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The next challenge for WOrld wide Robotized Tele-Echography eXperiment (WORTEX 2012): From engineering success to healthcare delivery

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Abstract*— Access to good quality healthcare remains difficult for many patients whether they live in developed or developing countries. In developed countries, specialist medical expertise is concentrated in major hospitals in urban settings both to improve clinical outcomes and as a strategy to reduce the costs of specialist healthcare delivery. In developing countries, millions of people have limited, if any, routine access to a healthcare system and due to economic and cultural factors the accessibility of any services may be restricted. In both cases, geographical, socio-political, cultural and economic factors produce 'medically isolated areas' where patients find themselves disadvantaged in terms of timely diagnosis and expert and/or expensive treatment. The robotized tele-echography approach, also referred to as robotized tele-ultrasound, offers a potential solution to diagnostic imaging in medically isolated areas. It is designed for patients requiring ultrasound scans for routine care (e.g., ante natal care) and for diagnostic imaging to investigate acute and medical emergencies conditions, including trauma care and responses to natural disasters such as earthquakes. The robotized tele-echography system can hold any standard ultrasound probe; this lightweight system is positioned on the patient's body by a healthcare assistant. The medical expert, a clinician with expertise in ultrasound imaging and diagnosis, is in a distant location and, using a dedicated joystick, remotely controls the scanning via any available communication link (Internet, satellite). The WORTEX2012 intercontinental trials of the system conducted last year successfully demonstrated the feasibility of remote robotized tele-echography in a range of cultural, technical and clinical contexts. In addition to the engineering success, these trials provided positive feedback from the participating clinicians and patients on using the system and on the system's perceived potential to transform healthcare in medically isolated areas. The next challenge is to show evidence that this innovative technology can deliver on its promise if introduced into routine healthcare.

I. INTRODUCTION

Universal access to good quality healthcare remains a problem in both developed and developing countries. In both situations, geographical and economic factors, combined with lack of experts or their concentration in main healthcare centers, produce inequalities in access to healthcare. This is the case for access to ultrasound imaging, a non-invasive low cost imaging technique routinely used for, but not limited to, diagnostic investigation of abdominal and heart conditions, fetus physiopathology and breast cancer detections. However, ultrasound scanning is expert-dependent: sonographers and doctors trained in ultrasound scanning can give a real-time diagnoses only by combining their knowledge of a patient's anatomy and the current position of the ultrasound probe they are manipulating on the patient's body. The robotized tele-echography approach, also referred to as robotized tele-ultrasound and first developed in the late nineties [1, 2], offers an ideal solution to real-time, expert diagnostic imaging, with the potential to enhance the quality of healthcare in medically isolated areas. In this context, the University of Orleans (France) in association with Pontifical Catholic University of Peru-PUCP (Peru), Cyprus University of Technology (Cyprus), and the University of Vermont (USA) led an international consortium of clinical institutions, academic and industrial partners to demonstrate an intercontinental deployment of the robotized tele-echography concept to show evidence that this innovative technology can potentially deliver worldwide benefits if introduced for routine healthcare. The WORTEX2012 intercontinental trials involved heterogeneous socio-cultural, technical, clinical and governmental networks. Five geographical sites and four countries were chosen as remote expert and patient sites to test the impact of the following global tele-ultrasound interventions:

- From a main hospital to a local hospital - sharing sonographers in areas with high-density clinical resources for emergency diagnoses of patients, using existing videoconferencing networks, to avoid unnecessary patient transfer to main centers;
- From a main hospital to an isolated location – sonographers provide diagnoses for patients living with reduced medically facilities access (in mountain or island areas) or any given territory accessible by a given large bandwidth network (e.g. satellite);
- From a nomad expert to a fixed patient site (dispensary) - sonographers are enabled to make on-call diagnoses to that site at any time;

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- From a health professional (HP) seeking a second opinion; one expert calls another expert, anywhere in the world, and shares the control of the same tele-echography robot positioned on the same patient.

During the intercontinental trial, each concept was successfully tested at least once. This paper presents, in section II, a short historical assessment of the robotized tele-echography that led to the WORTEX2012 deployment. The clinical, technical and economic requirements are described in section III. The descriptions of the experiment trials are given in section IV. This is followed by the health and economic Impact that could strengthen the delivery of the concept in routine healthcare worldwide. The last section provides a conclusion to the successful WORTEX2012 trials.

II. ROBOTIZED TELE-ECHOGRAPHY PLATFORM

A. *from tele-echography to robotized tele-echography*

Ultrasound scanning plays an important role in modern healthcare. It serves as an important diagnostic tool in both routine and emergency care. In a comprehensive review of non robotized tele-ultrasound as a transformational technology for medically isolated areas, Pian et al. [3] concluded that it was an ideal imaging modality for remote and under-resourced communities; the technology appeared to be ready but it had not yet been shown to be effective in routine clinical use. In an eHealth intervention, a portable ultrasound robot can scan a patient located in one setting while transmitting images to the HP who controls and interprets the ultrasound scan from a distant site. Successful early trials of this robotized tele-echography technology, first developed and patented by the PRISME laboratory, University of Orleans (France), focused particularly on testing engineering and technical issues such as connection stability, responsiveness and image quality. In 2004 the robotic ultrasound device was tested during a zero gravity flight for the European Space Agency [4] and this was followed by a series of three successful trials of increasing technical difficulty between France and Cyprus - from a remote mountain location, from a moving ship and from a fast moving ambulance - using healthy volunteers as ‘patients’ [5]. In 2007 Arbeille et al. [6] reported on a series of tests between four clinical centers in France to compare image quality from scans using the robotic device and those produced by traditional ultrasound scanning: according to the authors, 90% of the comparisons showed equal diagnostic capability between the novel and standard techniques. While the concept has been extensively technically tested, it has not yet been trialed in multicultural, geographical and international contexts to evaluate the social impact of the technology. Currently, there are only two comparable available industrial technologies to our knowledge; one is a Japanese robotized tele-echography device (FAST) that is being developed particularly for use in disasters [7], and the other is a Swedish product “MediRob” limited to cardiovascular ultrasound investigation [8].

B. *Principle of robotized tele-echography*

The robotized tele-echography system enables an HP to remotely scan a patient located in a different location and to transmit images to allow interpretation of the ultrasound scan from a distant site. It relies on Internet (or satellite) technology to relay the hand movements of the HP remotely conducting the scan and to transmit the scan images (figure 1); the overall platform is composed of three main elements:

Figure 1: *WORTEX intercontinental deployment setting: the health professional controls, via satellite, with a haptic probe the remote MELODY robot positioned by a paramedical assistant on a patient.*

The Expert Station: the ultrasound HP sends robot controls and is fed back with the patient’s ultrasound images. The HP uses a haptic probe to control the remote robot end-effector holding the real ultrasound probe. The HP receives, in almost real time depending on the available bandwidth, the patient’s ultrasound images and gives his diagnosis.

The patient station: has 3 main components: a lightweight six-DOF serial robot that holds any ultrasound probe available at the patient site, an ultrasound device and a videoconference system. A force sensor, embedded in the robot end effector measures the contact force between the real probe and the patient’s skin and enables to limit this force to 20 N for the patient’s comfort and safety. An assistant maintains the robot on the patient. Ultrasound images are sent via the videoconferencing to the HP.

The communication link: The network links the two stations to exchange robot control data, ultrasound images, haptic information, ambient images and audio instructions. Most of the bandwidth is required for the transfer of ultrasound or ambient images. Terrestrial links, fixed and mobile satellite solutions or 3G technologies with various bandwidths have being tested in the frame of this project. However, these network links may generate transmission varying time delays; this hinders the stability of the teleoperated robot and force feedback rendering at the expert site [9].

III. REQUIREMENTS

A. *Clinical and technical requirements*

Standard ultrasound examinations (abdominal, cardiac, fetus) have been analyzed in order to quantify the positions, movements, and velocities of the probe used by ultrasound specialists. To satisfy the control at a distance a serial 6-DOF robot for the probe positioning and for its handling during the robotized tele- echography have been shown to be the mechanical concept able to match the medical and mechatronic requirements [10,11]. Interesting points can be reported: a continuous contact has to be kept between the probe and the patient's skin, even when the probe is applied around ribs area and irregular abdominal zone. The contact force value should vary from 5 to 20 N for patient safety. The HP maintains the haptic probe most often close to the normal direction of the skin except in some specific cases, such as in bladder investigation, where the probe can be tilted up to 60 ○from the normal direction. Once the probe is positioned on the area of interest, rotations, inclinations, and small translations are performed around the chosen contact point with the skin. Although the reproduction of the HP gesture via the communication link has to be performed with accuracy by the light weight robot, the images fed back to the medical expert have to be of a quality comparable to the one provided by a standard ultrasound device [10]; this requires a minimum bandwidth of 256 kbps.

B. *Communication requirements*

In general Telemedicine applications can be classified according to their bandwidth transmission requirements. The availability of network choices in telemedicine in recent years have been implemented over various communications technologies such as plain telephone lines, ISDN and ADSL technologies. However, recently other modern technologies, such as, broadband networks (e.g. broadband ISDN) with the asynchronous transfer mode (ATM), satellite networks, WLAN and Bluetooth as well as digital land-lines or cellular/wireless, allow the operation of ambulatory and mobile telemedicine systems [12].

When considering telemedicine and telecommunications technologies, it is important to consider and evaluate not only their cost/performance trade-off and capabilities but also the general technical development aspect [13]. Concerning the transmission of medical data there are no defined standards or any predefined theoretical bandwidth specifications. The complexity and range of telecommunication technology requirements vary with the "nature" and specificity of the given telemedicine application. As a general rule it can be said that a lack of bandwidth is interpreted as a longer transmission time [14]. Examples of bandwidth requirements for telemedicine real time transmission applications include a digital blood pressure transmission, digital thermometer reading, or oxygen saturation meter each of which require no more than 8 kbps. For an Ultrasound telerobotic application a 320 kbps would be sufficient.

Standard GSM can only provide data-transfer speeds of up to 9.6 kbps that only allows real-time small data transmission. GPRS and Edge theoretically allows transfer up to 171 kbps and 384 kbps respectively, but all users in a communication cell share the same bandwidth. It can reliably be used for real-time small data transfer or at least a reasonable quality ambiance video [15]. The 3G cell phone technologies, based on UMTS may support up to 1.75 Mbps, and can support 384 kbps transmissions for medical images [16]. Wi-Fi Lan (802.11g, 802.11n) can support from 54 Mbps up to a 300 Mbps bandwidth, but must be very well controlled to avoid too many collisions and have real limitations in terms of mobility and coverage [17]. Nowadays, wired communications using dedicated digital lines with high baud rates are present in many hospitals and can be used for telemedicine applications. The connection to mobile or isolated area may use commercial links with high baud rate, such as ASDL, or high cost geostationary satellite communications [9]. Whatever the choice of transmission technology and selection of the communication link the selection-usage of the IP routing protocol is highly recommended. Protocols such as TCP over IP, which is considered to be connection-oriented protocol, can be used for basic connection set-up (i.e. data control to ensure the devices connections) but due to its connection-oriented "nature" is not suitable for images or videos transmission [18, 19].

Inevitably, this kind of protocols reduces the network rate when the transmission reaches the speed limitation of one of the link of the network chain due to the repetition of packet loss. On the other hand, connectionless protocols such as UDP are better tailored for images or videos transmission, and are not sensitive to the latter problem. The down side is that data is not guaranteed to reach its destination. For real-time telemedicine, the guiding principle is straightforward: it is better to loose one image or one frame than to overload and block a communication link.

In the robotized tele-echography application presented in this paper, a connection-oriented protocol is used to ensure the connection between the distant sites, and connectionless protocol for data/images transmission. When a control loop is required through the network (e.g. to control a remote robot), data are sent using UDP. For this specific medical tele-operated robotic application, to avoid a mechanical divergence of the robot when data loss occurs and to ensure patient safety, data sent are not robot joint velocity or torque set points but position set points. Hence in case of data loss, the robot remains orientated in the last received data position. Specific protocol (e.g. hybrid connected–connectionless) are developed to control robots through the network, but are not normalized [20]. Once the protocol is well defined for a given telemedicine application, the users have to cope with the time varying delay inherent to the chosen communication link and its consequences on the stability and transparency properties for the tele-operated robotic system;

IV. WORTEX EXPERIMENT

Setting a worldwide deployment of a robotized tele-echography platform for an intercontinental trial amidst heterogeneous socio-cultural, technical, clinical and governmental networks requires a strong synergy among the partners similar to that which will be required by numerous end-users. Five geographical sites and four countries were involved to test the impact of the global tele-echography concept.

The WORTEX2012 experiment was made possible thanks to the unlimited support of the National Institute of Maternal and Perinatal Health (INMP), the Radiology department of Nicosia General Hospital of Cyprus (NGH), Satlink Tototheo Group, Hospital Nacional Regional de Arequipa (ARE), Health Technopole CENGETS, Regional hospital of Bourges (BGS) and university of Vermont (UVM) and Adechotech company. AdEchoTech made robotic tele-ultrasound her heart business. Three years of experimentation have resulted in a robotic solution in total harmony with the actors of the medical sector. MELODY is available on the market since January 2013 and has a medical CE Industrial ready.

Each of the five chosen sites (NGH, ARE, BGS, UVM and INMP) were all respectively and sequentially equipped with a "patient" station and/or an expert station. These settings made it possible for each site to act as an expert center and a patient station whatever the hospital center was decided to be. Time difference among countries was challenging, clinical and technical staff adapted and responded quickly to overseas unexpected solicitations and the technical settings (bandwidth and network quality of service) was in agreement with the requirements providing high quality ultrasound imaging to various sites for the benefit of the HP.

V. HEALTH, SOCIAL AND ECONOMIC IMPLICATIONS

Scotland and Peru can be looked at as two examples of the potential application of the robotized ultrasound concept. Telemedicine is included under the term eHealth, which covers a broad range of innovations in the organization and delivery of health services and information [21]. The drivers for eHealth in Scotland, in common with elsewhere, are changing demographics and growing demands on health and social services combined with financial constraints [22, 23]. Black et al. identified facilitating remote care as one of the three main, overlapping functions of emerging eHealth technologies [24]. The particular challenges facing the NHS in Scotland's remote and rural (RR) areas have been highlighted by several bodies. Among recommendations arising from work aiming to advance equality of access to healthcare for RR patients is that General Practitioners (GPs) should have greater access to a range of diagnostic tests, including ultrasound scanning [25]. A portable robotic ultrasound device potentially offers the means to deliver that RR capability and greater equality of care. It has the potential significantly to improve patients' experience of and quality of care through timely, local access to ultrasound scanning, without the current inconvenience and time of travelling sometimes considerable distances for an ultrasound scan. Further, it has the potential to show significant cost savings through reduced travel expenses for patients living in medically isolated areas in Scotland.

Peruvian Health Care System includes [26]: Ministry of Health (MINSA), which provides services for 60% of the population; Social Security System (EsSalud), which provides for 30% of the population; the Armed Forces (FFAA), National Police (PNP), and the private sector together provide services to the remaining 10%. Some characteristics of Health Sector are: a) Health system's performance is not effective; b) Inequities due to geographical, social, cultural and economic barriers; etc. As a result, most deprived areas, has no effective health intervention in average. Peruvian population increasingly demands improvements on [27]: 1. Quality of healthcare services; 2. Human Resources and 3. Information. There's not enough staff with the right level of knowledge of technology at Peruvian Health Care System [28]. This situation has a negative impact in the quality of the diagnosis and treatments mostly in the poorest and most remote areas of Peru.

Telemedicine improves the accessibility to health services and facilitates the improvement of the quality of diagnosis and treatment for complex cases in Peru. From an economic perspective, it replaces the need to travel and reduce the time and costs of consultation for the regions (Andes, Amazon and far areas from Lima, the capital) of the country. Ministry of Health [29] promotes the supply of Internet servers and/or telephone lines for health centers and hospitals in the country. The government understands also the Telemedicine as a key factor for development of the health sector.

Robotized tele-echography was successfully tested in Peru: Lima and Arequipa region, the immediate attention from an expert and the resulting cost contributed to an improvement in the quality of healthcare of the mother – child. As a result, the robotized tele-echography responded effectively to one of the national priorities of MoH: Maternal and Child Health Care [30].

Vermont USA is a rural state with remote mountainous regions. Advanced healthcare is centered at the University of Vermont with its medical school and teaching hospital. Telehealth has been utilized since the mid-1990s. Robotized tele-echography was successfully deployed here as part of the experiment with the involvement of the university's Technical Services Partnership biomedical engineering group and the Department of Radiology. Radiologist Dr. Kristen DeStigter led clinical involvement as a global expert in tele-ultrasound imaging. She is co-founder of *Imaging the World* (http://imagingtheworld.org/) who has developed an innovative program to improve maternal health in Uganda.

Remote ultrasound technology is an engineering challenge; the continued development of this innovative technology and its routine use in healthcare are socio-technical challenges.

Introducing new technology requires financial resources (e.g., capital investment for buying device, supporting infrastructure, staff training) Effective adoption and use of the technology requires new ways of working and service delivery. When performing this remote robotized service, interactions between technologies and people can result in unintended consequences, highlighting a need for further evaluation and understanding of the consequences of introducing this technology into different care settings.

VI. Reflecting on the WORTEX trail

We conducted a small number of preliminary interviews with participants in the WORTEX trial to gain insight into experiences of the trial and views about the potential of this new technology. An independent qualitative researcher (AR) spoke to a range of people in France, Cyprus, Peru and USA using Internet-based video calling. Participants (N=16) included hospital doctors, volunteer patient, hospital informatics staff, engineers and academics. The unusual, multidisciplinary, global collaboration achieved within the trial was itself felt to be of value.

> *"The resulting global connections were a good outcome of the experiment."* Academic.

Interviewees involved in the technical and engineering side of the intercontinental tests reported that the system had worked well and had been very well received by the HPs. Interviewed HPs who had conducted robotized scans were similarly positive: they rated the resulting ultrasound images as comparable to traditional scans. They reported that it had been easy to learn to use the new technology after a short period of practice with the joystick. The patient and healthy volunteer interviewees also spoke positively about their experience of being scanned, finding the video conferencing link to the distant expert and the presence of the healthcare assistant quite acceptable.

> "*It felt as if I was in Peru with an ultrasound probe in my hand. Very, very impressive."* Doctor and ultrasound expert (USA).

> "*It was comfortable."* Volunteer patient (Peru).

Interviewees felt the new technology had the potential to support RR health professionals to deliver a widely accessible and timely ultrasound service, both as a diagnostic tool for urgent and non-urgent medical conditions and for routine ante-natal care. The barriers to its routine use these interviewees identified did not concern technical or medical issues with the robotized technology; rather they foresaw the main barrier as being persuading high level policy makers in healthcare to adopt, and fund, this innovation in healthcare delivery.

VII. Conclusion

We successfully demonstrated the feasibility of intercontinental tele-echography in a range of clinical contexts. The main expected benefits of introducing remote ultrasound identified included: access to expert healthcare for remote communities globally; improved patient outcomes; and cost effective service delivery. The main perceived difficulties with introducing/using the technology identified included: gaining policy maker and health service management commitment; and securing the necessary investment.

Future work will include an independent, mixed methods socio-technical evaluation of the ultrasound robot in a variety of primary and secondary care settings within a remote health community (e.g., rural and/or island community).

Robotized tele-echography provides patients living in isolated locations a diagnostic with the same level of quality as at that offered in the hospitals in the city or even in other continents. The effectiveness of the diagnostic performance is an adequate solution to the increasingly demand for accessibility to health services from the population of the regions of developing countries like Peru or of developed but remote areas such as the Shetland island in Scotland.

Finally, the WORTEX2012 experiment was a successful result of an intercontinental collaboration, exchange of knowledge, cultures and expertise and joint capacities based in engineering, medicine and management, all focused on development of innovation for the health sector.

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