Telemicroscopy: The First Step in Telemedicine Foundation in Yugoslavia

BRANIMIR RELJIN [1], PETAR SPASIC [2], IVICA MILOSAVLJEVIC [2],
PAVLE KOSTIC [1], SLAVIŠA MIJUŠKOVIC[3]
[1] Faculty of Electrical Engineering, University of Belgrade, Bulevar Kralja Aleksandra 73

[2] Institute for Pathology and Forensic Medicine, Military Medical Academy, Belgrade
[3] Data Control Co., Belgrade
YUGOSLAVIA

Abstract: - The main characteristics and benefits of the telemedicine (TM), as a new concept based on three significant aspects of human activities: medicine, electonics and telecommunications, are exposed. The first Yugoslav telemedical-telemicroscopy network, built in 1997, is described and general guidelines for forming TM network are introduced. By an interactive connection of remote medical centers, which is the fundament of the telemedicine, the highest-level medical services are enabled for all participants irrespective of the geographic distance. Moreover, the global financial saving is obtained, since the traveling of doctors and their patients is unnecessary and the occupancy of the specialized healthcare centers is minimized. TM services will be of great importance not only for medical centers, which need not possess complete highest-level diagnostic equipment as well as top-level specialists, but also for small clinics and ambulances, having in mind both highest-level medical services and low-cost devices necessary for it.

Key-Words: - Telemedicine, telemicroscopy, digital image processing

1 Introduction

In the recent years there has been a growing interest in the use of new technologies (electronics, telecommunications and computers) for medical purposes. Actual technology permits to develop and implement a new medical service called *telemedicine* (TM) [1]. Telemedicine may be defined in several ways. We have found the following definition useful: “Telemedicine is the interactive audiovisual (multimedial) communication between healthcare providers and their patients or other healthcare staff using systems which allow ready access to expert advice and patient information, regardless of a geographic distance.” Thus, a main goal of telemedicine has been to eliminate traveling for patients and specialists, retaining high quality of medical services irrespective of the locations. Also, using telemedical capabilities the hospital need not to have all specialists but offer all top-medical services. Countries with rural areas (e.g., Canada, Norway, Australia, etc.) have been especially active in the field of telemedicine. In Yugoslavia the challenge of this attractive field is also in the focus of several research centers. The segment of telemedicine, named *telemicroscopy* ~~t~~elepathology, has been built in Yugoslavia in 1997, connecting three medical centers: Belgrade, Nish, and Sremska Kamenica. From the very beginning this network is in active use, performing permanent contacts and exchanges of information/diagnosis between these centers. The existing network could be used as a core network for further expansion - for the ‘pure’ telemedical network in Yugoslavia.

This paper is organized as follows. In Section 2 the brief history of telemedicine is exposed. Section 3 explains, in short, the main objectives of telemedicine while in Section 4 the first telemicroscopy network in Yugoslavia is described. Some reflections about future trends in telemedicine in Yugoslavia are noted in Sect. 5.

2 Brief History of Telemedicine

Telemedicine is not a new concept. Healthcare professionals have been using the telephone to carry out their services for years. By upgrading telephone equipment an electric stethoscope was invented in 1900, permitting telediagnosis over telephone lines. By discovering X-rays in 1895 (W. K. Roentgen) a nondestructive examination of the interior of bodies was possible, opening the new area in medicine and diagnosis named *radiology.* In 1907 the first transfer of the still image is obtained in the direction Paris-Lion-Bordo, using telephone lines. The main principle, almost unchanged, known as telephoto is used up today. In addition, research efforts have begun utilizing more of the telecommunication repertoire, including speech, text, data, picture, and video communication. The first serious results in the field of TM are obtained at the end of 1950s, when independent experiments in the field of telepsychyatrics (Dr Cecil Wittson, University of Nebraska, USA) and teleradiology (Dr Albert Jutas, Montreal, Canada) were performed. After the mid-1960s, the computers become more and more multi-purpose powerful engines. The computer could transport and store the data, as well as route and retrieve them, much more quickly and efficiently than people could, and with less chance of losing them. In the next twenty years the global development and improvement of electronic devices, computers and telecommunication equipments led to the growth of the telemedicine, too.

The first 'real' use of telemedicine dates back to 1969, in the USA, when X-ray images were transmitted across telephone lines. This concept was based on the interactive transfer of the video signals (IATV). In the mid-1970 in the USA 17 different IATV systems were in use. However, only the system built in the Memorial University of Newfoundland is in use even today because this system is based on the modern TM principles: simplex video, duplex audio and interactive access using shared whiteboard. In the last decade the main researchers' efforts were concentrated to the remote consultations using different videoconferencing techniques and data compression. Besides technical-technological problems in the TM realization different administrative-ethical problems arise, too as: security, privacy, and data protection. Note that some of these problems could be only of the local importance. For instance, in the USA different countries have different regulatives determining the private medical practice, so, the medical doctor must registrate his practice in all countries connected to the TM network.

The European telemedicine pioneers are the Norwegians. In 1988, Norwegian Telecom Research started a project on telemedicine in North Norway [2]-[4]. This area was chosen partly because this region is characterized by sparsely populated communities spread over vast distances, and there is a lack of qualified personnel in certain sectors of the health service. The main purpose of this project was to connect the hospitals from the far north of the country that were not equipped with appropriate medical departments, to the departments of other hospitals and university clinics, in order to implement EX-TEMPORE diagnostics services using a variety of networks, ranging from ordinary telephone network to specialized networks as ISDN (*Integrated Services Digital Network*), broadband ISDN (B-ISDN), and satellite connections enabling the adequate data transfer rate of audio/video signals. Today, their telediagnostic network consists of three telemicroscopic diagnostics centers connected with five hospitals from the north of the country – users of telediagnostic services. In their publications in the last two years they expressed very positive opinions about the quality and reliability of such a diagnostic approach. With recent computer technology progress, in last five years, the similar telemedicine centers in Europe have been founded, most of them in Germany, Italy [5], and Switzerland, while in Greece, the great interest in the telemedicine exists, too, due to the geographic structure of this country.

The health committee in European Unity started the project EUROMED, in 1955, dedicated to forming the global telemedical information society. In this project 20 fundamental elements necessary for obtaining efficient functionality of the system were defined. Note that within EUROMED Project two basic components are being developed in Yugoslavia – the *Distributed Information System* and the *System for Manipulation and Processing of 3D Medical Models* [6],[7]. Independently of these activities the segment of TM, named *telemicroscopy-telepathology*, has been built in Yugoslavia in 1997, connecting three medical centers: Belgrade, Nish, and Sremska Kamenica. The existing network could be used as a core network for further expansion - for the 'pure' telemedicine network in Yugoslavia.

3 The Main Objectives of Telemedicine

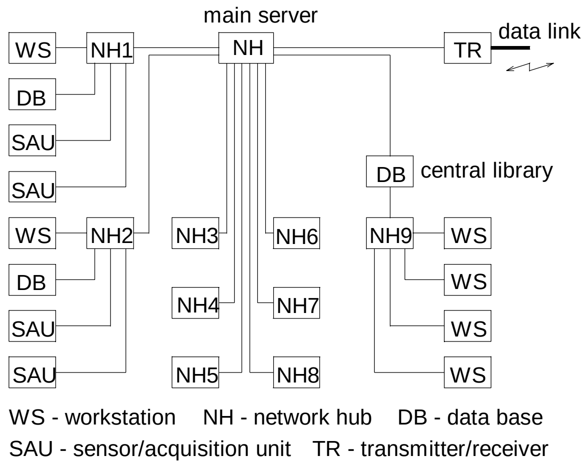
Modern medicine is strongly related to technology, electronics and computers. Different sensors permit us to acquire different data from the human body, and convert them to electrical signals. Using computers different signal processing are available. Finally, we can store signals in different memorizing media and/or visualize signals over different displays. In addition, telecommunications hardware and software enable us to transmit data over distance, connecting a number of medical centers. Different signals are obtained using medical sensors. From the technical point of view we can classify these signals as one-dimensional (1D) signals, two-dimensional (2D) and multidimensional. As 1D signals we consider different monitoring signals (ECG, EEG, blood pressure, body temperature, inspiring- and expiring times in pulmonal ventilation, etc.), 2D signals are those corresponding to different still images obtained from 2D sensors in microscopy, ophthalmology, radiology, cardiology, etc. Three-dimensional (3D) visualization of human organs can be obtained from MRI or CT sliced images using VRML (Virtual Reality Modeling Language). This standard is in hard expansion and today it is applicable not only to the (expensive) workstations but also to the widespread personal computers. Also, using a sequence of still images we can produce a video (moving) signal describing the real-time work of any human organ under consideration.

Although telemedicine concept is very simple: we acquire medical data from appropriate devices and transfer them to other centers, its realization is very difficult due to very hard technical requirements. The general requirements for a digital imagery environment in medicine were determined through experiments. Note that existing technology has a great influence on the digital image formatting. For instance, the display workstations generally provide contrast (gray-scale) resolution of 12 bits (4096 levels), while computer storage capability is 16 or 32-bit quantities. The X-ray film has excellent resolution (fine grain) and wide contrast ratio. However, although the actual plane film scanners reach high-spatial-contrast resolution (4.096 x 5.120 pixels, 16 bits per pixel), the X-ray film (as the primary image source) may be under- or overexposed and must be reshooted, spending time and money. The digital image can be obtained directly from the X-ray unit, without film, by using a laser scan of a reusable phosphor plate contained in a standard cassette. This sort of image acquisition is known as a computer radiography (CR). The resolution of 2 K x 2.5 K x 12 bits is available and the full-screen (35 x 43 cm) scanning is made by less than a minute. With CR wrong exposures and delays, due to the film developing, are eliminated.

Within the last ten years, various image processing, transmission, and archiving systems have been developed for medical applications. These have been focused in the areas of Radiology and Pathology, yet they are now finding their way into such areas as Cardiology, Neurology, Orthopedics, and Surgery. The introduction of computed tomography (CT) and other digital diagnostic imaging techniques in the 1970's has resulted in a variety of data formats for digital images and associated information. In addition to image acquisition devices there are digital devices which act as image sinks, including display stations, laser film writers and printers, as well as different storage media as magnetic tapes, magnetic disks, and optical disk systems. As hospital departments have acquired an increasing number of digital devices the need for a standard format for exchanging digital information has quickly emerged. By the 1980's the concept of a very large, complex network of imaging devices, archival storage systems, and image viewing workstations all connected by a high-speed local area network (LAN) is established [8]. A possible configuration for this system, known as a PACS (Picture-Archiving and Communications System) is depicted in Fig. 1 [9]. The large volume of image data is one of the fundamental characteristics separating PACS from more common local area networks LANs). In a typical medium sized hospital (300 beds), the volume of image data generated is about 3 Gigabytes per day (20 GB per week) [10].

The PACS configuration as in Fig. 1 could be used as a building block for the TM network. In Fig. 2 a possible TM network configuration is depicted. The units denoted as US are 'users', i.e. terminal PACS units located in medical departments, hospitals, or clinics, while the units denoted as RC correspond to regional centers, i.e. the reference medical clinics as university clinics. The connection between units could be star-like (solid lines) and/or loop-like (dashed).

Using computers different postprocessing steps permit us to enhance raw medical data obtained from acquisited images, extract objects of interest, recognize and describe particular areas in the tissue. High-level processing, including the expert system, data base and the decision unit, lead to the automatic primary diagnosis. Besides digitized images and other medical data, the telemedical system would also handle patient tracking and billing and equipment scheduling in a hospital-wide network.



NH1 - Computed tomography	NH6 - Pathology
NH2 - Nuclear medicine	NH7 - Surgery
NH3 - Computer radiology	NH8 - MR imaging
NH4 - Angiography	NH9- Conference room
NH5 - Ultrasound	etc.

Figure 1. A possible configuration for a PACS.

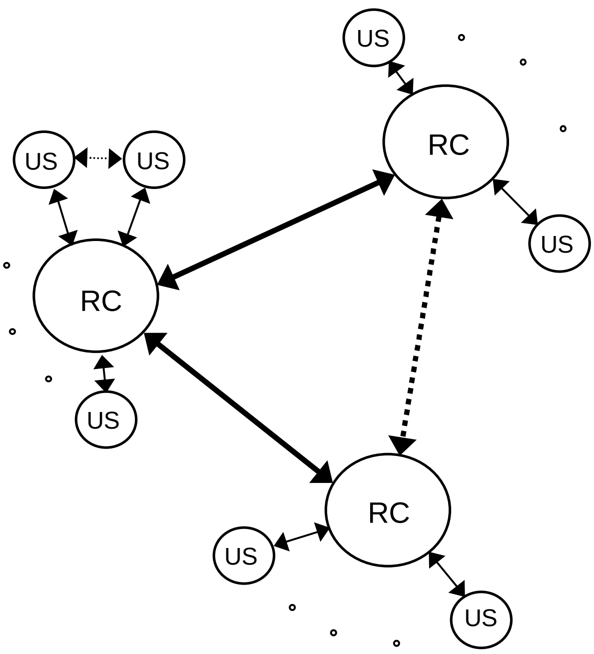


Figure 2. A possible telemedicine network configuration.

The digital viewing station must display images of high quality, several at the time, and be able to change them rapidly (note that radiologists become impatient if the image writing time exceeds 2 seconds!), as well as provide simple image processing. There is no agreement on which quality of digital imagery is necessary. Recent studies show that the resolution required depends on the examination type and the specialist doing the reading. Through a large number of studies written in the last few years, researchers tried to agree on the minimum quality standard of digitized images. In some of them it can be found that standard TV PAL resolution (780 x 585 pixels) can be used to display the usable diagnostic digitized image. However, in other publications it is claimed that the resolution of 1024 x 768 pixels is the absolute minimum and higher resolutions are recommended (1600 x 1200 pixels, or more). The same disagreement can be found about the pixel depth (the minimal number of bits per pixel, in other words, the number of contrast levels and/or the number of colours used to display the diagnostic usable digitized image). While one group claims that 8-bit palette (ability to display 256 gray-scale levels or 256 different colours) is sufficient, the others, mostly from the countries with developed communication resources, believe that only by use of 24-bit palette (ability to display 16.7 million of colours) the correct telemedical diagnosis can be obtained. In a very carefully created study by Department of Biomedical Engineering of Medical Faculty of University of Chapel Hill, North Carolina, USA [11] it was cleared that most of diagnosticians make no difference between 8 bit (256 colours) and 24 bit (16.7 million colours) image. A very useful technical way for reducing the number of bits is the diffusion dithering method allowing us to use 8 bit-palette but producing the same visual effect as 24-bit palette. Similar procedure, named *halftoning* [12], could be applied in displaying and/or printing monochrome images (8 bits per pixel or 256 levels) but using only 2 levels (1 bit per pixel). Several methods are suggested making the halftone image be similar to the continuous toned images, due to the low-pass characteristic of the human eye. [13]. Multilevel halftoning [14],[15] produces almost the same visual effect as the original image but using 3 bits per pixel (eight levels).

An additional problem in telemedicine is a data storage. Assuming standard image quality: 1024 x 768 pixels per image and 8 bits per pixel, and having in view the volume of digital data, ordinary generated in a typical hospital, archiving requirements become very pessimistic. Namely, for every thousand beds, a large hospital generates about 3 Gigabytes of picture data per day. For storing these data, almost 5 optical compact disks (CDs) per day, having about 650 Mbytes capacity each, are necessary. Storing the five-year hospital's archived picture-data would require a stack of 8500 CDs, all of 85 meters tall. So, the image compression is necessary. Actual technology uses JPEG (*Joint Photographic Expert Group*) compression (up to 20:1 compression) and/or enhanced JPEG (up to 100:1 compression) for still image compression, permitting thus a considerable reduction of the necessary disk space. For videosequences the compression is made using MPEG (Moving Picture Expert Group) standards (MPEG-1, -2 and -4) and/or ISO H.261 and H.263 standards through ISDN.

Recently, a serious investigation was made [16] for determining the minimal quality of digital images necessary for accurate diagnosis in pathology. The team of pathologists has analyzed a series of digitized images of microscopic tissue samples. In the experiment the image resolution, the pixel depth and the JPEG compression ratio were changed and the specialists were asked to make a diagnosis. It was shown that the image resolution of 768x576 pixels with 8-bit colour palette (256 colours) and the JPEG compression up to 10:1 are a minimal quality permitting accurate diagnosis of 94%. Note that fault diagnosis was obtained not only over the digitized samples but also using an original microscopic samples, due to the specific circumstances.

3 Telemicroscopy Network in Yugoslavia

In 1995 at the Institute of Pathology and Forensic Medicine of the Military Medical Academy (MMA) in Belgrade we created a digital microscope workstation [17] for developing a bank of digitized images to be used for diagnostic and educational purposes. The initial results and experiences obtained encourage us to create a project to study, develop and test an integrated environment for telepathology services by using affordable and widely available telecommunication and information technologies. The applications of interest were: remote consultation, access to a distributed morphometry laboratory, quality assessment of cytology and histology laboratories and tools for remote interaction with a distributed multimedia archive for training, continuous education and reference.

We have been experimenting with a particular model of a low-cost telepathology network using the Intranet-Web as a common ground for exchange of hypermedia histocytologic data. We have set up a telepathology system consisting of a PC Pentium 200 connected to Intranet by an 33.6 Kbps modem, containing a MiroDC30 videoblaster board connected to the composite output of a Philips camera fixed within an Olympus optical microscope. We have been using the Adobe Photoshop for image acquisition, which provides tools for image rendering and filtering. We carried out telepathology sessions by Intranet using the data access by HTML request and report forms and interactive with NSCConference and shared whiteboard. In this way it was possible to create a web of interconnected pathologists using the Intranet for asynchronous or interactive exchange of data.

Telemicroscopy Center (TMC) was founded at MMA in Belgrade as the fundament of the telemedical network of the Yugoslav Army. The main goal is the connection of the largest possible number of diagnostic centers to a unique system intended to deliver the primary diagnostic and consulting services as well as the support of educational and research processes in pathology, forensic medicine and other areas of interest where the microscope is the main diagnostic tool. The system is based on client/server architecture principles, and consists of the diagnostic stations connected to a server through LAN/WAN network. The heart of the network is communication server which runs SQL (Structured Query Language) database server and WEB server with database connectivity. WAN diagnostic workstations connected to the server through telephone lines, enabling the data transfer rate of 33.6 kb/s which appears to be fast and reliable enough to secure the accurate diagnosis.

In 1997 we have designed the first telepathology network in Yugoslavia using digital microscope workstations as a basic building blocks. This network is a hierarchically organized telepathology system, as in Fig. 2, connecting small hospitals with a single pathologist to regional centers and connecting these regional centers to the TMC in Belgrade. Hitherto, except in the MMA in Belgrade, two regional centers were built, too: in the Military Hospital in Nish (linking also the Institute of Pathology of the Medical Faculty of Nish), 250 km on the South-East, and in the Institute of Oncology in Sremska Kamenica (near Novi Sad), 80 km on the North-West from Belgrade, as depicted in Fig. 3. Possible future connections, located in other university centers, are indicated, too [18],[19].

Note that the existing network is built as a star-like configuration, but loop- (or mixed) configuration is possible, too.

An example of a telemedical session performed via the existing telepathology network would look as follows. After being connected to TMC server, the user is accessed to the home page of the Department of Pathology and Forensic Medicine in MMA, where he can find brief information about this department and its personal structure, Fig. 4.

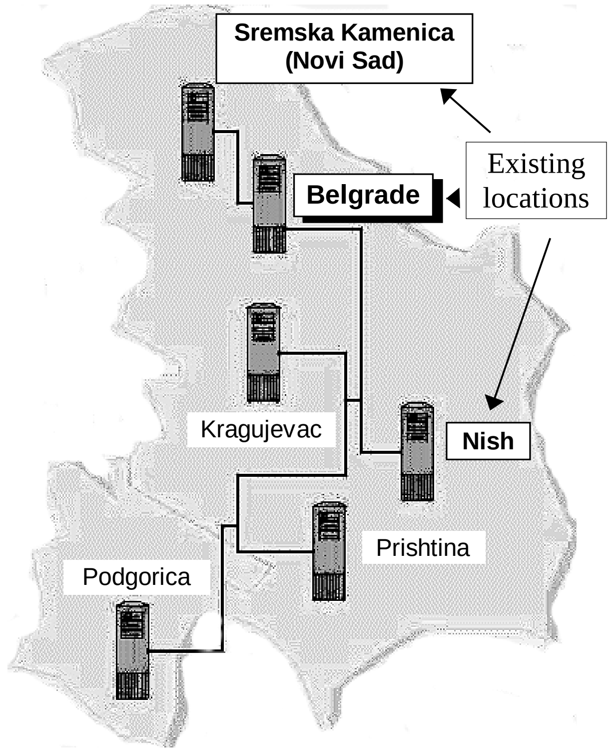


Figure 3. Existing and (possible) future telepathology locations in Yugoslavia.

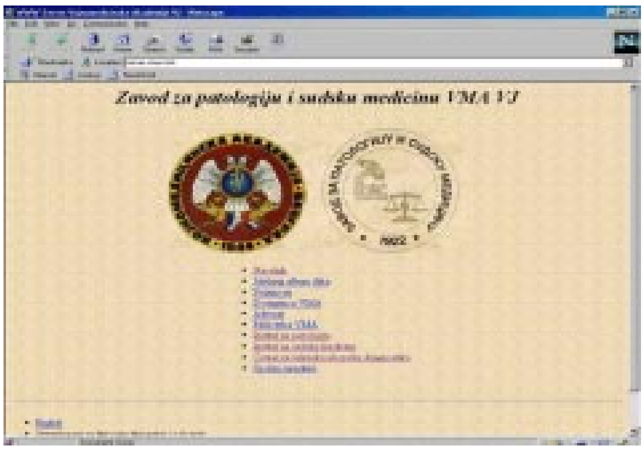


Figure 4. Home page of the TMC in MMA .

By pressing the bullet button of TMC the user gets the TMC page, where by a similar action he can run the request for telemicroscopic medical service. Before approving the access to the request form, the system requires the user identification through his username and password, Fig. 5. At the user side two forms are available: the request form and the form for previewing of the answer. At the provider side there are also two forms: the form for a preview of requests and the answer form, as indicated in Fig. 6.

After performing the connection between two (or more) users an interactive consultation is possible using shared whiteboard and videoconferencing capabilities. If there are any doubts regarding the image contents and its quality at the user's side, he can announce himself by the telephone or using sound blaster in order to make on line consultation through internet conference session enabling mutual analysis of images in bidirectional audio communication. An existing transfer through telephone lines is not so fast (about 10-20 minutes is necessary for transmitting 10 diagnostic 8-bit gray-scale images, or one full-colour (24-bit) microscopy image) but the complete telediagnosis is available after 1-4 hours [20]. In that way, several dozen diagnostic consultations between remote diagnostic centers can be realized in a single day. Also, the existing system is transparent to other telecommunications networks and services (LAN/WAN, FDDI, satellite links, etc.) permitting higher bitrates including interactive real-time video.

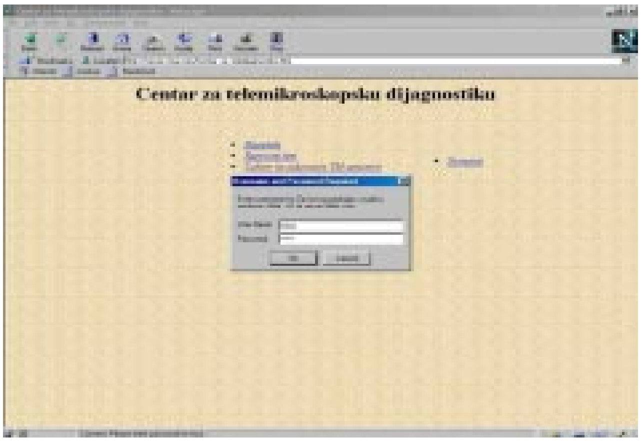


Figure 5. User identification and authorization confirmation.

Figure 6. The request/answer form for telepathology session through existing network.

At the very beginning, since November 1997, the telepathology network has been in permanent use, mainly between MMA and hospitals in Nish. Except data transfer for educational purposes in first 12 months more than 100 expert consultations/diagnosis were derived in the field of telepathology, cytology and histology, as well as in dermatology. The diagnostic accuracy was very high, 88.9%.

Note that the same network and the basic hardware could be used for the transfer of images obtained from other sensors, as MRI, CT, echo, etc. As an illustrative example in Fig. 7 the radiology image transferred from Nish to Belgrade through the existing network is depicted. The digitized image was obtained after scanning the 'classic' X-ray film.

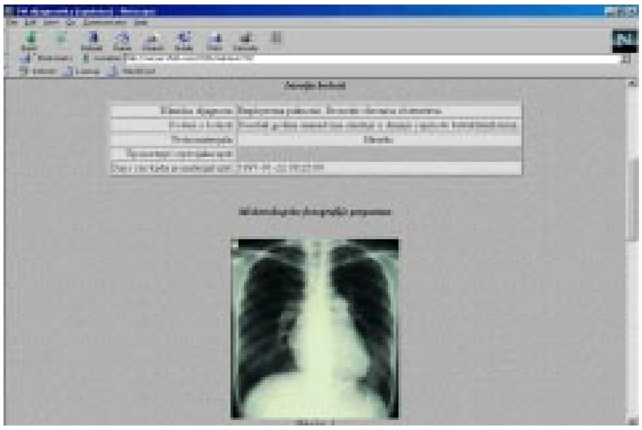


Figure 7. The transfer of digitized radiology image through existing telepathology network.

It is usual to improve telemedical system by adding different data processing hardware and software units. The basic image enhancement software (for noise removal, image sharpening, contrast and histogram modification, etc.) is usually implemented in the sensor/acquisition equipment. More sophisticated processing procedures as: image segmentation, extraction and classification of objects of interest, determination of different morphometric parameters, etc., are very attractive features. By adding data base, expert systems and artificial intelligence an automation in primary diagnosis is available [21],[22]. The computer is capable to analyze and classify a series of images and select only those samples belonging to the desired class. This procedure could be performed out of the working time in the medical center, for instance, by night. The medical doctor, the specialist, then will check only selected items, forming the final diagnosis directly or by consulting colleagues. In this way the medical doctor is engaged only to diagnosis, not to routine examination of many noninteresting samples. It is known that the concentration and visual perception drastically decay after few hours.

Although general purpose image processing tools, as PhotoShop, or similar, provide different image processing capabilities, in many cases specific procedures are necessary. For instance, from a microscopic (and other medical) image it is often necessary to extract only objects of interest, classify them, describe their shape and/or tissue, synthesize 3D object from sliced projections, etc. For this purpose the image analyzer program named CAMIA (Computer-Aided Medical Image Analyzer) is being developed at the Faculty of Electrical Engineering, University of Belgrade [23].

4 Future Trends in Telemedicine in Yugoslavia

The existing telepathology network could be used as a core network for further expansion - for the 'pure' telemedical network in Yugoslavia.

The strong correlation between the technical capabilities (telecommunications, electronics, and computers) and the possibility of forming an efficient telemedical services is evident. Certainly, the developed countries and countries having PACS have the great advantage in this field. In this case TM services could be assumed as a specific extension of the PACS by using remote workstations. However, PACS should not operate as isolated islands but must support common standards for compression, archiving and displaying of images, as DICOM. Also, it is necessary to stress that only lossless compression techniques may be used, permitting perfect image reconstruction. On the contrary, possible artifacts could produce false (and even fatal) diagnosis. Actual TM concept is based on the client-server architecture: the image data base is archived on the server while the client-workstations communicate with this base through telecommunication network. The server workstations are powerful multimedial computers having high-resolution display (17" or 21", 1024x768 pixels). The communication network should be 100 Mbps *Fast Ethernet* or ATM.

Although the developed countries have the great advantages in all technological challenges, including telemedicine, it will be very mistaken to comprise that only those countries can develop telemedicine. The investments into TM are great but the savings and benefits overcome investments. If the 'small-steps' strategy is introduced, as in the described telepathology network in Yugoslavia, then the small countries can develop and introduce telemedicine, too.

Two main questions arise in telemedicine foundation: the quality and the price. The modern market offers excellent equipments. Note some of them. The powerful workstations having impressive performances exist (Sun, Silicon Graphics), permitting excellent signal processing. An acquisition equipment is capable to obtain high-resolution high-quality images (4kx5k pixels, 24-bits per pixel), while modern networks and protocols permit high bit rates. But, for a potential user the practical question is: is it necessary to have the highest-level equipment? Certainly, better equipment will yield better results, but the price is a very limiting factor. Recall that the very accurate diagnosis (94%) in pathology (as very sensitive field of medicine) is obtained using low-cost low-level devices: Pentium machine, telephone lines with 33.6 kbps, medium image quality (768x576 pixels, 8-bit colour palette), and compressed image (JPEG with 10:1 compression ratio) [16]. In addition, different user-friendly computer routines and tools, dedicated to PCs (Windows based), are very widespread. So, we can declare that for the small countries this way could be a good solution in developing telemedical network.

For the TM foundation the first step could be forming the LAN network in the medical department. By permanent (everyday) use of computers in research, diagnostic, statistic, educative, even for administrative purposes, the medical staff will educate themselves for using computers, accepting new technologies and their advantages. The second step, which could be performed simultaneously, will include the use of the equipment for digitalization of images. The modern acquisition-diagnostic devices produce digitized signals. However, even the existing (mostly analog) equipment could be extended and updated by adding AD cards, frame grabbers, video cards and other interface devices for obtaining digitized signals. The regional medical centers should be the initial units introducing new technology, connecting different departments. The possible configuration is depicted in Fig. 1. Naturally, intra-hospital network could connect not only departments producing and processing medical images but all hospital departments as monitoring devices in emergency units, the administrative units, etc.

The next step in the TM development should include the connection of two (or more) medical centers in the network using telecommunications capabilities. The data transfer could be through simple telephone lines or ISDN, but also, through optical cables, radio- and satellite links. The modern telecommunications offer very rich repertoire.

5 Conclusion

This paper introduces the concept of telemedicine emphasizing the telemicroscopy (telepathology) network realized in Yugoslavia. The possible way of realizing TM in the small countries, which can be characterized as 'step-by-step' realization, is exposed. Namely, by low initial investments, using (almost) standard equipment, very useful TM network can be realized. The realization offered is based on the low-cost Pentium machine and communications over telephone lines. However, this realization is scalable, expandable, and transparent to other communications resources, permitting thus easy upgrading. The offered realization could be interesting not only to medical centers and hospitals but also to small clinics, remote ambulances, emergency and terrain services. In addition, the savings and benefits (highest-level medical services in the whole country) will overcome initial investments.

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