

Interactive Telemedical Networks via Satellite for Improvement of Medical Diagnosis and Therapy

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Abstract—By the application of modern information technologies simulation, navigation and interactive communication have been realized for an improvement of medical diagnosis and therapy. Using a specially developed high-end software communication system (WinVicos) and respective hardware (WoTeSa) various telemedical applications like intraoperative teleconsultation and teleteaching have been enabled. WinVicos has been designed for medical applications in different EU-projects e.g. GALENOS - Generic Advanced Low-cost trans-European Network Over Satellite, MEDASHIP - Medical Assistance for Ships, EMISPHER - Euro-Mediterranean Internet-Satellite Platform for Health, medical Education and Research, and the ESA-project DELTASS - Disaster Emergency Logistic Telemedicine Advanced Satellites Systems, etc. Laser induced fluorescence diagnosis and photodynamic therapy have improved the diagnosis and therapy of cancer.

Index Terms— telepresence, telemedicine, satellite-based networks, photodynamic therapy.

A. SATELLITE NETWORKS

I. INTRODUCTION

The Surgical Research Unit "OP 2000" (Operating Room of the Future) of the Max-Delbrueck-Center for Molecular Medicine (MDC) and the Robert-Roessle-Clinic, Academic Hospital Charité, University Medicine Berlin has developed and tested several modern interactive telecommunication components in close cooperation with worldwide leading academic and non-academic institutions as well as industrial partners [1-3]. Modern laser, video-, communication- and computer-technologies have enabled the realisation of extended competence networks, which allow students and young and/or inexperienced physicians, although at remote locations, to be trained by experts in a highly interactive way. These training and education possibilities in such competence networks may play a key role in ensuring the

quality of medical care in the future.

II. MATERIAL AND METHODS

One of the key modules of the concept OP2000 (Operating room of the future) is the interactive video communication software WinVicos (Wavelet-based interactive Video Communication system) for telemedical applications, training of the physicians in a distributed environment, teleconsultation and second opinion. It has been especially developed for applications via satellite, wireless and terrestrial-based networks (in cooperation with EUTELSAT, Paris (France) and Ing-Buero Vedat Guerkan, Alsbach (Germany)).

WinVicos is a high-end, interactive video communication system in OP 2000 providing real-time video, still-images and audio transmission. The system has been designed with interactive medical applications in mind, e.g. teleconsultation, second opinion, teleteaching, etc. The video conference partners can see each other, talk, exchange images and even use remote-pointers to point at certain details.

The WinVicos main user dialog is sufficient for the standard actions of the user. This includes calling the video conference partner (address book), changing bit-rate, frame-rate, video-size, as well as speaker- and microphone-volumes. The menu also offers more possibilities: showing the document camera, sending documents, configuration of the video-inputs, etc.

Besides the main user interface up to four video-windows can be shown on the user's desktop. The user can also alter the size of the Self-View window sent to the connected partner, e.g. 176x144 pixels, 384x288 pixels etc. A special size designed for medical purposes is the endoscopy-mode. In that mode the user sees the entire video-input in the Self-View-window. Here he can select via dragging and resizing a box, which part of the image will be transmitted in full resolution to the connected partner. This is especially useful when transmitting endoscopy images.

By using a special video compression hardware (Quincunx by „Vidisys“) two video streams can be combined into one video signal and transmitted by the WinVicos system. Thus the transmission of stereoscopic or even two different video sources using the same bandwidth is possible. For example during telesonographic

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Fig. 1: WinVicos user's desktop

examinations the output of a laparoscope or an endoscope together with an ultrasound video stream can be transmitted simultaneously. This multi-video streaming makes teleconsultations more flexible and user-friendly (Fig. 1).

For video compression WinVicos employs a hybrid speed-optimised wavelet-codec. This codec is based on the concepts of Partition, Aggregation and Conditional Coding, PACC (patent DE 197 34 542 A1, "Deutsche Telekom", Germany). The wavelet-transformation-based PACC codec processes a whole frame at once, without splitting the frames in 8x8 blocks. Therefore the wavelet-codec has no blocking artefacts like the DCT-based H.261 and MPEG-4 codecs. Thus, the image quality is much better at a small bandwidth and there is no need for a de-blocking filter. In order to reduce the temporal redundancies in a video sequence only the difference from one frame to the next is coded. There is no complex motion estimation and compensation. A reason for such a simplification is to use small bandwidth transmission channels of up to 1 Mbit/s and to use the codec mainly for typical medical applications, i.e. not for fast lateral motions. The PACC codec is a software-only codec, hence improvements on the algorithm are much easier to implement than on a hardware-based system.

Audio compression is done by the MPEG Layer 3 compression algorithm – mp3 – developed by the German Fraunhofer Institute.

The hardware requirements of a WoTeSa (Workstation for Telemedical Applications via Satellite) are met by an IBM-compatible PC with Pentium® IV processors (≥ 3 GHz), 512 Mbytes RAM, an Osprey Video-capture card (Osprey 100 or Osprey 500); a camera with F-BAS and S-Video output as live source (e.g. Canon VC-C4); a second camera as document camera for transmission of non-digital images; standard headset with microphone and small loudspeakers. The different video inputs of the Osprey video capture card can be directly connected to the different medical equipment. WoTeSa serves quasi as a medical video hub.

III. TELEMEDICAL NETWORKS

OP 2000 has been active partner in several telemedical networks using satellite-based technology for the communication between European centres of excellence [4-5]. Two projects will be described in detail in the following.

A. MEDASHIP – *Medical Assistance for Ships*

(Duration: 4/2002 – 12/2003, financially supported by the European Union, EU; in cooperation with: D'Appolonia S.p.A. (I), Eutelsat (F), NCSR Demokritos (Gr), Avienda (UK)).

In **MEDASHIP** an integrated system for telemedical consultations on board of ships was set up and evaluated. Such a system should allow an improved medical care for passengers and crew members, probably in a more cost-effective way. In case of medical emergency on board of ships, the usual procedure is that the medical staff contacts the closest support centre via radio and asks for help and advice. However, the medical information that can be transmitted during a radio consultation is clearly too limited for the experts to give valuable advice. Often it is then decided to meet up with a rescue team (e.g. in a helicopter) to have the patient transported to an expert centre for further diagnosis and therapy. This is often accompanied by a

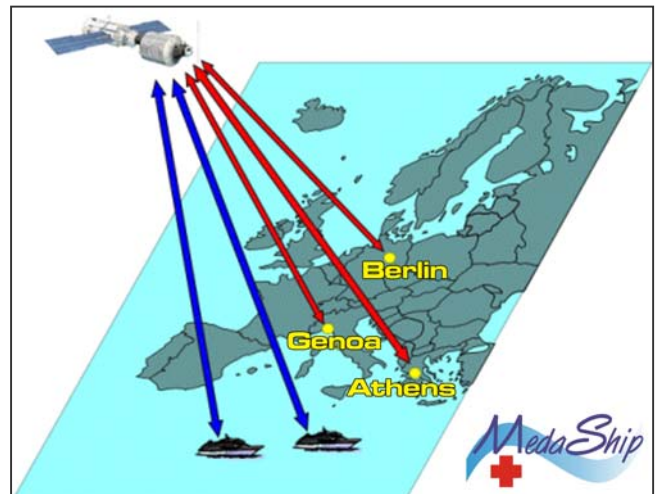


Fig. 2: Satellite-based communication between ships and expert centres in MEDASHIP

Fig. 3: Teleconsultation in the MEDASHIP network



forced deviation from the planned route, causing substantial extra costs. During the pilot phase, the ships are equipped with an ultrasound medical system and an electrocardiograph (12 channels), interfaced to WoTeSa / WinVicos, as well as a satellite terminal (VSAT) on a stabilised platform (e.g. stabilisation of the antenna and satellite tracking). In the course of the project also the integration of existing terrestrial networks is in tests and used to involve other centres of excellence. In the project a cost analysis is performed, combined with an evaluation of the availability and value of the medical teleconsultations. Forensic aspects are analysed and juridical protocols developed.

B. EMISPHER – *Euro-Mediterranean Internet-Satellite Platform for Health, medical Education and Research*

(Duration: 9/2002 – 9/2004, financially supported by the European Union, EU; in cooperation with: Eutelsat (F), Telemedicine Technologies S.A. (F), IsMett (I), ANDS (AG), EHTEL (B), University of Cyprus (CY), Ain Shams University and Egyptian Ministry for Health and Population (EG), CICE (F), IMA (F), SEPELM (F), FORTH (GR), Casablanca Medical Faculty (MO), Istanbul Medical Faculty (TU), Faculty of Medicine of Tunis (TN), NCSR Demokritos (GR)).

The **EMISPHER** project is putting together the cutting-edge European technology, developed in the frame of previous projects, to provide an integrated Internet and Satellite platform, dedicated to health applications and covering most of the countries of the Euro-Mediterranean area (Italy, France, Greece, Turkey, Egypt, Morocco, Algeria, Tunisia and Cyprus). Mature satellite technologies can be cost-effective if combined with appropriate internet application services to guarantee the required bandwidth when and where it is required. Thus, the required quality of service (response time, quality of video transmissions and transfer of large medical records, synchronisation of databases etc.) is achieved.

Three priority applications are being developed:

- e-learning applications to develop the concept of a cross-Mediterranean Virtual Medical University (with Teletraining facilities); establish a permanent medical and scientific link
- real-time telemedicine applications for remote expertise and second opinion and foster cross-Mediterranean cooperation at expert level and for research
- shared management of the medical assistance file in case of repatriation of travellers and expatriates

A network of 10 expert centres is now in preparation which permanently interconnects the medical centres and creates a *contribution network* able to foster the widest cooperation in the long term. We use bi-directional satellite terminals enabling a permanent mesh connection between the various regional areas of up to 2 Mbps. It is the intention of the project to extend this network to up to 25 centres, on the basis of public regional or private initiatives.

These centres will work as "hub" centres for a wider network, built on the existing cooperation in the medical assistance area (*distribution network*). These centres will be interconnected, enabling the exchange of multimedia patient record elements and the electronic management of the workflow in relation with medically assisted repatriations. By combining these two networks intimately, a sustainable model for telemedical services in the Euro-Mediterranean area will be evaluated very soon.

C. *Telepresence by Remote-Control of Equipment*

Experience has shown that the goals of telemedicine can only be achieved adequately when a high degree of interactivity is implemented. A very high degree of interactivity is called telepresence and includes e.g. remote control of various medical equipment, sufficient transmission quality for remote expertise (second opinion), telerouting, etc.

For example the BERTA software module (Bi-directional Extended Rendering for Telemedical Applications; in collaboration with the Computer Graphics Group of the Institute for Computer Science, Technical University Berlin)



Fig. 4: Centres of Excellence in the EMISPHER network

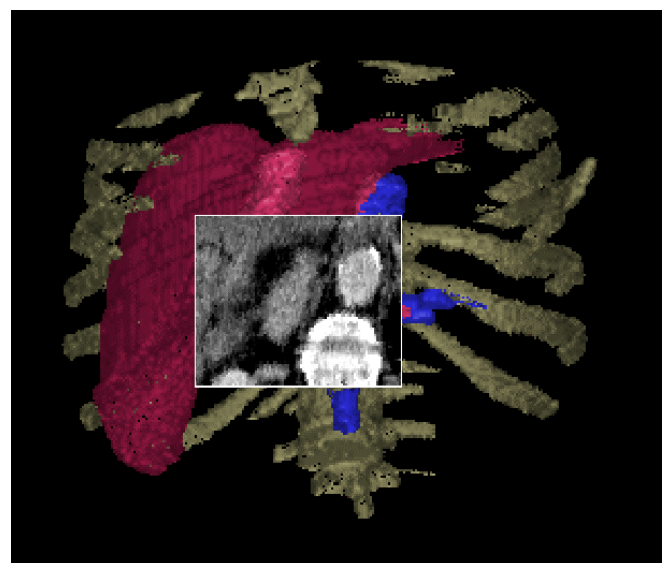


Fig. 5: 3D reconstruction of CT data (BERTA)



Fig. 6: Telepathological workplace

was designed to enable fast 3D visualization of CT and MRT patient data (Fig. 5). By transmission of the control signals with a COM-server the user at the remote side is able to rotate the 3D reconstruction of the patient data in real-time using a special joystick. The output of the graphics computer can be transmitted to him as live-3D images to achieve a teleradiological application.

A telepathological workplace has been realized using a fully motorized microscope (Carl Zeiss) (Fig. 6). All functions of the microscope can be controlled by a PC-software. By using a remote-control software the local PC connected to the microscope can be accessed from remote via a TCP/IP connection. The image of a 3-CCD microscope camera (Ikegami) is transmitted to the remote pathologist at a quality sufficient for remote diagnosis. For transmission ISDN, ATM and satellite networks can be used. Thus the rapid section diagnostics at the Robert-Roessle-Clinic can be realized by this telepathological link.

IV. CONCLUSION

Telemedical networks will play a decisive role in assuring the quality of care. Such networks will probably have an influence on diagnosis and therapy planning and enable a cost effective use of resources. Last but not least networks will be used for education and training of physicians by interactive teleteaching and teletraining.

B. LASER-INDUCED FLUORESCENCE DIAGNOSIS AND PHOTODYNAMIC THERAPY

In 1900 it was discovered that certain per se non-toxic fluorescing dyes develop a cytotoxic property after illumination with light. Basis for this cytotoxicity is a photochemical process in which the absorption of a photon brings the dye into an energetically excited triplet state from which energy is transferred to an oxygen which can as highly reactive singlet-oxygen block a number of cell-

physiological processes. The possible clinical use of this so-called photodynamic therapy (PDT) depends on the selective accumulation of specific photosensitizers (PS) in tumor tissue compared to normal tissue [6]. For a more selective accumulation PS with carrier systems on the basis of human serum albumine and methoxy-polyethylene-glycol have been developed [7].

The application of multi-photon (MP-) excitation of PS in Laser-induced fluorescence diagnosis (LIFD) and PDT of malignant tumours exhibits several advantages compared to the classical single-photon (SP-) excitation:

- The penetration depth of the light into the tissue is much deeper because of the used longer wavelength (near infrared spectral range: 700-1100 nm);
- The activated tissue area can be much better confined due to the intrinsic confocal effect (required photon density);
- The unwanted photobleaching of the PS is in part strongly reduced;
- Preliminary experiments show that in certain cases other mechanisms have to be responsible for the energy transfer (anoxic type I), so that in case of hypoxic or anoxic tumour areas MP-PDT is promising.

In a first project phase (Duration: 10/2002 – 3/2004, financially supported by the Senate Administration for Economy, Work and Women, Berlin; in cooperation with: Max-Born-Institute, Berlin, Laser- and Medicine-Technology, Berlin) different laser irradiation workplaces with cw-radiation at 800 nm and pulsed radiation with pulse width 130 fs, repetition rate 82 MHz and a wavelength range of 770-820 nm were set up. The following laser irradiation workplace (Fig. 7) consists of a Ti:sapphire pulse laser (Spectra Physics) pumped by an argon ion laser. For monitoring the wavelength and pulse duration of the generated laser pulses a fiber spectrometer is used.

For the clinical investigations of tissue samples a surgical microscope (Leica) has been equipped with two infrared-sensitive CCD-cameras (Ikegami) (Fig. 8). The samples can be irradiated with a cw-diode-laser emitting at 800 nm. The

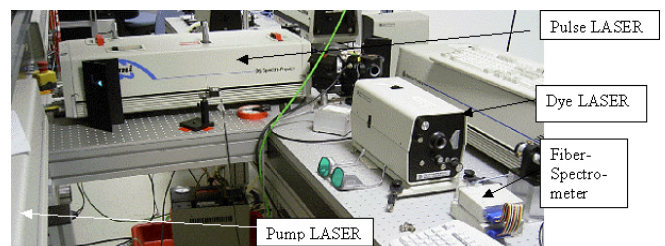


Fig. 7: Laser setup for LIFD and PDT

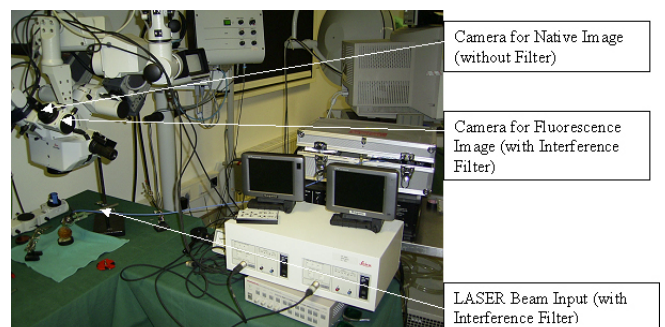


Fig. 8: Surgical microscope for LIFD

first camera detects directly the native image of the sample while the second camera detects the fluorescence image through an interference filter suppressing the exciting laser light.

To treat cell-biological questions a workplace for single-photon detection and spatially resolved spectroscopy has been set up (Fig. 9). On an inverted microscope (Carl Zeiss) samples can be irradiated by cw-laser light. Spatially resolved spectra between 400-1000 nm at a wavelength resolution of approx. 6 nm can be measured by a Spectra Cube system (Applied Spectral Imaging). Weakly fluorescing samples can be detected at the same microscope by a single-photon-counting camera (Hamamatsu, sensitivity 10^{-7} lux).

Fig. 10 shows results of a phantom made of textile fibers treated with porphyrin-derivative as PS irradiated by 488 nm laser light. The upper left native image shows the image like it would appear by observation through the ocular of the microscope. The lower left fluorescence image shows the image after enhancing the pixels of the image which exhibit an intensity at wavelength higher than the excitation wavelength. The right images show the spectra of two pixels of the image (upper right from a fluorescing area, lower right from a non-fluorescing area). The peak at 488 nm corresponds to the laser excitation while the intensity between 580 and 740 nm corresponds to the fluorescence of the PS.

To supply the different laser irradiation workplaces which can also be located in the operation room with the pulsed laser radiation, a suitable system for the transport of the radiation over a distance of 20 m has to be developed. The main problem is the broadening of the pulse during propagation through a conventional glass fiber resulting from the dispersion of the fiber material. The approach to compensate this broadening by pulse stretchers and compressors leads to intensity losses which might prevent the achievement of the required intensity for MP-excitation.

Alternatively newly developed hollow photonic crystal fibers could be used where the light does not propagate through a solid core but through a hollow photonic crystal structure.

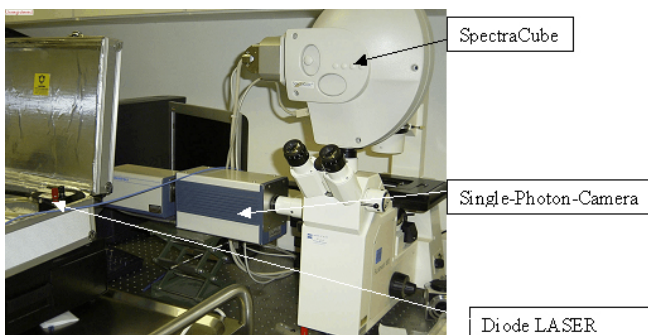


Fig. 9: Cell-biological workplace for single-photon counting and spatially resolved spectroscopy

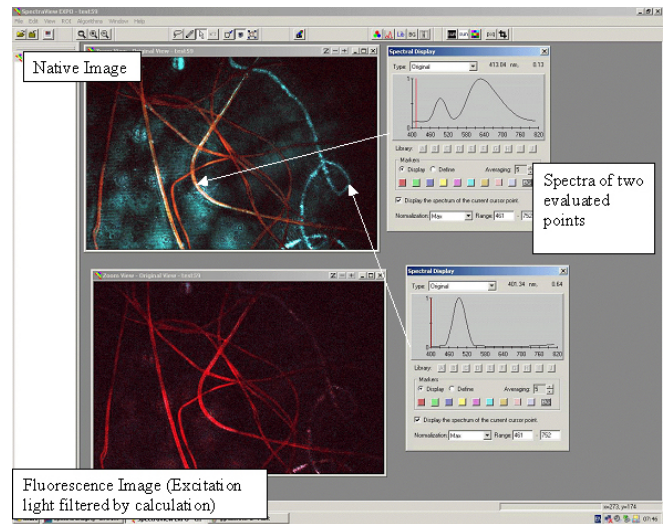


Fig. 10: Identification of fluorescing and non-fluorescing areas of a phantom made of textile fibers treated with porphyrin-derivative irradiated by 488 nm laser light with the Spectra Cube system

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