

EU-TeleInViVo: An integrated portable telemedicine workstation featuring acquisition, processing and transmission over low-bandwidth lines of 3D ultrasound volume images

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Abstract

A transportable telemedicine workstation has been designed, developed and evaluated for use in isolated areas such as islands, rural areas and crisis situation areas. The EU-TeleInViVo is a custom-made device integrating in one solid case:

- a portable PC with telecommunication capabilities and
- a light, portable 3D ultrasound station.

The system developed has low price, low weight, is transportable and non-radiating. The integrated workstation uses advanced software techniques to acquire 3-dimensional ultrasound data of a patient.

The device is now being tested in different socio-economic conditions and adjusted accordingly to meet needs of developing countries and countries in transition. It currently comes in two versions, one fully portable, self-containing device, and a workstation version (PC attached to an ultrasound scanner for internal hospital use). A dedicated software package has been developed for the needs of this project, based on the InViVo ScanNT software package developed at Fraunhofer IGD. During a teleconsultation both partners, connected over a telecommunications network, are able to share the same interface and perform tasks visible in real-time, even on low bandwidth channels, to both ends on the same data set. The system supports various ways communication, such as Internet, ISDN, common phone lines, GSM, etc.

Keywords: Telemedicine, teleconsultation, 3D free-hand ultrasound, interface sharing, portable workstation.

I. Introduction

Worldwide, people living in rural and remote areas struggle to access timely, quality medical care. Residents of these areas often have substandard access to specialty health care, primarily because specialist physicians are more likely to be located in areas of concentrated population. The EU-TeleInViVo is an applied international and intercontinental telemedicine project, which is proving in practice that telemedicine today can dramatically improve the medical and health care provided to every person anywhere on this planet.

The EU-TeleInViVo has set-up a transportable telemedicine workstation (PC plus telecommunication capabilities) integrated in one case with a lightweight, portable ultrasound station. The system developed has low price, low weight, is transportable, non radiating, and supports a very large range of applications varying from gynecology over pathology to abdominal scans. It is a medical teleconference workstation, able to provide health care service where this is not possible by the usual means (ecological disaster areas, remote rural areas or isolated islands). Since advanced telecommunication means are usually not available or are very expensive in such locations, the system has been designed to work with over simple low bandwidth telephone lines.

Medical care can be provided through this system almost anywhere at anytime. The physicians and health care organizations are therefore able to guarantee high quality care, without the patient having to travel and being carried over long distances. Ultrasound supports a very large range of applications varying from gynecology to cardiological examinations and is currently the only economically and practically affordable imaging modality.

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Previous work included a prototype 3-D ultrasound telemedicine system developed in 1996 based on IGD's software technology and telecommunication modules for use by NATO military peacekeeping forces during the war in Bosnia under field conditions. This system, called the MUSTPAC-1, was tested using satellite communications between Germany, Bosnia, and several sites in the U.S [1].

Members of the EU-TeleInViVo Consortium are:

- IGD-Fraunhofer Institut für Graphische Datenverarbeitung (Co-ordinator), Germany
- CCG-Centro de Computação Gráfica, Portugal
- HUC-Hospitais da Universidade de Coimbra, Portugal
- UNESCO-United Nations Educational, Scientific and Cultural Organization, France
- CATAI-Centro de Alta Tecnologia en Analisis de Imagen, Spain
- DSC-Dr. Staerk Computer Systeme GmbH, Germany
- HPD-Hospital de Ponta Delgada, Portugal
- PIE-Pie Medical BV, Netherlands
- ZGDV-Zentrum für Graphische Datenverarbeitung, Germany

Fraunhofer IGD is the Project Coordinator and along with ZGDV and CCG performs the software development and coordinates the hardware integration. DSC provides the computer spare parts and PIE Medical provides the ultrasound hardware. HUC is the co-ordinator of the medical trials. CATAI is the co-ordinator of the application of EU-TeleInViVo in the Canary Islands (two units) and HPD is a medical user in the Azores Islands (1 unit). UNESCO co-ordinates and monitors the implementation and trial of the EU-TeleInViVo device in Kazakhstan (Almaty and Aralsk) and Uganda (Kampala and Nakaseke).

II. Materials and Methods

The use of advanced technologies allows the workstation to collect 3-dimensional ultrasound data of the patient, i.e. to perform an "echo-tomography". The doctor in the field scans the corresponding part of the patient. By means of the built in flexible telecommunication channel (from a simple phone line and Internet to ISDN, GSM or satellite) the acquired 3D-dataset are transferred to a remote expert, who can be virtually everywhere in the world. After data transmission both doctors are linked online over the telecommunication channel performing "virtual echography" on the 3D-data replicated in each site and viewing identical images on their screens in real-time and practically without lag,

even through narrow-band telecommunication channels.

The solution implemented partly lies on the principle of "scanning the data and not the patient". The main idea is to establish a kind of "information equivalence" between the patient and the representation of that patient in digital form, so that there is little to no loss in examining the patient through the data representation, compared with what would be lost during a direct in-person examination. Given that it is faster and cheaper to ship information around than to ship people (patients and doctors), volumetric representations become compelling as a substitute for the live patient. The point for the radiologist is that the volume representation can be "re-sliced" from any direction one might desire. This avoids the need to acquire a whole new set of images (requiring the patient to make another trip to the hospital), if for some reason the original set leaves 3D relationships ambiguous.

The system is available in two versions. The first is a fixed workstation (Fig. 1) running the EU-TeleInViVo software, which connects to an existing ultrasound scanner, equipped with a magnetic tracking system to measure the spatial position and orientation of the ultrasound probe for the creation of a 3D ultrasound data volume. The second is an integrated portable system, which combines in one solid case an ultrasound board and Intel-based PC parts connected to the ultrasound board via a frame grabber (Figs. 2 & 3).



Fig 1: The fixed workstation installed in Coimbra

The EU-TeleInViVo fixed workstation is based on an ultrasound device already existing in the trial site's radiology or ultrasound department. It extends the existing device first by the capability to acquire 3D ultrasound data sets and second by the necessary hardware for tele-consultations. This expansion is performed with a powerful PC including a frame grabber card for the acquisition of the original ultrasound frames via the ultrasound video output (VHS or SVHS)

and an electromagnetic tracking system for recording the spatial co-ordinates of the ultrasound frames. With these two forms of information - ultrasound frames and their position and orientation in space - 3D ultrasound data sets of a patient can be reconstructed (or as engineers say "re-sampled"). This 3D data set of the patient - a "virtual patient" - is the ultrasound based information equivalent of the real patient and can be transferred to a remote site for medical diagnosis. EU-TeleInViVo stationary workstations are located in well-equipped clinics where the necessity for a portable device is rather small.



Fig. 2: The portable workstation

The portable EU-TeleInViVo workstation consists of two main components: a PC and an ultrasound device integrated in an electronic board at the size of a typical PC main board. The ultrasound system is connected to the PC via several lines: a video cable for connection of the ultrasound video output to the input of a frame grabber, which makes the video frames of the ultrasound device available to the PC. On the other hand, the PC hardware controls the functionality of the ultrasound board via a control line, which uses the RS232 serial interface of each component. The PC is additionally equipped with a spatial motion tracking system (pc-Bird, Ascension Technologies, USA) which can record the spatial position and orientation of the ultrasound probe. These parts allow the acquisition of 3D ultrasound data sets during a patient examination. Having such volumetric data sets enables the physicist to make a diagnosis without the presence of the patient. This data set can be transferred over a communication line integrated in the PC (ISDN, modem, network) to a distant expert who runs another EU-TeleInViVo application and who, after transmission, has all the informa-

tion - the same 3D ultrasound volume data - available at his/her own application. Both can then collaboratively interact on the data and produce a common diagnosis (Fig. 4). With a battery integrated in the power supply of the system, the device can be used without external fuse as a portable emergency system.



Fig 3: The portable workstation being moved



Fig 4: Sharing the "Virtual Patient"

The software part of the EU-TeleInViVo workstation is based on InViVo ScanNT® (Interactive Visualiser for Volume Data) software package [2], which has been developed over several years at Fraunhofer IGD (Fig. 5). It was mainly designed for fast and interactive visualisation of volume data and various extensions have been developed covering several other aspects of medical data visualisation. Together with the 3D ultrasound freehand scan extensions it has become a fully CE certified medical software. The main work in software development for the EU-TeleInViVo workstation is the extension of the existing 3D-ultrasound scan software to a collaborative application. This was achieved by the introduction of several communication

layers in the software structure of the application. The topmost layer is the layer of the InViVo ScanNT® application itself. The next layer below is an adaptation layer that adapts the InViVo software to a communication layer, which hides further details of the communication from the adaptation layer and the application layer. InViVo has a modular structure that can be easily extended by “plugging in” additional modules. The adaptation layer is implemented by an InViVo module, which acts as an interface between the application and the communication layer. The communication layer is based on the HOUCOM software package, developed by Fraunhofer IGD and ZGDV.

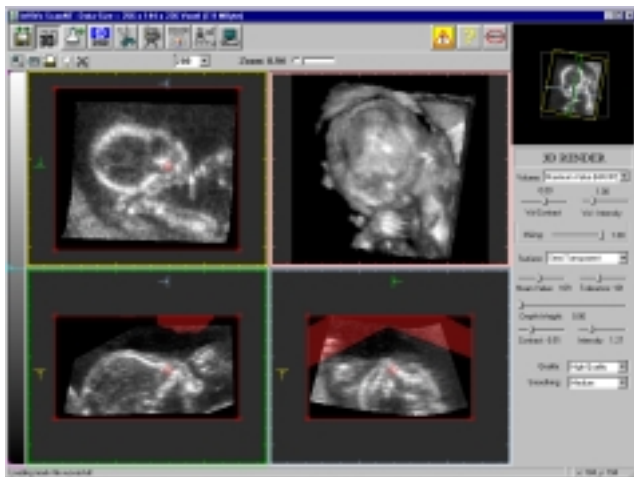


Fig. 5: The user interface of TeleInViVo

Important is the issue of the transmission of large data sets over the (usually low) bandwidth available. A wavelet-based image compression [3] algorithm has been implemented for the size reduction of the image data sets to be transmitted. The compression is lossy, but very efficient in cases where bandwidth is a crucial issue. Otherwise, a loss-less compression can be used for the data transmission. Log-files are implemented to monitor the process of the data transmission and the actions during a session mostly for statistical purposes.

III. Results

The system developed is tested in different socioeconomic conditions and is being adjusted accordingly to meet needs of developing countries and countries in transition. Currently, 7 EU-TeleInViVo portable devices have been manufactured (1 for each partner in Fraunhofer IGD, CATAI, CCG, HPD and Aralsk in Kazakhstan and 2 for the trial sites in Uganda). Fixed EU-TeleInViVo workstations (PC connected to a local ultrasound scanner) are set-up in HUC, CATAI, CCG and Fraunhofer IGD. Another unit is expected to operate soon at the Almaty Diagnostic Centre in Kazakhstan.

The University Hospital in Coimbra is coordinating the pilot medical trials of the EU-TeleInViVo system with the Hospitals of Ponta Delgada (HPD), La Laguna (Tenerife, Spain, monitored by CATAI) and Mulago Hospital (in Kampala, Uganda) and Almaty Diagnostic Centre (in Almaty, Kazakhstan) both monitored by UNESCO. In addition, secondary locations in the Canary Islands, Uganda and Kazakhstan perform local trial sessions with the principal Hospitals in these areas (Fig. 6). This is one of the first telemedicine networks worldwide (Fig. 7), covering such diverse socioeconomic, cultural and environmental domains.



Fig 6: Installations in: Kazakhstan and Uganda (upper row), Portugal and Spain (lower row)

Canary Islands (CATAI) and Coimbra Hospital (HUC): The trials started on 13 July 1999 and ended on 30 May 2000. They included 39 teleconsultations on 89 acquisitions (30 pathological cases, 49 normal), performed on 55 patients, all females, referred to the Department of Obstetrics and Gynecology in Tenerife. From the acquisitions discussed, 7 were transmitted to HUC via Internet (average transmission time 4' 10"), the rest via ISDN (average transmission time 5' 38"). 43 of them were transmitted on-line (with the physicians from HUC and CATAI on both sides conducting the discussion at the same time) and 46 off-line (transmission was performed by technicians and discussion between physicians followed at another time). The teleconsultation sessions averaged a time of 16' 55", however varying substantially between 5 and 40 minutes, depending on the severity of the case.

When the diagnosis proposed by the reading site was compared with the clinical pathological follow-up or the previous diagnostic of the patient, 96% specificity, 92% sensitivity and an accuracy of 93% have been reported. These are considered to be excellent results for a new, innovative system in its introduction phase.

Azores Islands (HPD) and Coimbra Hospital (HUC): Since the beginning of the trials between HPD and

Coimbra on 23 November 1999 and until the end of May 2000, 43 patients have been examined during 112 (9 normal cases, 99 pathological, 4 excluded due to poor quality) acquisitions. Almost all trials are done using ISDN (2' 11" average transmission time, 2 data sets were sent using Internet) during 25 teleconsultation sessions (57 acquisitions transmitted and discussed on-line, 55 off-line) taking an average of only 5' 15" for the discussion of each case. The accuracy of the remote diagnoses is 77%, with sensitivity of 88% and specificity of 38%.

In addition, UNESCO is monitoring the pilot implementation of the EU-TeleInViVo Project, in collaboration with Fraunhofer IGD, CCG, ZGDV and HUC, at the following locations:

Mulago Hospital, Kampala, and UNESCO ITU Telecentre and Nakaseke Hospital, Nakaseke, Uganda:

The main mission of the implementation of EU-TeleInViVo in Uganda is to improve the healthcare services in remote areas in African countries and to test and adapt the EU-TeleInViVo device to specific diagnostic needs in African countries.

Mulago Hospital is the major Clinic in Uganda's capital city Kampala and is located within the campus of the Mulago Medical School. Two doctors in the Mulago Hospital conduct medical examination of patients and issue diagnoses using EU-TeleInViVo. In case of problems and difficulties the doctors request advice from the Coimbra Hospital. One EU-TeleInViVo portable device is installed in Mulago Hospital and a second at the Nakaseke Hospital, a rural clinic 65-km outside Kampala. Mulago Hospital conducts trials with Coimbra (HUC) and serves as an intermediate point between the Nakaseke Hospital and Coimbra.

Since the first trial on March 23, 2000, 10 acquisitions (all associated with pathological findings) from 7 patients have been discussed between HUC and Mulago Hospital, using Internet during 9 sessions (all transmissions off-line). Average time for data transmission for each data set is 16 min and a teleconsultation session might take well over 5 hours (with average discussion time of about 30 min). From these first tests, the accuracy of the remote diagnoses has been calculated to be 82%, with sensitivity of 89% and specificity of 50%.

Almaty Diagnostic Centre, Almaty, Kazakhstan and Central Regional Hospital, Aralsk, Kazakhstan: The main mission of the implementation of EU-TeleInViVo in Kazakhstan is to improve the healthcare services in remote calamity areas and to test and adapt the EU-TeleInViVo device to specific diagnostic needs in them.

One EU-TeleInViVo fixed workstation is installed at the Almaty Diagnostic Centre attached to one of the local ultrasound scanners. A portable device is placed in the

Aralsk Hospital, which is located near the Aral Sea, an area of a great ecological disaster, due to the extended and continuous drainage of the Sea. Two doctors in Aralsk conduct medical examination of patients and issue diagnoses using EU-TeleInViVo. If necessary, the data are transmitted to the Almaty Diagnostic Centre. Two physicians evaluate these diagnoses in Almaty. In case of disagreement or difficulties, the doctors in Almaty translate the diagnoses-in-question to English and request the advice of HUC. Apart from validating diagnoses for the Aralsk Hospital, the doctors in Almaty also perform an independent screening of local patients and validate the diagnoses with HUC.



Fig 7: The geographical distribution of TeleInViVo stations

Although sessions between Almaty and Coimbra started only on May 15, 2000, 12 acquisitions (all pathological cases, sent on-line via Internet) have been discussed from 7 patients during 3 trial sessions until the end of June 2000. Mean transmission time of 4MB volumes was 15 min and the discussion of each case averaged 7' 45". The accuracy of the remote diagnoses with TeleInViVo was calculated to be about 87% with a sensitivity of 93% (no specificity calculated since no normal cases were discussed).

For figures and photos regarding the EU-TeleInViVo Project, one can refer to the Project's Web pages:

<http://www.igd.fhg.de/teleinvivo>,

<http://www.igd.fhg.de/igd-a7/images-video/teleinvivo/teleinvivo.html>

IV. Discussion

The recent advances in Information Technology allow today the transmission of images, video, voice and data from remote locations to a centre of expertise. The EU-TeleInViVo system has been designed to provide high-tech diagnostic applications based on telecommunications technology scalable from simple telephone lines and Internet connections to ISDN, GSM

and satellite systems. It makes also optimal use of today's powerful but still low cost and robust PC systems and the impressive advances in ultrasound technology with the dramatic reduction of the size of modern ultrasound scanners and the simultaneous spectacular improvement of their capabilities.

Apart from being a telemedicine device, the EU-TeleInViVo brings to these remote areas the revolutionary advantages of 3D ultrasound. This is a new emerging technique, which is maximally contributing to the recent uprising of this imaging modality, suppressed during the past years by other (but expensive, not readily available and sometimes invasive) imaging methods such as CT, MRI or nuclear medicine. Hundreds teleconsultation sessions have been performed until now between HUC and the rest of the trial sites, as well as within these sites themselves, proving that the system is reliable, accurate and allows detailed and correct diagnoses to be carried out from a distance.

Despite this multitude of technologies and concepts integrated in one single compact device, the users who are participating in the initial implementation phase have found the system quite easy to learn and use. The EU-TeleInViVo is an existing and operating device since the early 1999. Its implementation today extends on three continents (Europe, West Africa and Central Asia) and spans over six time zones. Its operation has been tested in well-developed areas in Europe and major cities elsewhere (e.g., Almaty in Kazakhstan), as well as in remote locations such as islands (Canary and Azores) and poor regions under development (Uganda, Aralsk in Kazakhstan).

Tangible benefits from the project's implementation (with direct monetary value) are:

- savings from reduced travel costs of specialists engaged in tele-consultation sessions;
- savings from reduced travel costs of patients;
- savings on hospital accommodation of patients that can be diagnosed remotely;
- savings on hospital processing costs of patients that can be diagnosed remotely;
- savings due to provision of health care in remote clinics or mobile health units versus expansion of urban or regional hospitals (i.e. the difference in the construction and running costs of facilities).

Intangible benefits (with a definite perceived value but with actual value not directly able to be determined) include:

- better opportunity for consultations and second opinions resulting in avoidance of delays or costly mistakes;

- reduced waiting time and transfer delays which can in some cases prevent serious complications;
- reduced loss of income for patients who need not travel;
- reduced expenses for family members who might otherwise accompany the patient
- improved effectiveness of specialists: broader reach with more patients being seen due to reduced travel;
- improved overall health-care management, both internally and externally;
- increased collegial support to medical personnel working in remote and isolated areas, resulting in increased job satisfaction;
- improved teaching and learning possibilities and opportunities.

Looking further in the indirect benefits from a large-scale implementation of the EU-TeleInViVo project one can easily list:

- increased revenues to equipment providers, hospitals, telecommunication services providers and the like;
- enabling specialist and technical personnel to increase their knowledge and qualifications;
- facilitating decentralization of care and distribution of competence;
- promoting maximization of scarce central resources (e.g. specialists, diagnostics apparatus and computers).

The EU-TeleInViVo is therefore a glorious example of how the recent advances in medical imaging, with the help of advanced telecommunications, can be applied to provide better health care and diagnosis, improve patient handling, reduce health service costs and save lives.

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