interestingly, OSS appears to answer some of these issues by providing more stable—if less feature-rich—software, and providing a generally larger pool of developers and users than for proprietary software.

Open Source Software

Open source software (OSS) has gained very wide acceptance particularly in the Web server community. Projects such as Apache (Mockus, Fielding, & Herbsleb, 2000) have involved large scale participation, and dominant market share. In the healthcare domain, Sourceforge.net lists 58 applications for download. Many of the applications are extremely specialized, but on the other hand, some like the Web Interface Repository server (WIRM), (Jakobovits, Rosse, & Brinkley, 2002) are effectively complete development environments. This article will argue that successful development and use of OSS in healthcare requires a number of critical "success" factors, and that these reflect both the nature of OSS projects in the wider world and particular aspects relevant to healthcare. OSS can be seen as part of a wider movement that has been characterized as innovation from the user community (Hippel, 2001). This emphasizes the point that OSS is not just "free" but also is able to be modified by the community that uses it.

DEVELOPING NATIONS AND THE CASE OF BHUTAN

Health information systems are important for developing nations as well as industrialized ones. A large review of the use of information technology in primary care in developing countries (Tomasi, 2004) identified five main areas of application—data processing in the healthcare system, decision support, electronic data transmission, electronic patient records and telemedicine. Many developing countries have low levels of trained clinical staff, and this can increase the load on secondary and tertiary providers. In order to audit their performance, and increase efficiency, electronic records and workflow systems can reduce the workload on the staff available.

Both of these aspects are particularly important for developing nations for a number of reasons:

- Developing nations have extremely limited health budgets, but the burden of disease on individual households can be very large. For example, up to 100% of household income being spent on end-stage care for AIDS patients in some nations in Africa (Russell, 2004).
- Developing nations often have a diverse mixture of groups within them, and it cannot be assumed that all citizens have a common language. Even when a common language exists, it may be spoken by a relatively small percentage of the world's population, and commercial development of software using that language may not be feasible.
- Infrastructure and resource constraints, in particular for network connectivity, may reduce the utility of high-perfor-

mance systems routinely used in the west. For example, PACS systems involving transmission of large images via network connections may not be practical, but memory stick-based approaches may be feasible (Parry, Sood, & Parry, 2006).

- Open source approaches allow the development of expertise in multiple sites away from large commercial organizations. Therefore, they can encourage the upskilling of software developers in smaller centers. This expertise can be applied to the localization of standard packages and the development of a solid base for software support. In this aspect, both the development and the use of open source software can be beneficial in the education sector. Developing nations often have large and increasing numbers of young, educated people available for project development. OSS tools are attractive for teaching information systems development because of cost, wide availability of documentation and localized versions being available. For example, Debian translators are available in over 80 l language versions including Dzonga—the national language of Bhutan.
- Commercial software suppliers may be reluctant to sell advanced software packages in developing nations because of the difficulty of arranging support and the perceived threat of piracy.
- Developing nations' health systems often have a complex collection of groups working within them including governments, commercial organizations, local and international charities and international official organizations. The requirement for reporting and data analysis may well be more complex than in industrialized nations.
- Infrastructure developed to support call-center development or tourism, including Internet and telecommunications technology, is easily adapted to allow links between nations. Because OSS tools are supported via the Web, this approach avoids the reliance on expensive and out-of-date paper manuals and development kits. OSS's licensing structure allows cross-national projects to be completed much more easily.
- Mobile devices have particular promise for e-health in developing nations (Iluyemi, Fitch, Parry, & Briggs, 2007). Mobile OSS development is a particularly active area of research (Raento, Oulasvirta, Petit, & Toivonen, 2005).

The case study in this article deals with the intersection of a number of research domains, (Figure 1), which means that the choice of methodology for analysis may be challenging. There have been some recent papers on the use of OSS in health information systems, focused mainly on developed country applications (Kantor, Wilson, & Midgley, 2003; McDonald et al., 2003). Interestingly, these papers point out that the use of OSS in healthcare is not new and that although perhaps small-scale, this work has been consistently ongoing. However, these papers do emphasize the potential gains to be had by the use of 0SS in healthcare both in terms of health providers and also developers.

Because of the widely varying state of communications infrastructure in developing countries, western models of development which emphasize in-hospital systems linked by fixed line, high-capacity networks may not be appropriate. In the context of less developed countries, there have been a number of telemedicine projects, often concerned with communication from centers of excellence in western nations (e.g., Swinfen, Swinfen, Youngberry, & Woot-

ton, 2005), or within developing countries (Deodhar, 2002), but a shared approach to development is vital (Wooton, 2001).

Methodology

In order to analyze a case study, some sort of framework of analysis should be adopted. The development project was actually quite complex with elements of telemedicine; knowledge management and information processing included in the overall design (see Figure 2).

A survey of telemedicine projects in India (Pal, Mbarika, Cobb-Payton, Datta, & McCoy, 2005) identified six critical success factors for telemedicine success; these were used as practical and simple measures that could be applied in this complex, yet small-scale project. The success factors identified were:

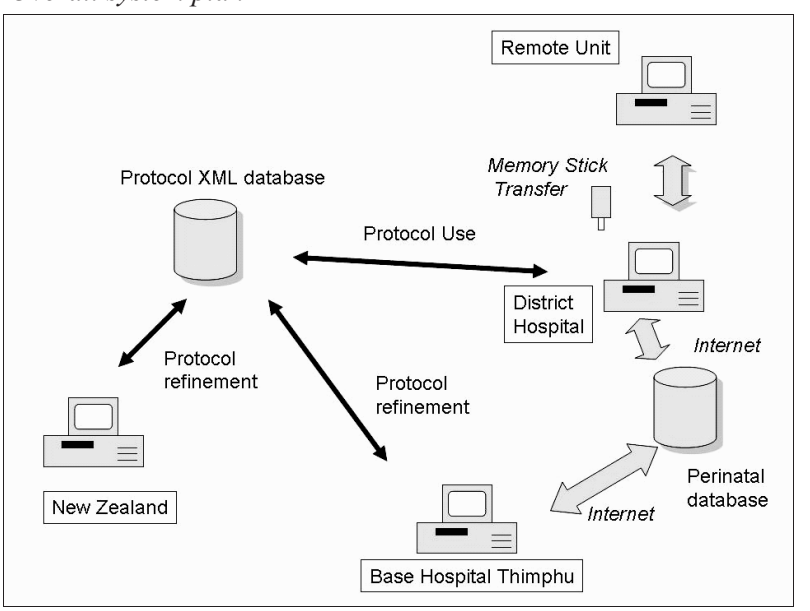
1. Set clear program objectives
2. Garner government support
3. Adapt user-friendly interfaces
4. Determine accessibility via telecommunications and Internet access
5. Implement standards and protocols
6. Measure cost-effectiveness and user satisfaction

The case study will deal with these areas, although the project is wider than a simple telemedicine project as it includes database development and integration with the audit system, along with Web-based protocols.

CASE REPORT: E-HEALTH SUPPORT FOR OBSTETRIC SERVICES IN BHUTAN

Bhutan is a small Buddhist kingdom located in the Himalayas, with a population of fewer than 700,000. Land transport is extremely slow because of the geography—for example it takes three days to travel across the country, a distance of around 300km.

Figure 2. Overall system plan



There is only one airport and no facility for helicopter transport. Seventy percent of the population live in rural areas with 30% more than a one-hour walk from the nearest road head. Bhutan has had major successes in increasing life expectancy and improving healthcare, but avoidable perinatal and maternal mortality and morbidity remains an issue. Current figures for Bhutan suggest an infant mortality rate of 67/1000 and a maternal mortality rate of 4.2/1000—compared with New Zealand's rates of 4/1000 and 0.07/1000 respectively (World Health Organization, 2006a).

Large numbers of preventable neonatal deaths continue to occur in the less developed countries. However, recent work has suggested (Darmstadt et al., 2005) that evidence- based interventions in antenatal and intrapartum care could reduce these rates by between 37% and 67%. These interventions are not complex and are relatively inexpensive. The overarching imperative is to ensure appropriate care for pregnant women that involves patient education and cooperation with antenatal and intrapartum services. Although there have been many studies on the use of e-health in obstetrics and perinatology and in less developed nations (Deodhar, 2002), there remains relatively little work on the evaluation of these systems. In particular, the outcome and integration of these systems into existing structures, and the changes that occur because of their introduction have not been studied, although the 1 to 45 cost benefit ratio quoted in this study is impressive.

The World Health Organization has been running a "Making Pregnancy Safer" Initiative (World Health Organization) in order to reduce the level of neonatal and maternal mortality. Previous work in Bhutan had developed a protocol book for emergency obstetric care (EmOC). Other countries using EMOC have recorded improvement in outcomes, for example, Bangladesh (Islam MT, 2006) and Peru (Kayango et al., 2006). One of the major lessons learned in these trials was that a record of outcomes via a perinatal database, and the wide dissemination and use of protocols are vital for success. In general it is important that all health workers caring for pregnant women use health information that is based on clear evidence from rigorous studies (Tita, Stringer, Goldenberg, & Rouse, 2007). Surprisingly perhaps, the identification of appropriate procedures for dealing with high-risk patients has been shown to be effective in reducing the demand for interventions (Islam MT, 2006).

The Bhutanese Health System

Healthcare is free in Bhutan, and is delivered via a tertiary structure. The primary healthcare unit is the "Basic Health Unit" (BHU), of which there are approximately 170 around the country. These units do not always have medically qualified staff, but they run outreach and clinic services and usually a number of beds are available. Birthing services, run by nurses, are sometimes available. District health units (around 30) will have at least one generalist medical officer; some of these units have the capacity to perform caesarean sections and ultrasound scanning. There are three referral hospitals in the country which have at least one obstetrician and theatre services. The Jigme Dorji Wanchuck National Referral hospital (JDWNRH) in the capital has four obstetricians and is the tertiary referral unit for the whole country. Because there is no general practitioner service, patients have the opportunity to refer themselves directly to hospital-based consultants even in cases where primary care would be more

appropriate. This and the paucity of qualified obstetricians, results in a large workload and the obstetricians are busy and often difficult to contact for advice. A current project is running to introduce the EmOC system to Bhutan, and the protocols are being integrated with these to provide seamless care.

Project Description

The aim of the project described in this article was to collaboratively develop a number of treatment and/or diagnostic protocols to allow the clinical staff to apply appropriate evidence-based care for the major problems that would be dealt with by a perinatal service. The role of the perinatal service is described in Mascarenhas, Eliot and MacKenzie (1992). Essentially, it provides care for mothers and babies from conception to birth, and aims to reduce the risks to mother and baby in this process, by appropriate intervention and monitoring. In addition to the staff applying the protocols in practice, the aim is to raise awareness of the issues that affect perinatal outcomes amongst others, for example, referring to clinicians. The development of a collegial editing and review process involving clinical staff in Bhutan and New Zealand was also seen as a vital part of the project. The project also included the development of a perinatal Web-based database to allow for more effective management of the service on a day-to-day basis and also allow for analysis of clinical performance.

OSS occurs in a number of places in the system. The perinatal database is written in PHP with a mySQL database engine. Web page development was done using open source tools, as was the XML protocol development. However, proprietary products were used for the operating systems and Web server software in Bhutan, along with the Linux/Apache setup for the Web server in New Zealand. In addition, standard proprietary products were used to develop the protocols.

Review of Success Factors

Clear Objectives

The objectives of the project were identified in initial discussions and codified in the agreement signed between the stakeholders. The objectives included the development of a perinatal medicine service, continuing support for this service and standardization of treatment based on the best possible evidence. An additional objective was sustainability of the service. OSS supported this by allowing low- or no-cost technical documentation and development tools to be made available to local staff.

Government Support

The Royal Government of Bhutan (RGOB) is the sole supplier of healthcare in the kingdom. The RGOB runs a series of five-year plans which identify objectives and priorities as well as sources of funding. Plans developed by overseas providers are examined and extensive negotiation takes place to ensure that the country receives appropriate and sustainable help that is consistent with the RGOB objectives. This process began in the case of this project, two years before the initiation, when representatives of the funders—The Magee Family—met with other stakeholders including government representatives, clinical staff from New Zealand and Bhutan associated with the project, and UNICEF. This resulted in a project agreement that was signed off in a formal ceremony. The project composed a number of other elements including funding for hardware and training of clinical workers in the perinatal medicine area. Continuing involvement of the stakeholders has been a great asset to

the project. The RGOB department of IT has been running a long-term project to support OSS and is getting closer to the development of a policy on its use (Bhutan Department of Information Technology, 2007).

Adapt User-Friendly Interfaces

The user interface adopted was a standard Web browser, whatever the source of the data—even locally stored protocols would display in a browser. The native protocols were stored as XML documents, which were then displayed in a human-readable format via a Web browser. XML was chosen for ease of updating—in that the editing process could alter content without a great deal of formatting issues and with the awareness that other display methods such as voice responses or mobile devices may be used in the future. As an open standard, XML is very well suited to this approach. The XML design is intended to be expandable and able to represent both diagnostic and therapeutic protocols.

A fragment of the XML representation is shown in Figure 3. The initial outline was based on the PubMED (may need to define this) schema, but simplified to remove excessive bibliographic elements. The XML documents identify the responses to particular diagnoses or symptoms which would be expected to be encountered commonly. The aim is to allow clinical staff, who may be at a remote site, to identify what emergency care is needed, whether the patient needs to be referred or transferred and the degree of urgency of that referral. Also, the protocol can identify what additional tests or procedures need to be performed.

Determine Accessibility

Although land transport is difficult, Bhutan is in the process of increasing the availability of Internet access. Apart from dial-up connections, there are microwave links and recently the international telecommunications union (ITU) e-post initiative (International Telecommunications Union, 2006) has recently been launched in Bhutan using very small aperture (VSAT) satellite ground stations for rural access to electronic communications, and this may be useful for rollout to remote areas. OSS tools are often very efficient in terms of file size, and machine footprint (use of processor time and memory) so they can

Figure 3. XML protocol fragment

```
<Root_Element>
  <Name>Cord prolapse</Name>
  <Definition>
The cord that normally presents itself is within intact membranes. When the membranes rupture, the cord
      prolapses. This is an emergency as cord compression and/or occlusion can cause fetal asphyxia.
 </Definition>
  <Keywords>
    <Keyword>Rupture of Membrane</Keyword>
    <Keyword>Prolapse</Keyword>
  </Keywords>
  <Diagnosis>
    <Diagnostic_step>Palpable cord on vaginal exam</Diagnostic_step>
    <Diagnostic_step>Observed cord protruding onto vulva</Diagnostic_step>
  </Diagnosis>
</Root_Element>
```

be used in a wider range of scenarios than might be possible for the latest proprietary operating systems or applications.

Implement Standards

The protocols themselves were developed in a standard format (Table 1), and as seen above, implemented using XML. In addition to this, an attempt was made to standardize the production of the protocols so that candidate protocols from other sources would go through an editorial process and be routinely revised. This process was formally followed using paper-based systems, but electronic approaches allow instantaneous updating of the live protocol without fear of version control issues and also allow a trail to be kept of previous versions that can be linked to any events linked historically to the implementation.

Measuring Cost-Effectiveness and User Satisfaction

This aspect is perhaps the most difficult part of the project. As part of the process, protocols will be regularly reviewed by stakeholders. In addition, a perinatal database is being implemented in order to record outcomes, and assess performance against that expected in the protocol, in particular, areas where the protocols are not being followed, and whether the protocols or behavior or both should be modified. It is hoped that improvements in the mortality and morbidity figures will also be noticeable, because of the currently relatively high rates of morbidity. Substitute measures, such as adherence to protocol may also be used. Finally, a rise in awareness of the general maternity service and increased access to it by women, only half of whom currently have an attended birth, would be expected to accompany improved outcomes among those who have contact with the perinatal service.

Lessons Learned

Integration of protocols from diverse sources was one of the major challenges facing

Table 1. Major elements of the protocol document

Element	Comment
Name	Name of protocol
Definition	
Keywords	Used for searching
Diagnosis	For diagnostic protocols
Diagnostic Step	
Procedure	For procedural protocols
Procedure Step	
Audience	Intended user, includes country and location
Evidence	A small selection of the supporting evidence
Author	Multiple authors possible
Last Update	
Review Date	

the team. Protocols were sourced from the National Women's Hospital Auckland, New Zealand, the World Health Organization and EmOC protocols in Bhutan.

Collaborative review of protocols was extremely important, as buy-in from clinical staff is vital. However, the process of maintaining a common electronic repository was technically difficult as each of the reviewers tended to work asynchronously using paper copies. The final approach used was to produce paper prototypes and distribute them, collect back annotated versions and then combine them in a final Word document. This was then converted to XML. Development of the perinatal database was restricted by the very small numbers of users available to test and comment on the system, and a wide user community, which may only be available online, may well increase the quality and speed of development..

DISCUSSION AND FUTURE WORK

There are some general issues that affect e-health initiatives, and the use of OSS in the developing world, in particular, connectivity, computing resources and skills.

Connectivity

Less developed nations have generally much lower availability of fixed telephone lines. In addition, geographic, economic and governmental issues often conspire to make conventional dial-up access less common than in western countries. However, wireless and satellite solutions such as VSATS including the international telecommunications union (ITU) e-post initiative (International Telecommunications Union, 2006) are overcoming these issues. It is important to recognize that not every nation's infrastructure is developing in the same way, and many nations may leapfrog to wireless solutions without the use of landline-based solutions. However, high bandwidth solutions may not be appropriate for developing countries. One of the most successful e-health projects has been the Swinfen Project, currently expanding in Iraq (Swinfen et al., 2005). This project uses e-mail in a store-and-forward model, between clinicians in various countries. The prospects of advanced tele-presence approaches being effective in routine care seem slight because of issues concerning quality of service, bandwidth and reliability of connection. Even though the "trauma pod" and other projects financed by the U.S. Department of Defense are beginning to show results (Romano, Lam, Moses, Gilbert, & Marchessault, 2006), costs are likely to render this approach problematic in other contexts.

Computing

Devices such as the Simputer (The Simputer Trust, 2000) and the sub $100 laptop (OLPC, 2006) promise much cheaper access to computing power. It should be emphasized that for e-health applications, the computing device can be fairly simple; indeed mobile devices may become the preferred means of access. Along with cost, the ability to survive rough treatment, extremes of temperature and humidity and long battery life—or even the use of clockwork power in the case of the sub $100 laptop—are more important in developing countries than in the organization for economic cooperation and development (OECD) member countries. Parts supply and transport cost can make the repair of computers extremely expensive. However, organizations such as global assistance for medical equipment (GAME) (http://www.

global-medical-equipment.org/whatwedo.html) have established links between professional organizations in the developed and less developed world. These approaches move beyond the shipping of obsolescent equipment to an integrated and well-thought and sustainable out collaboration between donors and recipients.

Skills and Information

At present, consumer e-health is of limited usefulness in the developing world. Low levels of literacy and information literacy cause difficulties. However, the fact that the vast majority of Web resources are written in English and are U.S.-centric in terms of organization of healthcare, availability of drugs and medical devices and naming, makes even materials designed for health consumers in the OECD countries less useful for those in other nations. However, these issues are much less important when the provision of e-health services for medical professionals is considered. Adapting general principles to specific cases is a key skill of medical professionals. Indeed the traffic is not all one-way; less developed nation professionals often have skills that are no longer available in more developed nations. Collaboration in training of medical professionals, where trainees from different nations are exchanged, can improve the training in both systems. This can be supported by the use of e-health tools such as Web sites, e-mail and instant messaging.

Other skills required include the support of the e-health infrastructure in terms of technical support for computing devices and connectivity. Fortunately, the requirement of tourists from western countries for Internet connectivity, wherever they are, along with the burgeoning industries of call centers and 'off-shoring' of software development are providing a strong push for training in these areas.

OSS use in education and training allows nations with limited resources to devote more funding to the human side of education, as well as allowing projects that involve software localization to advance quickly. Open source clinical protocols may become important repositories of clinical knowledge allowing rapid development and input from experience, especially based on standard electronic forms.

Another important aspect of skill transfer and collaboration is the use of early warning networks for disease surveillance such as the Global Outbreak Alert and Response Network (GORAN) that played a very large part in the early detection of SARS (Heymann & Rodier, 2004). Such networks link health workers throughout the world and the transfer of information is by no means one-way.

There remains a dearth of well-controlled studies of e-health initiatives in developing nations, but the need for effective collaboration remains paramount (Wooton, 2001). However, there are a number of pointers to success:

1. The e-health system must be compatible with existing organizational and cultural structures. Some "western" assumptions do not apply in less developed nations and vice versa. For example, routine ultrasound examination in early pregnancy has not been shown to be effective in reducing mortality in a Cochrane review (Neilson, 1998). However, an environment where mortality due to unsuspected problems is much greater, and the availability of on-demand scans is lower, may give different results.
2. Collaboration and training between the professionals involved is vital. This applies to both clinical and technical

staff. This may in fact be the area of greatest benefit.
3. Ingenuity is more important than technology. Store-and-forward e-mail may be of greater utility than tele-presence.
4. Open source technology is particularly suited to this area of work. Lower costs, availability of technical skills, greater range of customized languages and often lower technology requirements make open source approaches and especially Web-based open source tools particularly attractive.

FUTURE RESEARCH

Future work in this area will include greater use of multicenter collaboration, both within existing networks such as GORAN and GAME and outside them. Lower bandwidth costs, and easier access to high bandwidths will enable richer media to be used, such as tele-sonography via store-and-forward (Parry et al., 2006). Common health problems are starting to afflict north and south: aging populations, the rapid spread of new infectious diseases and chronic conditions. Common approaches to these issues, including the use of low-cost assistive technology, and offshoring of medical procedures such as radiology (Larson & Janower, 2005), may be controversial, but at least the discussion has started. There are enormous potential benefits in the development of e-health in collaboration with developing nations, and the benefit to the people of world may be immense. An additional benefit of the open source approach may be an increased ability for IT specialists in developed nations to assist people around the world. As virtually every nation now has a Web presence, the technical barriers to such collaboration are much lower than they were even ten years ago. It is hoped that further work will refine the system sufficiently to allow the software to be placed in a repository such as Sourceforge.net. Furthermore, it is hoped that such an approach will encourage increasing collaboration and development in this area.

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