DISTANCE-BASED MEDICAL OPERATIONS AND MEDICAL TELEPRESENCE: NEW WAYS OF DOING THE SAME OLD THING

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THE NEED FOR DISTANCE-BASED MEDICAL OPERATIONS

There is absolutely no question that one of the major problems of the modern world, particularly in the regions euphemistically known as the Less Developed Countries (LDCs), will be access to adequate medical care [1]. Population growth combined with the continuing inadequacy of fiscal resources will necessitate increased tempo in the shift from interventional to prophylactic medicine. Yet, even if such approach may lead to the reduction in the incidence of preventable disease (e.g., infectious diseases, certain forms of injury, diseases of childhood), there will still be issues of uneven distribution of medical personnel, progressive decline of medical preparedness that parallels the distance form major medical education centers, inadequate level of training frequently encountered in the rural and remote regions of the globe, etc [2]. Traditional means of solving these problems by merely increasing the number of assistance programs in expectation of allaying these burning issues results in a highly fractioned, wasteful approach. Funds are spent across a wide range of "warm-body-on-site" solutions whose relevance spans from critical to trivial or merely politically correct. As a result, the difficulties persist, while the policy makers assuage the growing discomfort of the medical professions by quoting the size of the forthcoming appropriations. Clearly, in many instances, the distance-based approaches may have a significantly more powerful impact, particularly in situations where medical advice needs to be distributed to a large group of providers separated by significant geographical distances yet linked by the common nature of the medical issue [1].

The events of 11th September 2001 pointed at another grim reality - the vectors of medical threats moved overnight from purely biological into the man-made territory. The doomsday prophecies of microbiologists, epidemiologists, and public health specialists who for many years warned about the possibility of severe disease outbreaks became frighteningly real as one of the possible forms of the international terrorism. Yet, despite the assurances to the contrary, in reality the level of our large-scale preparedness is either marginal or absent. Moreover, sites of very high medical sophistication are as vulnerable as the rural regions where medical services are significantly less efficient, a fact that contributes to the dilemma of adequate resource distribution, preparedness, and ability to respond swiftly to any freshly identified threat. To assure the satisfactory level of readiness, large numbers of widely dispersed medical personnel at all levels need to be trained in appropriate forms of response to the biological/chemical threat at both personal (precautionary measures, barriers, ability to perform in the contaminated environment) and organization or even national level (identification, containment, elimination of the threat.) Execution of a massive training task as that required by the newly changed reality is both prohibitively expensive and constitutes a logistical nightmare as long the traditional "face-to-face" measures are implemented. Once again, the fledgling concept of Advanced Distributed Learning and its combination with

Distributed Interactive Simulation that hitherto has been brushed off by the world of medicine as a quaint or even quixotic notion may become one of the essential tools needed to accomplish the task.

Curiously enough, medical operations at a distance are nothing new. Ever since the arrival of primitive radio sets aboard naval vessels [3], the medical advice has been transmitted to naval and merchant vessels over W/T for almost a century [4]. However, it was the Internet Revolution that introduced the major change in the way doing medicine at a distance. For the first time, rural and remote regions acquired face-to-face access to the superbly trained specialists at the major medical centers [5]. The victims of natural disasters, war, or simply those without the means to travel finally gained access to modern medicine. Apart from boosting the concept of operationally viable telemedicine, the advent of the Internet introduced other exciting forms of distance-based medical operations. Distance training, where teaching platforms as varied as CD-ROMS and either virtual or real simulation devices are routinely or nearly routinely used, attained the level of popularity unthinkable as late as ten years ago [6]. Telesurgical/telerobotic interventions reached the level of operational maturity sufficient to be contemplated as routine devices [7,8]. The same is true of telediagnostic devices that may entirely change our concepts of preventive medicine, public health monitoring etc.

TELEMEDICINE VERSUS MEDICAL TELEPRESENCE

Fig. 1 ViTel's Net's Metvizer system allows execution of several sophisticated telemedicine operations. Nonetheless, it is, essentially, a consulting system that does not allow for the experience of full medical telepresence. *Courtesy ViTel, Inc.*

Telemedicine has been defined as "the use of medical information exchanged from one site to another via elecronic communications for the health and education of the patient or health care provider and for the purpose of improving patient care" (Fig.1) [9]. The definition (incidentally, one of many proposed – see [10]) restricts the activity between the sites to a passive exchange that does not direct allow direct interaction with the patient. In practice this strict definition is significantly expanded into direct patient-provider contact in disciplines such as telepsychiatry, telepediatrics, or remote healthcare of prisoners [11]. Nonetheless a very significant portion of telemedical activities are devoted to "passive" disciplines where the such as teledermatology, teleradiology, or telecardiology, where the direct contact of the caregiver and the patient is either non-existent or very limited. Telecardiology represents a very special case that can be best described as med-telemetrics since the transmission of cardiac rhythms, no matter how vital for the patient's survival, is nothing more sophisticated than the transmission of a fairly simple wave form over Internet [12]. Despite its potential, telemedicine seems not to have taken off as readily as originally expected [13,14]. Although a detailed discussion of the issues that slowed down telemedicine in its development as the "medicine for the masses," probably the most inhibitory element was the profession of medicine itself whose innate conservatism and unwillingness to accept often sweeping changes that telemedicine brought along resulted in the dramatic slow down of its broad acceptance. Other factors such as technological and legal issues, some of which may be vastly more important than others (e.g., the debates of the privacy vs. the minimum required bandwidth) to mention merely a few had an equally adverse effect.

In its most restrictive definition, "telepresence" is defined as "the experience of being fully present at a live real world location remote from one's own physical location" [15]. Medical telepresence is therefore nothing else but the experience perceived in the medical context. While, superficially, the difference between the definitions of telemedicine and medical telepresence appears minute, in reality the difference is significant since, contrary to telemedicine, medical practitioner (or the patient, or both) experiences the encounter in a manner identical to that taking place the real life. In order to bring such experience to the utmost limits of reality, the introduction of three-dimensional (3-D) viewing becomes indispensable since the perception of depth is critical for our ability to interact with the surrounding world in a precise and coordinated manner.

THE WORLD OF TELEPRESENCE

The new possibilities opened by the rapidly advancing 3-D technology created confusing definitions of underlying concepts, with 3D graphics becoming an equivalent of stereo projection and viewing [2], and a standard teleconference either attaining the status of 'virtual presence" [3] or assuming, with only a minimal degree of correctness, the mantle of "telepresence"[4,5].

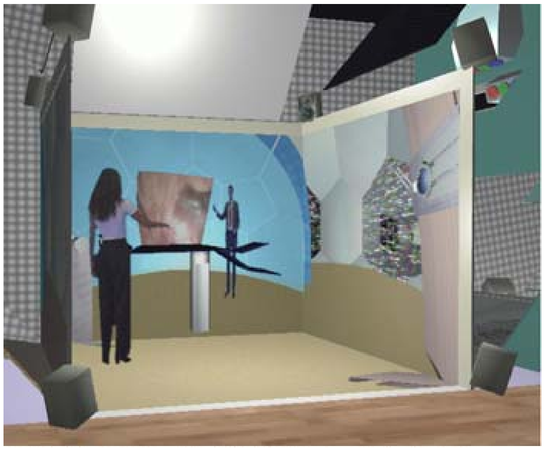

Fig. 2 A remote participant being virtually present in a 3-D virtual environment displayed in a CyberStage. *www.cs.up.ac.za/.~vali/Research/IMMERSIV/Immersiv.htm*

Virtual reality (VR) environments recreating physical envelopes that, typically, represent a physical location remote from the observer where the observer may [at least in some instances) interact with the surroundings (Fig 2)], have been also considered (with an equal lack of precision) as "telepresence" [20,21,22,23,24,25]. Surprisingly as it may sound (or, upon reflection – not at all), even a standard TV transmission may create the sensation of telepresence[26], since the viewers are transported to a remote location at which they experience its live, real time reality. However, within the environment described by the "Strathclyde definition" of telepresence [15], the observer turns into an actively engaged participant stimulated by a variety of sensory inputs leading to the execution of social interactions as if physically present at the remote site [15,27].

VR-based telepresence offers many attributes demanded by the formal definition of telepresence[27,28] both in the form of essential (but still quite rudimentary) haptic feedback and the environment in which appropriate social/professional interactions can be executed [28,29,30]. However, negative aspects are present as well. As defined [15], the environment in which the viewer is telepresent already exists. It is not a recreation, it has its own, independent existence and temporal presence where the events unfold independently of the viewer's presence. VR environments, on the other hand, need to be created, and, without the viewer's active interaction remain what they are – static and limited settings with no relation to the real world. The major drawbacks of VR environments are the time and the cost required to generate them at a convincing level of reality [29]. Moreover, despite the rapid emergence of low-cost VR systems, e.g., "gloves & goggles" (Fig. 3) and PC stations[130,31,32,333], the complexity and cost of the physical facilities required for the creation of the advanced immersive VR facilities and operations are prohibitive [24,33,34,35,36]. Unsurprisingly, the sophisticated VR platforms are scarce.

Fig. 3 The upper photograph shows one of the various types of Head Mounted Display (HMD).available today. The lower photograph shows a haptic force-feedback device. Just as HMDS, haptic systems come in a large variety of configurations. Their application in conjunction with with HMDs or other forms of VR allows interaction with virtual reality rendered objects
Both figures: MedSMART

While the disturbing physiological side effects of even comparatively short (10-20 min) VR exposure e.g., vertigo, nausea, headache, etc. [29,37], introduce yet another use-limiting factor, there is no doubt that immersive VR offers a unique capacity for training complex skills [28,29,38,39,40,41]. Among the best examples of such activities is preparation for the execution of complex procedures in unusual environments, e.g., training medical naval personnel in performing emergency interventions in the violently rolling sick bay of a warship at sea [our own pilot studies], preparation for command of large ships, urban warfare, decontamination procedures, etc.

In summary, VR, and particularly the immersive VR, may approach the reality of telepresence. However, the distant VR environments remain an artificial and, strictly speaking, a static creation since the current technology does not allow incorporation of real-time changes of the environment at the remote site as a simultaneous virtual rendition of these changes at the VR facility. Thus, while representing an almost ideal vehicle for advanced training [41], virtual reality does not, despite occasional claims to the contrary [e.g., 24], provide a suitable platform for operational activities.

A compromise solution between virtual reality-based telepresence and true telepresence has been also proposed. In these environments a "porthole" or a "portal" concept are used as the means of bridging the gap between passive and active awareness of ones surroundings [42]. In the former case, the system gathers static images of different environments then distributes them within the subscriber network [42]. The system uses a frame comparing software that allows detection of changes indicating human activity. In many ways, the operation of the "porthole"-based monitoring device resembles that of the currently employed perimeter security systems with the solitary difference of automated rather than human operator detected environment changes. The "portal" concept provides high fidelity static VR reconstruction of physical space as a background to the dynamic activity of the remote "collaborator." [43,44]. The "portal" concept has been developed to its (probably) ultimate level of complexity by the Medical Readiness Trainer (MRT) group at the University of Michigan where the combination of immersive VR, Human Patient Simulation, and Internet-based resources allows human operators (emergency room physicians, nurses, paramedics) execute training activities within an almost entirely synthetic environment of an emergency room patient bay [45]. The validity of MRT's approach as a platform for further development in the realm of advanced distributed learning (ADL) has been recently subjected to successful operational testing [1,45,46].

In a recently published essay, Eduardo Kac argued that true telepresence may be considered a new form of art [47]. Although the "Ornitorrinco on the Moon" project consists of nothing more elaborate than a telerobotic exploration of space based on the subjective ("whimsical") commands of the remote operator of the robot, one of the most compelling arguments for the importance of telepresence provided by the author is that of primacy of real time over real space. Due to their very nature, many of the activities that require observation or robotic execution under the command of remote operator must be executed in real time, within the environment that may be subject to almost instantaneous, often unpredictable, changes. However, the "real space" of VR-based telepresence provides only an approximation of the real time (by being "preconceived", VR space determines the temporal nature of all events that may take place within its boundaries, but the temporal relations of these events are, essentially, "pre-planned"). On the other hand, operations such as inspection of hazardous spills, telesurgery, or robotic disposal of high explosives demand real time, spatially coordinated response to the very real yet frequently random and potentially dangerous demands created within real space – a sudden tear in the repaired blood vessel, a shift of the explosive material resulting in the possibility of an imminent explosion, etc.

With all these constraints in mind, only the real telepresence, rather than its VR-based equivalent allows immediate and spatially correct response whose effectiveness depends only on the skills training of the operator of the remote robotic device, and the performance limits of the device itself. Unsurprisingly, the majority of practical applications of true telepresence relate to the environments where unpredictable changes within the operational space provide critical clues dictating the nature of the subsequent response. Robot-based surveillance of battlefield or nuclear facilities [48,49,50], agricultural robot operations [48], remote inspection of commercial and defense facilities subject to international treaty agreements [51,52], and the most recent addition – telerobotic surgery [7,8]. Less visualization-dependent telepresence projects concentrate on integrating computers and high speed networks to allow remote control of research instrumentation by the distant users [53,54,55]. Altogether, there is no doubt that, with the exception of military applications, the most dynamic development of advanced telepresence concepts takes place within medicine, particularly surgery.

CURRENT TELEPRESENCE VISUALIZATION SYSTEMS

Probably the most critical element of a telepresence system is the manner and quality of the displayed image of the remote site [56]. While the most common display in use is still screen of the desk-top CRT monitor, over the years, several different forms of stereoscopic technologies emerged, ranging from relatively simple to highly complex and costly devices [56,57,58,59,60]. Two types of stereo-viewing (3D) technologies appear to dominate the telepresence scene [57,58]. Planar displays using anaglyph (color multiplexing), polarization multiplexing, and field sequential (time multiplexing) approaches are used in order to assure separation of 2D left- and right eye images [56,60]. The other approach is based on location-multiplexed displays represented by Head-Mounted Displays (HMDs), BOOM (Binocular Omni-Orientation Monitor) and, the latest advent on the scene, the 3DDAC (3D Display with Accommodative Compensation) displays. Planar systems require special viewing devices either in form of polarizing or color filters or liquid crystal shutters, the latter either attached directly to the front of the monitor or worn as "shutter glasses" [60]. Typically, sophisticated planar devices (e.g., ImmersaDesk systems) are more expensive than HMDs. Moreover, initial studies have shown that HMDs may be more effective in training interaction with large-scale virtual environments [61, but see 62]. The greatest concern posed by either type of 3D viewing devices is their adverse effect on visual physiology [63,64,65,66]. The use of HMDs in particular, one of the preferable source of visualization in telepresence robotics [48,50,67,68], has been associated with visual stress and deficits [69,70], general discomfort [70,71], and postural instability [72].

AUTOSTEREOSCOPIC DISPLAYS SUITABLE FOR OPERATIONAL USE

Autostereoscopic devices [56,58,59,60] present three-dimensional images without the need for any additional viewing aids. Importantly, autostereoscopic systems offer not only the best optical approximation of the real object [58] but also support the physiological foundations of spatial vision, since there are, essentially, no differences in viewing objects rendered in autostereoscopic display from viewing them under natural conditions [60].

Fig. 4 The stretchable membrane mirror system - a relatively simple but very effective autostereoscopic device.
Courtesy Ethereal Technologies, Inc.

Probably the simplest among all autostereoscopic systems are those based on the re-imaging concept where mirrors (or lenses) are used as the image-transforming device [59]. While the concept is not new, the development of a mirror using stretchable membrane [73] made mirror technology a practical tool for 3D visualization. The MIRROR system developed at the University of Strathclyde, UK in association with Ethereal Technologies, Inc. (Ann Arbor, MI}consists of aluminized Mylar film stretched over a carbon fiber frame and tensioned under vacuum to form a concave surface approximately 120 cm across (Fig.1).

The construction of the MIRROR allows user-determined variation of the mirror's f/Number from optically flat surface to approximately f/1. Two lenses project the left and right view at the MIRROR and the projected image plane can be behind, on, or in front of the plane of the

MIRROR which is used as a directional screen creating the real image of the lens assembly in a manner preventing "cross-talk" between the left and right eye views. Essentially, the system creates a pair of "virtual windows" through which the viewer looks in order to see the stereo image (Fig.2). Presently, the system is a single viewer display, although work is conducted on the development of multi-user units. However, even as a single-user device, contrary to HMDs, the use of the MIRROR does not cause either physical or optical discomfort (own, unpublished observations). Moreover, the controllable aperture of the MIRROR allows creation of large, very bright images that can be viewed in broad daylight. The advantages presented by the stretchable membrane display become particularly evident in austere environments, where available technology resources are limited due to financial constraints, environmental conditions, or lack of trained personnel capable of operating more complex telepresence systems.

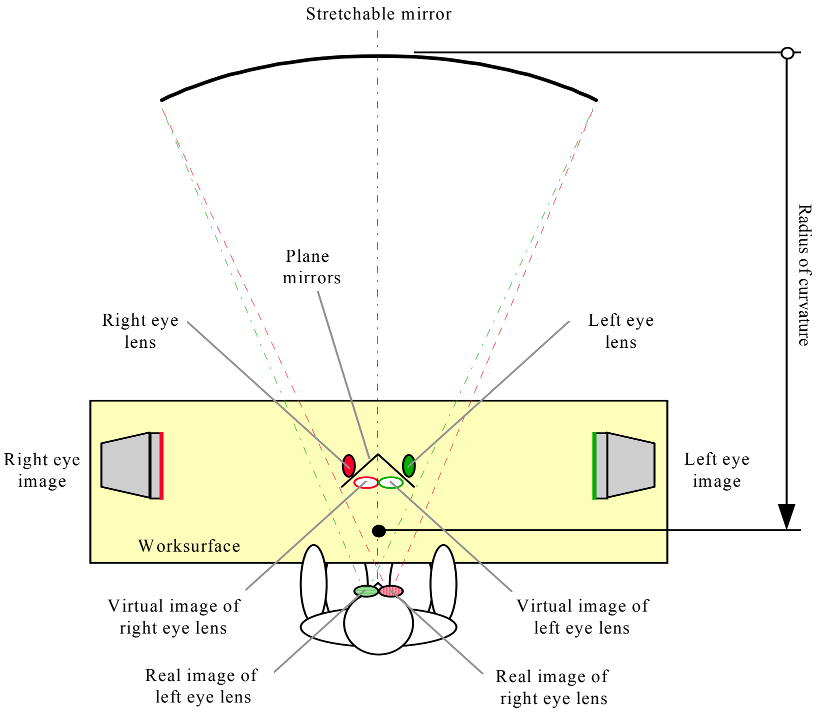

Fig. 4 Schematic diagram of the MIRROR system.
Courtesy Ethereal Technologies, Inc.

One of the best examples of the other end of the spectrum, i.e., highly sophisticated autostereoscopic technology that entered the US market and approaches the concept of a "true hologram" is provided by the LifeVision™ system. In similarity to the MIRROR device, the LifeVision™ Monitor reached the level of technological maturity to be contemplated for routine practical use in medicine and medical telepresence (Fig. 5). The LifeVision™ 3D Monitor is offered by IntrepidWorld, Inc. (Los Angeles, CA) and is based on a Laser Optical Element (LOE) serving as a holographic diffuser (Fig. 6). Images transmitted through LOE are perceived in three dimensions and are by utilizing a combination of lasers, optical lenses and mirrors, which record a diffusion pattern upon special film, and, with the potential of producing close to 100.000 line/cm, the image resolution of the LifeVision system significantly exceeds that of the human eye, resulting in the image of particularly high quality. Important from the user's standpoint is fact that LifeVision Monitors will be offered in a variety of viewing screen sizes (up to 100x180 cm).

Fig. 5 LifeVision desk-top system by Intrepid World Communications. Note the compactness of the device (the cuboid box behind the operator's desk) making it immensely applicable in a variety of limited space settings The flat screen folds down for transport. However, compared to the MIRROR device by Ethereal Technologies, the LifeVision system is more complex and less suitable for field deployments or deployments to the regions where technical assistance may not be readily available. The box on the right side of the desk is a 3-D videorecorder

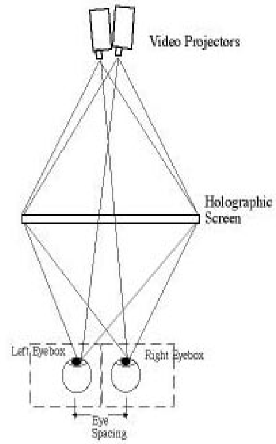

Fig. 6 The optical system behind the LifeVision concept of the IntrepidWorld Communications, Inc. Note the essential simplicity of both Life Vision and MIRROR systems that makes them very attractive in practical use

Both figures courtesy of IntrepidWorld Communications, Inc.

The range significantly enhances the flexibility of practical application by allowing desk-top mounting as easily as fitting of large, wall mounted display surfaces where the picture can be viewed by more than one person. However, the significant complexity of the LifeVision monitors which, apart from LOE, consist of several other major subcomponents, makes them better suited for stationary or "sheltered" environments of major visualization centers, where access to technical support is comparatively easy, and the degree of sophistication of the support personnel is typically rather high. This is in contrast to the MIRROR unit whose relative simplicity makes it highly suitable for the operations in the field where support requirements of the deployed system must be kept at their absolute minimum. Dimensional Media Associates (New York) revealed recently another type of an autosteresoscopic device, the HyperCube 3D Display. The details of the technology used by DMA have not been revealed with the exception of a statement indicating two major subcomponents of the system – a high speed video projector and a solid state volumetric projection element. Although DMA have used their devices commercially, a system that would find its applications in medicine is yet to be disclosed.

Both in the case of the MIRROR and LifeVision Monitor, the source of the images can be computer files, stereo film or videotape, or live transmission from stereo cameras. Either system combines advanced technology in electronics and optics with readily available computers and provide a pseudo-hologram image, where the light source appears to come from the model or subject itself and thus can be viewed as a floating object suspended in "free space" without special glasses (Figs 7, 8). The latter aspect is particularly important in medical applications, where prolonged viewing of objects in prepapration for, e.g., surgery may result in significant fatigue of the user exposed to other devices such as HMDs or even immersive VR. From the practical point of view, the emerging autostereoscopic systems are independent of format, brand, or software issues. Whatever sources provide a stereoscopic output and can provide a video standard output (NTSC, video, S-video, RGB, VGA, etc) can be viewed. Since these sources include computers, stereoscopic VCRs and cameras, DVDs, etc., the flexibility is substantial, and the range of uses covers the entire spectrum of Web based material to real time medical training, consultation, and, in probably not too distant future – telepresence-based surgery and telesurgery [74].

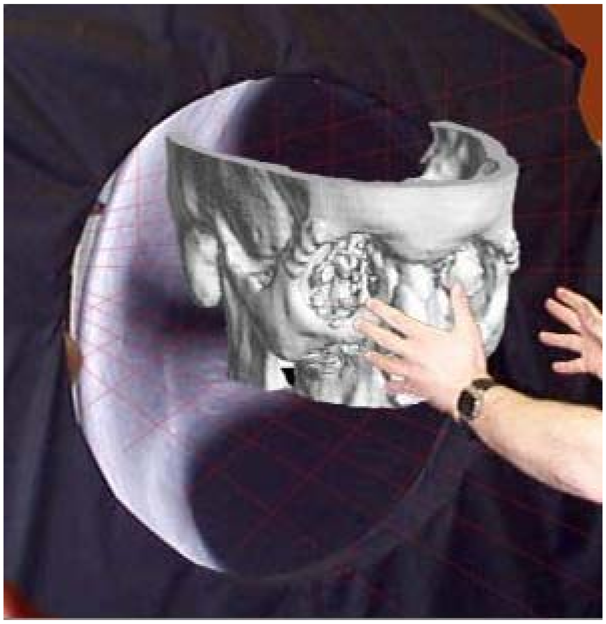

Fig. 7 Image as appearing in the MIRROR system. The impression is that of the 3-D object suspended in the space between the viewer and the mirror membrane. The details of the cranium are readily apparent. Advances in laser surface scanning technology make 3-D analysis of volumetric objects particularly attractive.
Courtesy Ethereal Technologies, Inc.

Fig. 8 A 3-D viewing kiosk by IntrepidWorld used by a group of scientist to study the picture of the abdominal cavity. Only the sitting viewer has the perfect 3-D picture. The 3-D character view of the two others is slightly distorted. The same is true of the color. *MedSMART*

There is no doubt that autostereoscopic devices are particularly suitable for medical applications where high picture resolution, high quality of 3-D rendition, and the flexibility in the generation of images independent of the source medium (e.g., DVDs, CD-ROMS, Web, or realt time stereoscopic transmission) are as essential as the freedom of viewing without the assistance of external devices (e.g., HMDs.) As a result of these capabilities, autostereoscopic displays may soon become a very popular visualization platform in such fields as trauma and emergency medicine, neurosurgery, microvascular surgery, laparoscopy, reconstructive surgery, etc. Education and training of medical personnel working in the rural areas or at the remote sites is another preeminent arena for vigorous implementation of auto-stereoscopy that, for the first time, will offer the trainees the visual 3-D telepresence access to the training resources of the sophisticated medical training centers (see below). Finally, providing the established telepresence link is bi-directional, the otherwise unavailable medical experts can provide instruction in the execution of complex medical tasks being essentially in personal contact with the students. Thus, 3-D telepresence-based training can provide the solution to the hands-on medical education and skills maintenance that continue to present a major problem both in the rural areas of the developed countries as well as in the less affluent regions of the world [6,27,46]. Other uses, such as distant supervision of scientific experiments, demonstration of experimental protocols, distributed simulation of medical events, etc., can be equally easily envisaged.

DISTANCE MEDICAL OPERATIONS: TELEPRESENCE FROM CRT THROUGH VR TO AUTOSTEREOSCOPY AND BACK

As pointed in our previous publications [1,45,46], medical training expert continues to remain the scarcest resource, and ready access to such expert remains the major problem, particularly in rural and remote regions. Telepresence simplifies access to such expertise and, as we have shown in our recent study [75], telepresence of an expert medical teacher improves execution of critical emergency medicine procedures during training based on the extensive use of human patient simulators. Equally, surgical telepresence results in virtually immediate performance of surgeries and elimination of costly (and often life threatening) delays caused by the need to bring the required expertise to the distant patient or transport of the patient to the expert facility [75,76,77,78].

Fig. 9 A typical, simple telemedicine station allowing teleconsultation, image transmission, and a bi-drectional video communications
Courtsy T.S.Welsh, twelsh@utk.edu

While many aspects of telemedicine, particularly teleconsultation, are rooted in the loosely defined sensation of telepresence [26,79,80,81,82], the most advanced medical approaches are based on the concept of *the operator experiencing real presence at the remote location* [83,84,85]. The narrowing of telepresence definition in medical applications is necessitated by the nature of the ultracomplex surgical tasks that are performed in 3 dimensions, demanding undistorted 3D visualization of the surgical field together with the exact reproduction of other sensory inputs (e.g., haptic feedback) that provide the operating surgeon with the required information [86]. Despite significant technical difficulties, experimental telepresence surgery has been performed in the areas as diverse as stereotaxic biopsies [87], vascular and open abdominal surgery [88,89], and neurosurgery [55,90,91]. However, introduction of telepresence surgery into clinical practice requires solution to many technical and non-technical issues involving ethical, legal, and technological dilemmas.

Some of the pioneering work involving telepresence has been performed by the now defunct Laboratory of Medical Simulation, Modeling and Advanced Research and Training at the University of Michigan.

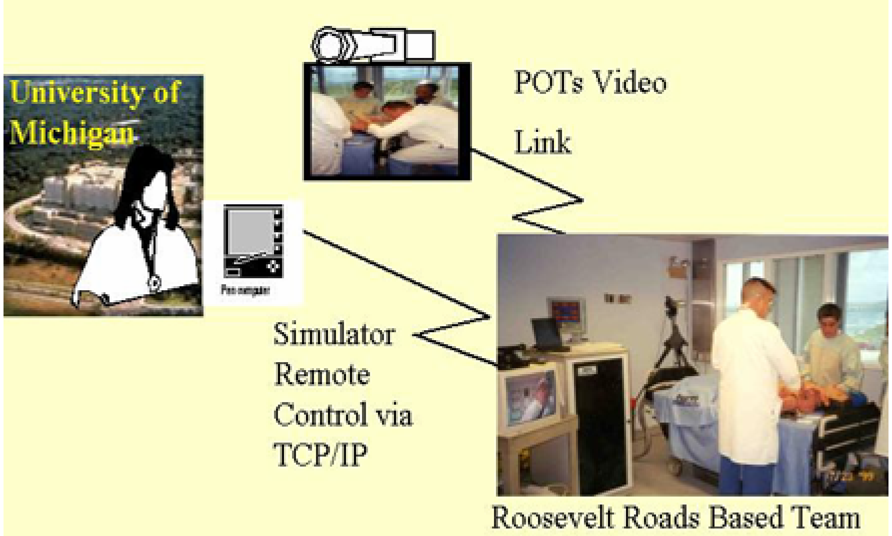

Fig. 10 CRT–based telepresence using standard 56 kbps modem, telephone line and TV display. Participants in Michigan and Roosevelt Roads are in voice/video contact. During this pioneering exercise, the training doctor in Michigan has full remote control of the Human Patient Simulator located in Puerto Rico, instructing the trainees (junior physicians at Roosevelt Roads) in real time. The course resulted in statistically significant improvement of medical readiness among the personnel in Puerto Rico [1,75]. *MRT/MedSMART*

The experiments tested innovative approaches to telepresence based education, training, and research in emergency and trauma medicine. The earliest studies conducted between MSMART and the Roosevelt Roads Naval Hospital and University of Puerto Rico School of Medicine involved CRT-based remote control of a complicated medical training device (Human Patient Simulator – HPS, see fig.4) and telepresence-based training of medical personnel over a very long distance (4500 km) confirmed the usefulness of telepresence as an operational medium in widely distributed medical operations. Importantly, telepresence-based training resulted in a measurable improvement in medical preparedness and confidence of the trained personnel [1,75].

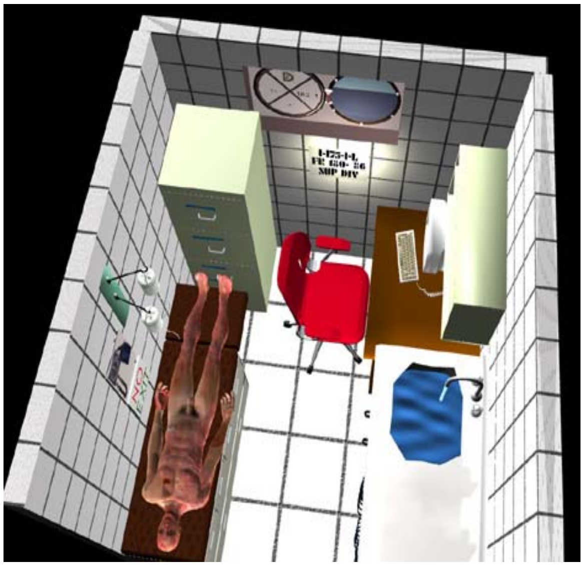

Fig. 11 VR-based medical telepresence system. The immersive VR (CAVE) environment represents the exact environment of the sick bay aboard US Coast 270ft cutter. The bay is capable of virtual movement (pitch and roll) controlled by the CAVE operator. Like in a real ship, sea sickness can be induced by varying the intensity of the "virtual storm." When the virtual sea state reaches 5 (moderate waves), the training personnel begins to roll their bodies to compensate for the "movement of the ship" despite completely stationary floor. The patient is the "first-ever" texture map (VR) of a badly burned survivor.
MRT/MedSMART

Subsequently, a hyper rich, VR-based telepresence portal [6] has been created in which VR-rendered environment surrounds a Human Patient Simulator HPS). While the HPS provided haptic feedback component, the VR shell constituted the telepresence environment. The latter could be easily changed (even during the same training session) from one environmental setting to another.
The "portal" represented by the integration of VR and HPS technologies allowed training under maximally realistic conditions that included environment-correct sounds and, if needed, motions (Fig.5).

While further development of the medical VR-portal concept has been temporarily halted by the lack of financial sponsorship and the subsequent collapse of the laboratory, there is no doubt that further development of "VR-mobile" platforms supporting multiple environments represents an alluring option. The price of the immersive VR units begins to decrease and the requirements for their technical support become less stringent. At the same time, immersive VR permits unique preparation of medical personnel for work under the specific conditions they may encounter during real life operations [6,17], e.g., survivor rescue during winter storm in North Atlantic, airway maintenance in a helicopter subject to turbulence, bouncing ambulance, etc. Presently, the major drawback of such systems is the limited number of participants that can be trained at the same time. Hence, their applicability is limited to sophisticated "just-in-time" scenarios, e.g., medical preparation of special forces units prior to their combat deployment.

The staff of Medical Simulation, Modelling, Advanced Research Training at the University of Michigan can be also credited wth the first experiments that demonstrated the feasibility of autostereoscopic displays (MIRROR) as a functional telepresence platform capable of "bridging" very large distances separating the viewer/operator and the site of the actual activity. The experiments also served as the initial validation of the 3-D portal concept as a foundation to the remote access and operation of the complex training equipment located at a distant site [93].

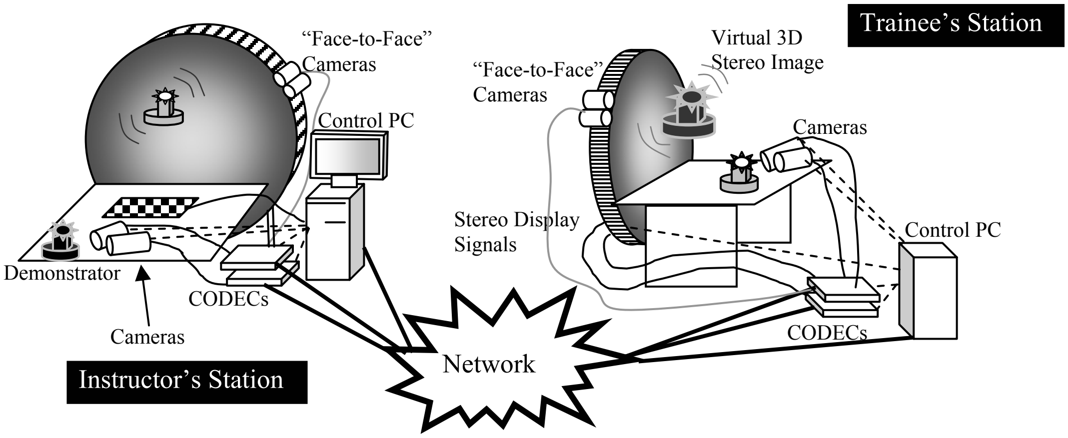

Fig. 12 Schematic illustration of the two training stations and their connections using two MIRROR autostereoscopic displays, two pairs of mini CCD cameras, two pairs of MPEG video codec units, and a high speed data network (Internet2, frame relay, ATM, IP with QoS). The system can be used for realtime transmission of complex 3-D information. It has been used for the first time in unprecedented 3D-based training of medical personnel in emergency and trauma procedures. The distance separating the physician trainer and the students was approximately 1,200 km. See text for details.
Eric Wolf/MRT/MedSMART

The experiments performed in two instances over a distance of approximately 1200 km, both the practical applicability of 3-D telepresence based on autostereoscopy and its preeminent suitability for real-time stereoscopic rendition of distant and constantly changing complex environments. Most importantly in the context of dissemination of 3-D stereoscopy applications as an integral concept of Advanced Distributed Learning (ADL) and Distributed Interactive Simulation (DIS), our qualitative observations clearly indicated that, at the subjective (qualitative) level, 3-D real time telepresence exceeded the "true life" capacity offered by any of the standard 2D telemedical systems available. Still, despite very encouraging initial success, our preliminary results can be viewed only as the indicators of the very large potential capacity of autostereoscopy-based telepresence in medicine that can be confirmed only through rigorous quantitative testing and experimentation conducted over a period of time, with a number of different target audiences representing wide variety of technical sophistication, and using different forms of technology. The latter aspect is particularly important in the context of the wide variety of resource characteristics of the environments in which such technology is used. Thus, at large medical training centers richly endowed with sophisticated technical support, routine use of more sophisticated systems (such as, e.g., that of the IntrepidWorld, Inc.) is far more realistic than in the environments characterized by the paucity of such support, or in which simplicity of deployment and operation are the elements of paramount importance (e.g., front line military operations, humanitarian relief activities, etc.) While we believe that under the latter conditions, devices such as the MIRROR (Ethereal Technologies, Inc.) may be extremely useful, also this assumption is the target of one of our forthcoming experiments in which different forms of 3-D autostereoscopic technology will be evaluated under operational conditions in the field.

Fig. 13 During the pilot experiment in transatlantic distributed, simulation-based training, the medical personnel in L'Aquila, Italy was trained in the management of emergencies using HPS in Ann Arbor and a training expert in Pittsburgh. The figure shows the screen showing the simulator (Laerdal) and the vital signs monitor. The remote trainee doctor can operate the simulator either via the remote control system (the computer monitor), or provide verbal direct instructions to his assistant in An Arbor. The remote managing physician has access to all diagnostic resources he/she would have during a face-to-face encounter with the patient. Despite the missing haptic element, the stress on the managing physician is considerable due to the time constraints, possibility of unpredictable events, and the frequent lack of readily available knowledge. The experiment proved the viability of the approach as a "refresher" platform whose application leads to the rapid enhancement of management skills. Preliminary studies also showed that this form of training decreases subsequent hands-on simulator time. *MedSMART*

Very recently, the staff of MedSMART, Inc (Ann Arbor, MI) who continue the work of the Medical Simulation, Modelling. Advanced Research and Training Laboratory at the University of Michigan, reverted to the original ideas of remote access to specialized training facilities. The demonstration, conducted between Ann Arbor (MI, USA) and L'Aquila (Italy) was based on the concept of distributed resource sharing. The Human Patient Simulator (Laerdal) was located at the training facilities of MedSMART in Ann Arbor and was accessible in real time to the training expert located at the University of Pittsburgh and to the faculty trainees from the Medical School at the University of L'Aquila. Technology developed by MedSMART allowed full remote control of the simulator from all involved locations together with the transmittal of all diagnsosis-relevant

While the demonstration did not provide hard-core scientific data on the efficacy of such training, it proved the practical feasibility of the concept of worldwide access to medical training facilities. It also showed that maximum enhancement of the management skills practiced by using distance-based human patient simulation may translate into shorter hand-on simulator sessions. Large-scale repetition of the experiment is currently planned in the near future. However, it is apparent already now that the implementation of concepts demonstrated during "Laquila Experiment" and described in a greater detail in an earlier paper [94] will allow medical personnel all over the world to use telepresence as the means of participating in the most sophisticated form of medical education and training available today. This is particularly important for the physicians, nurses, and paramedics operating in the world's regions

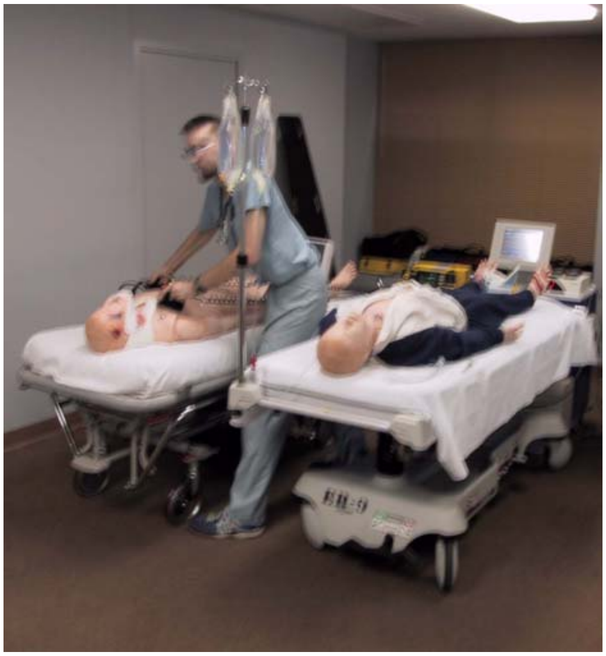

Fig. 14 Mass casualty triage training program for fire-fighters developed by MedSMART. The photo shows the training site of MedSMART in Ann Arbor. The remote trainees have full control of the casualty management either through the interaction with the assistant or remote control of the simulator. The simulators (Laerdal SimMan) represent explosion victims with severe blunt trauma and burns. The pilot program that MedSMART proposes is the example of a large-scale approach to distance learning based on remote access to interactive human patient simulation. Such approach assures simultaneous, rapid training of large numbers of personnel. *MedSMART*

that are characterized either by fiscal austerity or limited access to the latest and most advanced training technology caused by geographical barriers. Large-scale distributed simulation training also offers the essential capability to train large numbers of specialized medical personnel required during post-disaster rescue missions or in the event of either chemical or biological terrorism. Hence, distance-based medical training as demonstrated during the transatlantic and the preceding series of experiments described above may be the only feasible and economically viable way of providing education and refresher enhancement of previously acquired knowledge required under the circumstances of sudden increase in the demand for medical care at pre- and hospital levels. The present escalation in the activity of the armed forces due to their deployments either as parts of relief, international policy enforcement, or even war operations places equally challenging demands on the medical readiness within the military that needs to convert with minimum warning from classical garrison-based medical care to the stringent and often extremely adverse field conditions. We believe that in this arena as well a vigorously implemented program of simulation-based medical distance learning will provide at least a partial solution.

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