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IMAGE TRANSMISSION SYSTEM FOR RADIOTHERAPY PLANNING

In this paper we present a project developed in our University in order to provide Lublin hospitals with efficient software tools for 3D medical image processing and transmission. The system covers the entire image flowpath in the Diagnostic Radiology Department (i.e. image acquisition, processing, archiving, long term storage) and allows transmission of medical images through the Metropolitan Area Network. About 22000 CT examinations have been archived using our system. Over 300 special examinations for radiotherapy planning have been sent to the Lublin's Oncology Centre.

1. INTRODUCTION

Telemedicine is the electronic transmission of medical information from one location to another. First applications of telemedicine were developed in 1959 at the Jean-Talon Hospital in Montreal. Video monitors were set up so physicians could view radiographs from anywhere in the building. The subsequent laying of coaxial cable let hospital personnel show images electronically at locations up to 5 kilometres away. Telemedicine was used most extensively throughout the 1960s and 1970s by the NASA. In 1973 NASA provided health care via satellite to a remote, earthbound site – the Papago Indian Reservation in Arizona. As radiology is a speciality of medicine, so teleradiology is a speciality of telemedicine [2,4]. Teleradiology is the process of sending radiology images from one point to another through digital, computer assisted transmission, typically over standard telephone lines or over a local area network (LAN). Through teleradiology, images can be sent to another part of the hospital, or around the world. Teleradiology is the more specialized use of computer technology to transmit radiological images and supporting information from one location to another for interpretation, consultation, or education. Teleradiology [5] gives a medical centre ability to interpret images and provide consultation for many network sites. Image transmission systems on high speed networks are in constant development. Although they are very promising, they presently do not respond to many requests emanating from medical teams, since they are still at an experimental stage and remain quite expensive. A teleradiology system is working according to the following basic steps:

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- Either a technician digitizes analog images or the digital images are directly processed by a computer.
- Images are displayed on a computer monitor.
- If the displayed image is acceptable , it is archived.
- The archived image is transmitted via a network connection.
- The image is received at a remote site via the network connection.
- The image is processed by the computer at the remote site.
- The image is displayed on a monitor at the remote site.

The main goal of our project is to investigate the technical feasibility of developing, maintaining and operating an archive of digitized medical images and to provide local and remote access to archive over a wideband packed-switched wide area network such as the Internet. The availability of the existing Internet network and promise of its eventual upgrade to gigabit/second speeds, offers the opportunity to fill medical needs with a network solution. Hence, the proposed solution builds on the existing network infrastructure with a view toward utilizing future improvements. We have to remember that capture workstation should be capable of digitizing X-ray films as large as 14x17 inches at a minimum of 146 pixels per inch and 12 bits per pixel. Large films results in 10 Megabyte files and small films results in 5 Megabyte files. For CT images with size 512x512 pixels and 12 bits per pixel we have a 400 kilobytes file, and usually 20 scans are taken. Finally, CT examination needs about 8 Megabytes. For the purpose of radiotherapy planning, usually 60 scans are taken per one examination. Such CT examination is recorded using about 24 megabytes. In order to format archived images for display, software hosted on a reading workstation scales contrast resolution from 12 to 8 bits. Current teleradiology is based on a series of standards published by the National Electrical Manufacturers Association (NEMA) – the Digital Communications in Medicine (DICOM) standards. In term of size, the dominant items within DICOM are the images themselves. Digital images range from approximately 512 kilobytes (MRI images at 512x512x15 bits grayscale) to size reaching 24 megabytes (4096x4096x12 bits grayscale). During the last few years, information and communication technologies (ICT) have been introduced by various degrees into medical environment. The general goal of using ICT in medical environments [6] is to improve the overall quality of healthcare at an affordable cost.

2. PACS AT DIAGNOSTIC RADIOLOGY DEPARTMENT

Introduction of medical technology poses a very complex problem, especially in countries of low economical power. Digital technology is very costly. According to research on PACS (Picture Archiving and Communication System) cost, for hypothetical PACS implementation for CT, ultrasound and CR the hospital needs about 1 million $ over 5 years (approximately 180 000$ per year). Telemedicine system costs about 100 000 $. Our goal was to design and establish a low-cost PACS.

The objectives of our system:

1. It should have a maximum local access time of 10 second to any file on any volume.
2. It should support ANSI standard media, UNIX file system, SCSI connectivity and NFS.

3. The archiving software should be capable of handling both online media (hard disc) and offline media (CDs).
4. It should comply with the DICOM format of the images (USA HL 7 standard was not considered).

The system was designed to include PACS and teleradiology. A PACS should have a network solution, wide area digital viewing and provide a permanent digital record which may be either on-line or off-line. Our PACS [6] is based on a multi-vendor open architecture and a set of widely available industry standards, namely: Linux as an operating system, TCP-IP as a network protocol, DICOM standards, LAN and MAN. Our LC-PACS covers the entire image flowpath in a radiological department, starting from image acquisition at the diagnostic stage; through to on-line archiving, display, processing and long term archiving. Images can be exchanged between different offices in the same health organisation unit [10] or between ones in an Intranet (or the Internet). WWW server combined with DICOM database allows users to view cases from their low-end PCs. Software packages developed by us include:

– data management system,
– visualisation system,
– image processing system,
– patient database,
– image frame grabber driver,
– image format converters,
– WWW server,
– archiving system (on CD),
– image viewers.

Radiological images under Lublin PACS are collected in the form of:

– temporary files (GE workstation, Sun-Spark, 10 days),
– temporary files (PACS imaging servers, PC, 6 months),
– archiving files (PACS, CD, permanent).

A capture workstation should be able to handle huge images. Our system stores CT images of about 150 patients on one CD.

3. RADIOLOGICAL VIEWERS

Radiologists have access to four kinds of viewers from their PC workstations:

1. General Electric 2D and 3D viewers (Advantage Windows),
2. 2D viewers for CT images archived on a CD,
3. 2D viewers for specific CT images manipulations,
4. Commercial viewers (for example Imaging Windows or CorelDraw).

For Lublin PACS simple 2D Radiological Data Viewers (RDV) have been developed. The images which are locally stored at GE workstation or PACS imaging servers are available to RDV via NFS (on-line). The examination is selected from a list of locally available examinations. The images to be viewed are selected with a mouse from the overview screen. With the help of RDV, patient images recorded on CD can be analysed on a PC (off line).

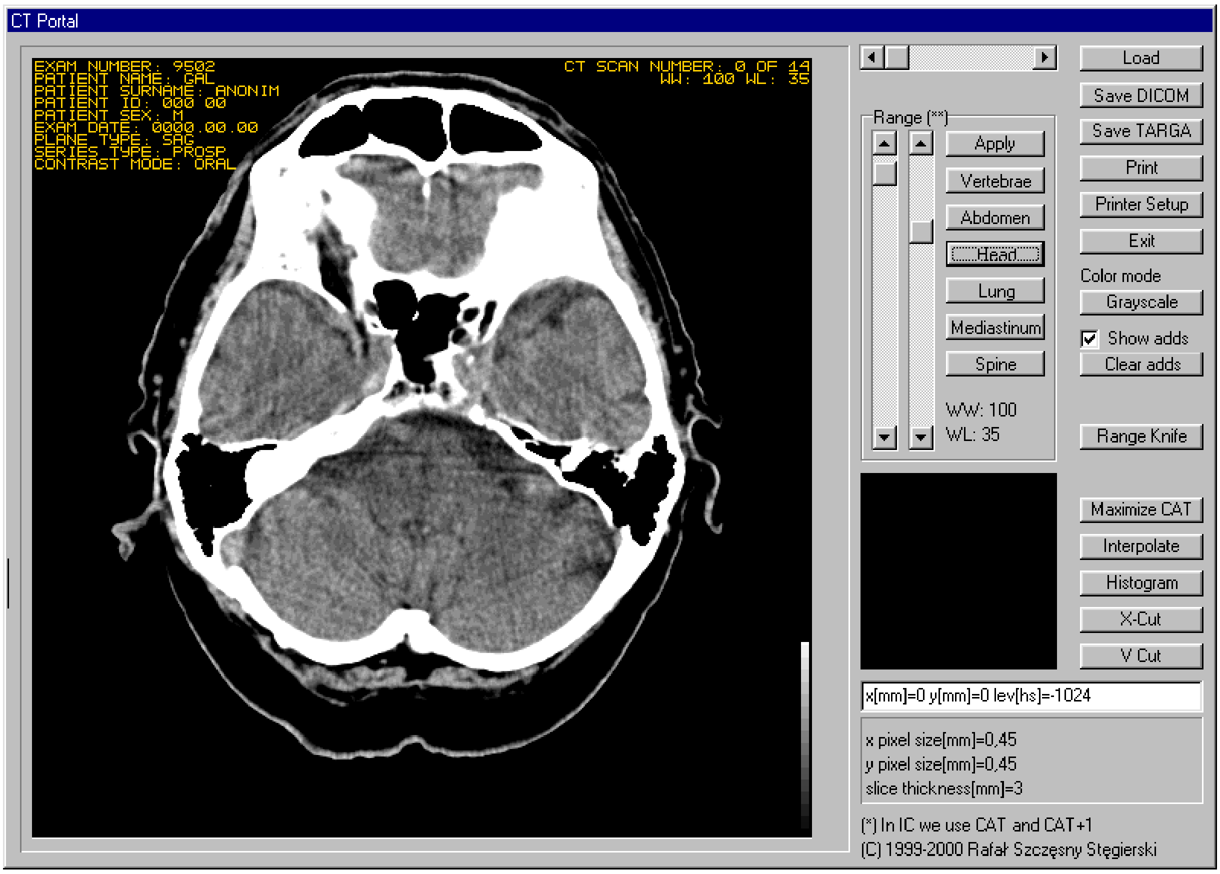

Fig.1 2D Radiological Data Viewer

4. LUBLIN MEDICAL NETWORK (LubMedNet)

We have developed a very efficient medical network system connecting several Radiological and Oncological Information Systems and enabling secure transmission of medical images through Metropolitan Area Network. The solution is based on a Virtual Private Network technique. A VPN is designed to give users privacy of a separate network over public lines by substituting encryption and other security measures [8] for the physically separated network lines of traditional private networks. Our goal was an efficient system ensuring data transfer between Diagnostic Radiology Department of Lublin Provincial Hospital and Lublin Oncology Centre . Hospitals are connected to our VPN using special *routers*. Each of them has built-in support for the following functions:

- connects all local networks of each hospital and acts as a plain TCP/IP router,
- works as a *gateway* to the *Metropolitan Area Network in Lublin* and the Internet,
- protects the private local networks from public access,
- allows access to the Internet from all computers of the local networks without officially assigned IP addresses for each of them,
- acts as a *VPN router*. It allows tunnelling (encapsulation) of native IP protocol through a secure network link to a remote network of other hospitals.

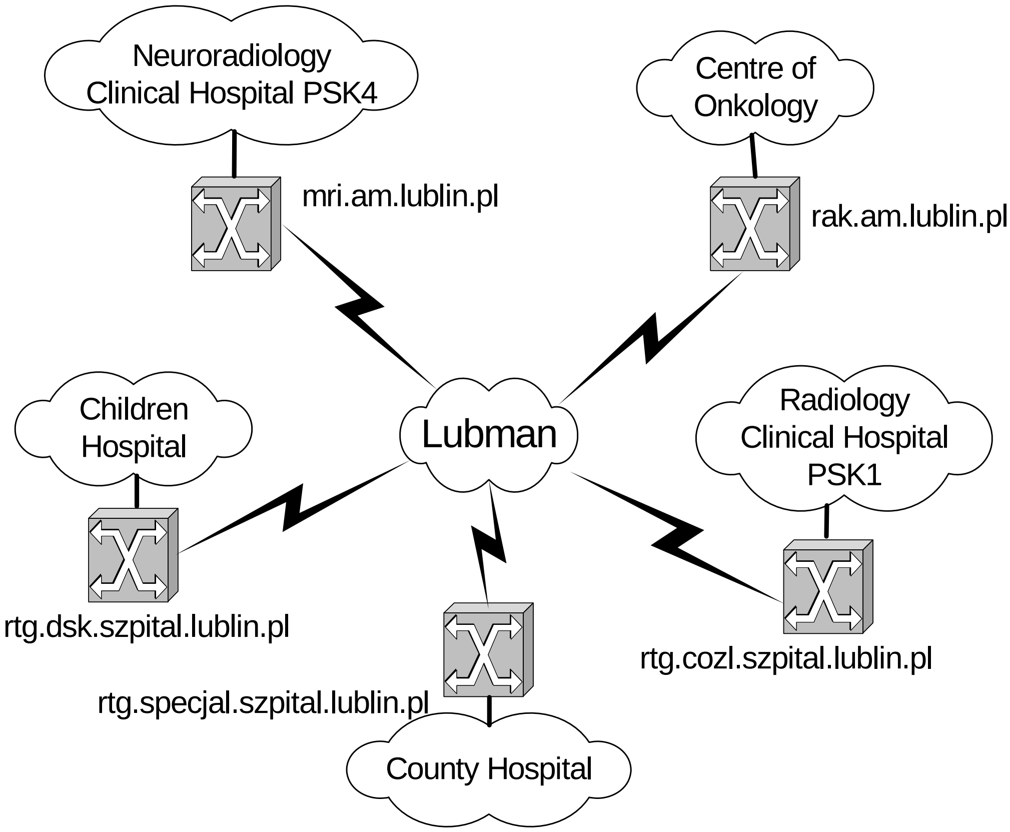

Fig.2 Topography of LubMedNet with encrypted connection channels

5. CT EXAMINATION FOR RADIATION THERAPY

A patient is immobilised in a special device which is fastened to the patient's skull with four nails inserted under local anaesthesia. In Fig. 3 a CT image taken during an examination is presented. This picture shows a patient's head with the mentioned device. Metal plates are clearly visible.

The CT examination is performed with following parameters: scan field of view 42cm, display field of view 42cm, no gantry tilt, slice parameters: 135 kV, 2s, 160mA (1mm slices) or 130mA (3mm slices). In most cases non-ionic contrast media is administered (about 1ml/kg patient weight).

The examination range should cover the lesion, eye-balls and a brain stem. The 1mm thickness of slices is required within the lesion with 1cm border, below and above the lesion slice thickness of 3mm is sufficient. Number of scans performed may vary from 50 to 70 depending on a localisation and size of the lesion.

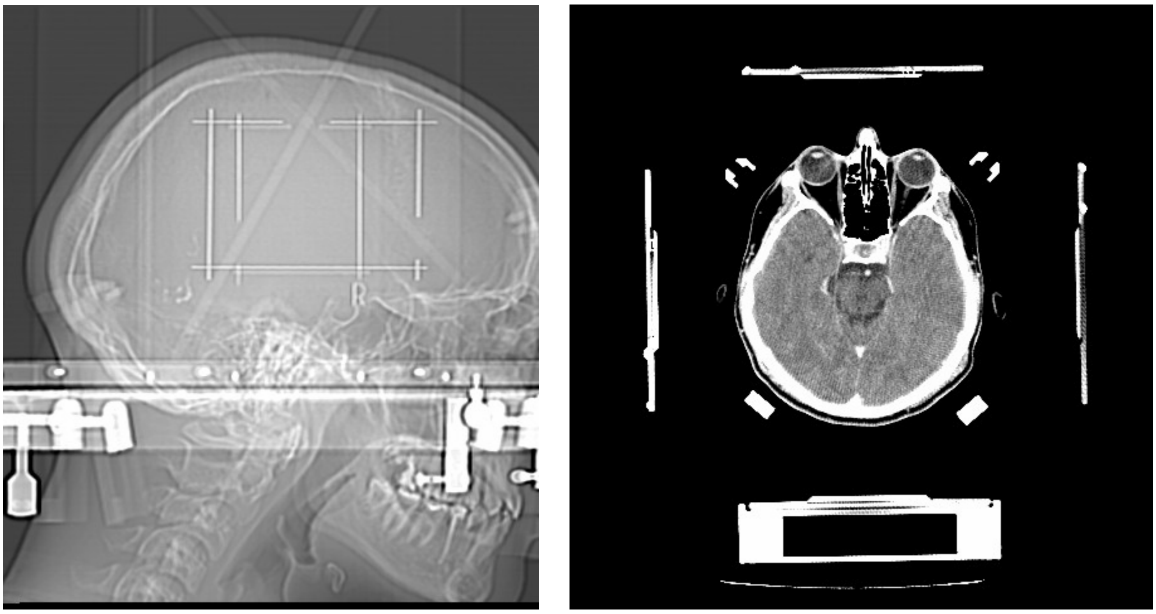

Fig.3. Scout and axial CT image taken for radiation treatment

6. FUSION OF CT AND MR IMAGES

In brain imaging it is common to acquire both MRI and CT scans. CT provides accurate anatomical information, especially about bones. Voxel intensities are proportional to the radiation absorption of the underlying tissues, which is useful in radiation therapy planning. MRI is less accurate, but soft tissues (including tumours) are delineated much better. The registration result has been shown in fig. 4. We have developed software for registration and alignment of CT and MR images. The task of multimodal image integration is not trivial due to unlike patient's orientation, datasets' resolutions and voxel intensity profiles. The purpose of the fusion is to find a geometric transformation that relates corresponding voxels in two different 3D image-sets of the same object. An algorithm based on maximisation of mutual information has been implemented.

There are two main groups of fusion (registration) methods: feature-based and voxel-based techniques. In the first case some corresponding points need to be recognized prior to the registration. They can be either external markers (stereotactic frame, screw markers, skin markers), which are usually inconvenient for the patient, or some anatomical structures (localized by an expert after a segmentation step). In voxel-based techniques a function of similarity of two images is computed with the intensities of all (or most of) voxels in the images [11]. It does not require a segmentation step and can be performed accurately and almost automatically. This approach is becoming more and more popular. However, it involves more computing time.

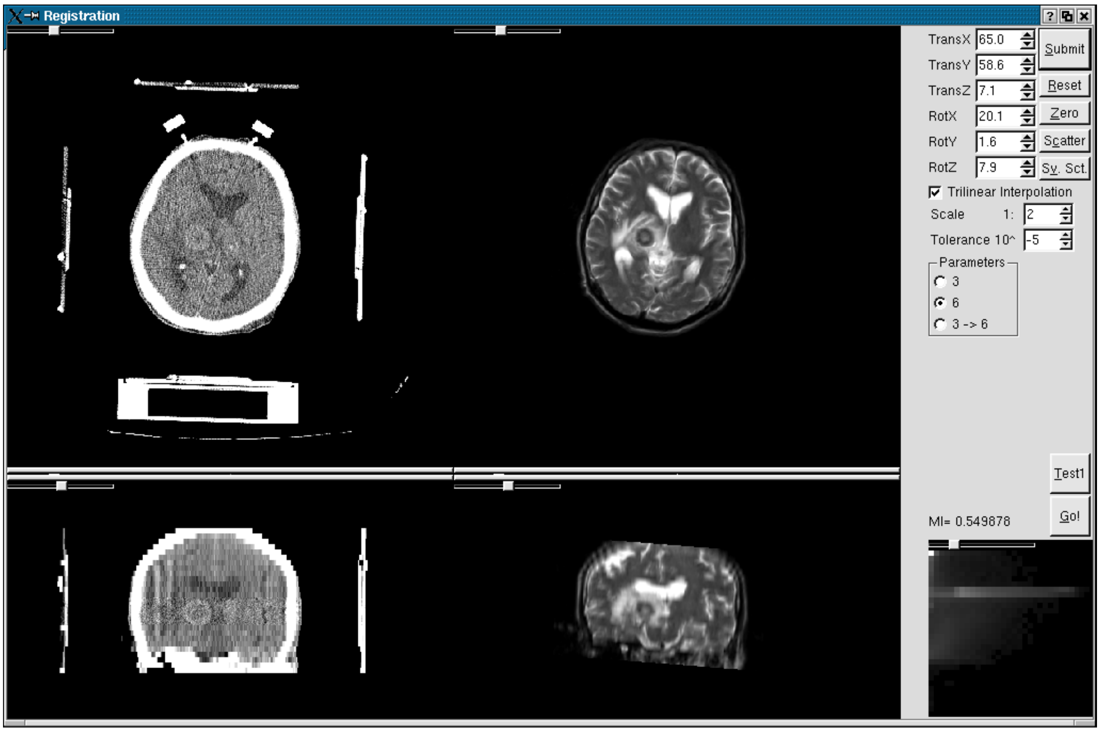

Fig.4. Screenshot of the CT – MRI fusion software

Regardless of the method used, the registration framework is always similar. It is necessary to implement an efficient similarity measure optimisation procedure in order to find transformation T parameters. The entropy H of a discrete random variable X with values in the set $\{x_1, x_2, x_3 \ldots x_n\}$ is defined as [3]:

$$H(X) = -\sum_{i=0}^{n} p_i \log p_i \ , \tag{1}$$

where $p_i = \Pr[X=x_i]$.

The entropy definition of a single random variable can be extended to a pair of random variables. Let us consider random variable Y with the probabilities q_i. The joint entropy of a pair of discrete random variables (X,Y) with a joint distribution p(x,y) is defined as:

$$H(X,Y) = -\sum_{i=0}^{n} \sum_{j=1}^{m} \ p_{ij} \log p_{ij} \ , \tag{2}$$

where $p_{ij} = \Pr[\ X=x_i,\ Y=y_j\ ]$.

The conditional entropy is defined as:

$$H(X \mid Y) = \sum_{j=1}^{m} q_j H(X \mid Y = y_j) = -\sum_{i=0}^{n}\sum_{j=1}^{m} p_{ij} \log p_{ij}$$
$$= -\sum_{j=1}^{m}\sum_{i=1}^{n} p_{ij} \log p_{i|j} \tag{3}$$

where $p_{i|j}$ = Pr[$X=x_i|Y=y_j$], $p_{ij} = q_j p_{i|j} = p_i p_{j|i}$.

The mutual information between two discrete random variables X and Y is defined as:

$$I(X,Y) = H(X) - H(X \mid Y). \tag{4}$$

The mutual information represents the amount of information that one random variable gives about the other random variable. I(X,Y) is a measure of the shared information between X and Y. If we treat image datasets as random variables, we can calculate for them any measures defined above and apply statistical techniques in image processing. It can be shown, that when two images are properly matched, their mutual information is maximal [12]. Then it can be successfully used as a similarity measure for registration. The optimisation is an iterative process of searching for a global optimum (minimum or maximum, depending of a convention) of the optimisation criterion (similarity measure) in order to find the optimal transformation parameters. The main problems are computational complexity and occurrence of local extrema. We used Powell's algorithm because it is one of the most commonly used techniques [7]. More refined methods (Davidon-Fletcher-Powell, Levenberg-Marquardt) usually require not only evaluations of the function to be minimized, but also the derivatives of that function, which may be a non trivial task.

The whole code has been written in the C++ language. The GUI consists of a collection of Qt-3.0.x library widgets. Thanks to this it is a cross-platform software. Currently it is running on a PC (RedHat Linux 7.x) and a SGI O2 workstation. It can be also compiled for any MS-Windows (using MS Visual C++ environment), Unix/X11 (Irix, Sun Solaris, HP-UX, Digital Unix, IBM AIX) or Mac OS X operating system.

7. CONCLUSIONS

Our teleradiology system enables image transmission between the Radiology Department and the Lublin's Oncology Centre. The solution is based on VPN and PACS design. Data is transmitted from Radiology Department using an Advantage Windows 2.0 workstation. In the Oncology Centre received CT images are evaluated at the treatment planning workstation. The principle of radiotherapy is to deliver a high dose of radiation to the tumour while restricting dose to the surrounding normal tissue. Several clinical protocols concerning image acquisition, transmission and treatment planning have been devised and implemented [1]. Our system has been working correctly since November 1999. About 22000 CT examinations have been archived using it. Over 300 special examinations for radiotherapy planning have been sent to the Lublin's Oncology Centre.

Major benefits achieved from our solutions are:

1. **Low costs of system implementation**. The cost of our PACS is significantly reduced – the solution was to develop a suitable software interface, sometimes called "middleware" and to choose OS system like "LINUX" which gives a hospital some financial flexibility, since it allows managers to pick and choose software modules they can afford.
2. **Reduction of the archiving cost.** One radiological film costs $3, for one examination 1 to 3 of them are needed. It makes conventional archiving costs about 12-36 PLN ($3–$9). The cost of electronic archiving is only about 0,01PLN (0,002$) per examination. We have reduced film consumption by about 70%. It brings about 100000 PLN (25000$) savings yearly.
3. **Reduction in number of destroyed or lost documentation.** Additionally no need to repeat the examination. Tight security of the electronic storage is in contrast with estimated 10–20% result disappearance from traditional archives.
4. **Quicker and more reliable access to the image database.** Our database software allows extensive search and statistical analysis, not to mention drawing out lists for clearing purposes.
5. **Better patient care, shortening patient's stay in a hospital.**
6. **Improvement of hospital's image in the local community.**
7. **Data transmission to the Lublin's Oncology Centre.** More than 300 CT examinations for radiotherapy have been made so far and this data was sent to the Oncology Centre. Suitable procedure has been established. From the technical point of view, as soon as the communication was properly established by the operators, we have not had any major problem with the system. All these data has been sent successfully over the VPN to the Oncology Centre. It provides almost real-time information transfer with a high degree of a clinical confidence.

Teleradiology technologies are now mature and widely available and there are well established, open software standards. The communication infrastructure is, however, often the weakest link in the provision of a widespread service. Our teleradiology system is still under development, and will be enriched by an intensive use in different medical departments and for various applications.

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