Min Invas Ther & Allied Technol 1998:7/2:89–95

Short communication

Telemanipulation for application of diagnostic and interventional ultrasound

L. Angelini, M.M. Lirici and V. Papaspyropoulos

Fourth Department of Surgery, University La Sapienza, Rome, Italy

Summary

Several research programmes on telemedicine and telerobotics are currently underway, most of them limited to diagnostics and teleconsultation. A new research and development programme started within the European workframe Advanced Communications Technologies and Services (ACTS), has the aim of developing and building two prototypes of remote controlled robots for interventional and laparoscopic ultrasonography. 11 centres (either clinical or technical) from six countries are taking part in the multimedia interactive demonstrator telepresence project (MIDSTEP). The user requirements for systems for diagnostic and interventional ultrasound (US) have been defined and evaluated in MIDSTEP Work-Package 1, whereas in Work-Package 2, all functional specifications have been included. The system architecture includes hardware, software and a communications network. The hardware consists mainly of a control station and a robot station, which includes a manipulator robot. Within the communication network, there are synchronous and asynchronous channels. Asynchronous transfer mode (ATM) lines are used for long distance transfer. Software for both the control (expert) station and the robot station (patient location) is under development. Special software will be developed to monitor all system functions and control all safety mechanisms, as well as to guarantee the security of data communication. In the teleinterventional US scenario, the robot scans the abdominal organs and performs, under US guidance, a fine needle aspiration puncture. In the laparoscopic US probe telemanipulation scenario, an expert in a control station moves the laparoscopic US probe in order to scan the abdominal organs during diagnostic laparoscopy.

Keywords

robotics, telerobotic surgery, tele-ultrasound, telepresence, MIDSTEP project.

Introduction

The need for cost containment while preserving both quality and easy access in health care delivery systems, is a driving force in the adaptation and application of telematics to medicine. Connectivity has become one of the key issues in promoting imaging modalities equipment. Teleconsultation, which is already operative in some countries, for example Norway, so far consists mainly of the transmission of data and images. Teleradiology is the most common manifestation of this development.

All these applications and projects are limited to diagnostic purposes [1, 2]. The addition of mechanical and robotic devices to telematics for diagnostic purposes marks a step forward in technological convergence [3]. Virtually no efforts, apart from some

Correspondence: Licinio Angelini, *MD, IV Clinica Chirurgica, Policlinico Umberto I, Viale del Policlinico 155, I-00161 Rome, Italy.*

with very circumscribed goals [4], have been made to expand telematics and robotics to interventional imaging procedures. This is the aim of the MIDSTEP (Multimedia Interactive DemonStrator TElePresence) project*.

Methods

MIDSTEP is an ongoing project within Area 1 ("Interactive Digital Multimedia Services", Task AC 112a "Application-oriented Demonstrators for Remote Real-Time Telepresence") of the ACTS programme. The objectives of the MIDSTEP project are to develop and realise two demonstrators for tele-interventional ultrasound (US), one for interventional US itself (US-guided biopsies, fluid collections, drainage, etc.) and one for the telemanipulation of a US probe in endoscopic surgery. With these two systems, the clinician at the console of a remote workstation will be able to control a number of peripheral facilities (interventional US units and endoscopic surgery theatres).

The system architecture includes hardware, software and a communication network. The hardware consists mainly of the control station (expert station) and the robot station (patient location). The latter includes a manipulator robot. All hardware components are linked to each other through communication channels. These channels are not always physical communication channels, but may also be simple functional information-transfer paths [5, 6]. Within the communication network there are synchronous and asynchronous communication channels. The synchronous communication model deals with numeric data, whereas the asynchronous model deals with logic and event data. All data are transmitted either through a local area network (Fast Ethernet, ATM) for local data transfer, or by ATM for long-distance data transfer. At 150 Mbits s^{-1}, a typical CT image can be transmitted in 0.5–1.5 seconds; since the Comité Consultative International Télégraphique et Téléphonique (CCITT) standard data rates for ATM traffic are 155 Mbit s^{-1} and 622 Mbit s^{-1}, this packet-based transmission technique allows the images to be transmitted virtually in real-time [7].

Software for the expert station, the robot station and the communication module is under development. Specially developed software is dedicated to: the telerobotic control unit; the medical imaging unit; and the system and communication unit of the expert station; as well as, on the other side, to the robot control unit, the image acquisition unit; the image processing unit; and the system & communication unit of the robot station. This software includes: a telerobotics controller; a telerobotics control unit human–machine interface; a model-based robotics module; a video and synthetic graphic module; and an expert station procedure supervisor [6]. Figures 1 and 2 show the configuration of the two systems. Figures 3 (a) and (b) show the procedures flow-charts for teleinterventional US and laparoscopic US probe telemanipulation. Figure 4 shows the overall functional architecture of the MIDSTEP demonstrator.

The sequence of actions described in the flow-charts shown in Figures 3 (a) and (b) starts with patient preparation for either the interventional procedure or the laparoscopic operation. From this stage on, the two sequences differ. In the teleinterventional US scenario, the nurse moves the US probe attached to the robotic arm close to the patient and the expert at the control station starts the scanning procedure. If a needle biopsy is needed, the expert indicates the co-ordinates of the entry point, and the angle and path of the needle. The robot memorises these data and moves back to a neutral position. The nurse then gives a local anaesthetic and fits the biopsy needle to the robot. The expert returns the robot to the entry point and fine-tuning of the position is performed. The command is then given to lock the robot in position and the expert specifies the target depth. The robot inserts the needle to the target under US guidance. The expert confirms the target, a vacuum is applied to the needle, or a syringe connected to the needle is activated, and, finally, the needle is withdrawn.

In the laparoscopic US probe telemanipulation scenario, the surgeon starts CO_2 insufflation to gain an optimal pneumoperitoneum and inserts the first trocar and the telescope. Once all other cannulae are placed, the US probe is inserted through one of these. The US probe is then moved to the organ to be scanned and connected to the robotic arm. The expert at the control station commands the movements of the US probe, while the surgeon tracks it with the laparoscope. After US scanning is completed, the probe is removed. If further examination has to be performed, or the angle

*Clinical and technological partners participate in the project. The clinical partners are: University of Rome La Sapienza, Istituto di IV Clinica Chirurgica (I); Ninewells Hospital and Medical School University of Dundee, Department of Surgery (UK); Eberhard-Karls-Universität Tübingen, Sektion für Minimal Invasive Chirurgie (D); Catharina Hospital, Eindhoven (NL); Facultade de Medicina do Porto Hospital de S. Joao, Department of Surgery (P). The technological partners are: FINSIEL (I), Telecom Italia (I), Armstrong Projects Limited (UK), United Medical and Dental Schools of Guys and St Thomas Hospitals (UK), Bristol General Hospital (UK) and Centre Etude Nucleaire Service Teleoperation et Robotique (F).

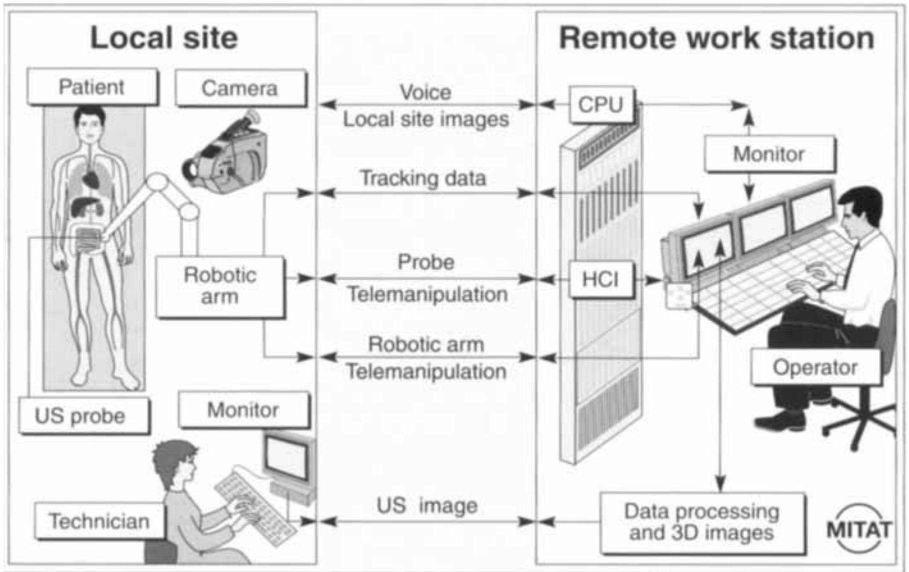

Figure 1. Robotic system for tele-interventional US.

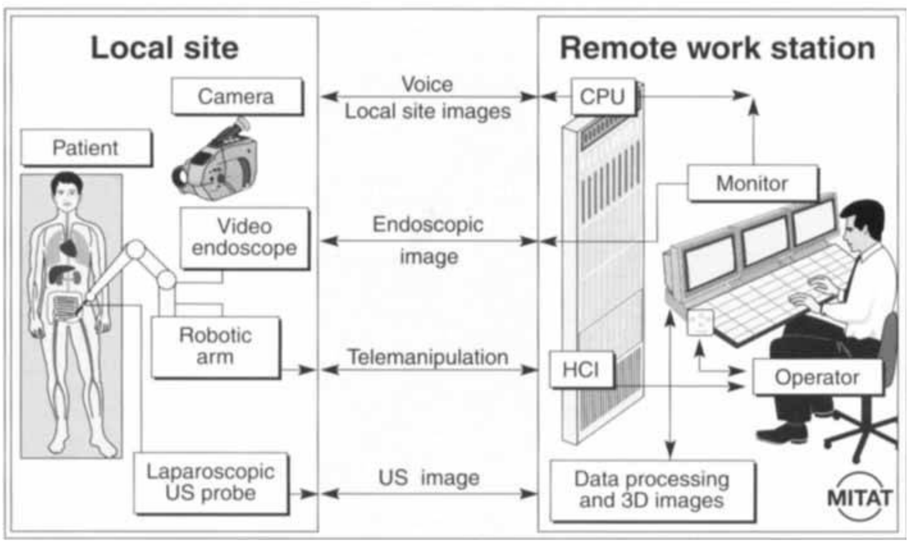

Figure 2. Robotic system for laparoscopic US probe telemanipulation.

of the probe has to be changed, the US probe is again introduced into the peritoneal cavity through another port and the sequence of actions starts again.

The MIDSTEP work breakdown structure includes seven steps: user requirements specification, functional specification, demonstrator development, Validation 1 (verification and preparation for demonstration), Validation 2 (demonstration trials), exploitation planning and project management.

This research and development project will contribute to the advancement of telepresence by instigating progress in the following areas:

- Audio and video image acquisition and processing.
- Augmented reality and perception by the human environment.
- Robotics.
- Ergonomics and human–computer interface.
- Standardisation trials and participation in the definition of new standards.
- Bandwidth requirements for networking and audio–video compression in networking.
- Security and safety for processing and communication quality in telemedicine.

The application of telematic technologies to diagnosis and therapy is related to special problems of transmission technology, concerning both the quality and delay of data transfer. The time delay in transmitting data is critical when using long distance connections and when interventional procedures have to be performed [7]. Within the MIDSTEP project,

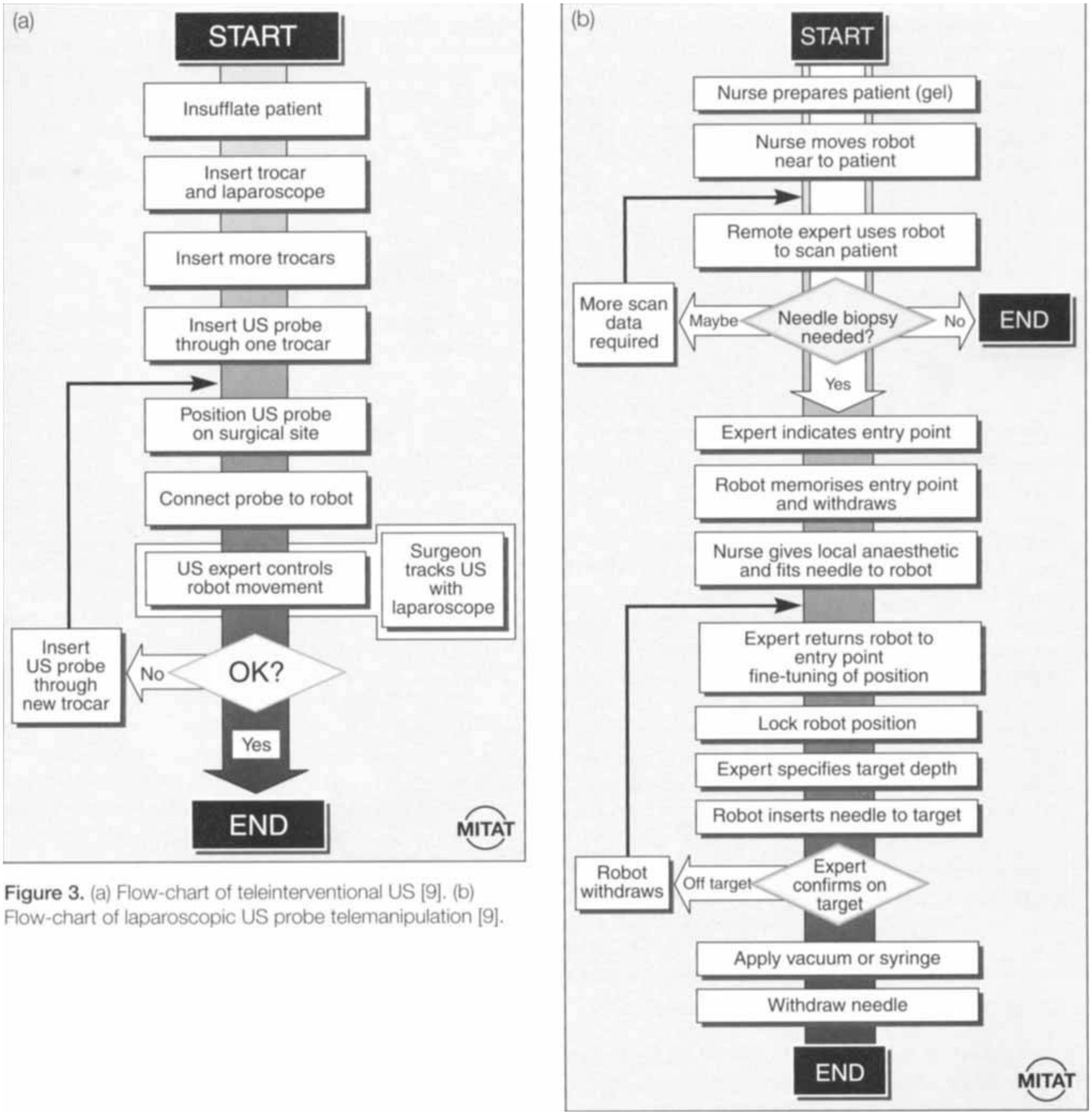

Figure 3. (a) Flow-chart of teleinterventional US [9]. (b) Flow-chart of laparoscopic US probe telemanipulation [9].

definition and solution of all system security and safety issues will lead to a precise definition of the rules for the control unit, strictly attaining to the following:

- The confidentiality of information between patient and doctor in accordance with the national norms.
- The safety of the data and the procedure that will guarantee their unaltered preservation.
- The completeness of the data; allowing the operation to be performed under the best conditions.

The distribution of the technological tasks among the partners is as follows:

- System architecture (Centre Etude Nucleaire Service Teleoperation et Robotique; CEA).
- Validation tests (Centre Etude Nucleaire Service Teleoperation et Robotique; CEA).
- Robot (Armstrong Projects Limited).
- Image acquisition (Bristol General Hospital, UBHT).
- Image processing (United Medical and Dental Schools of Guys and St Thomas Hospitals, UMDS).

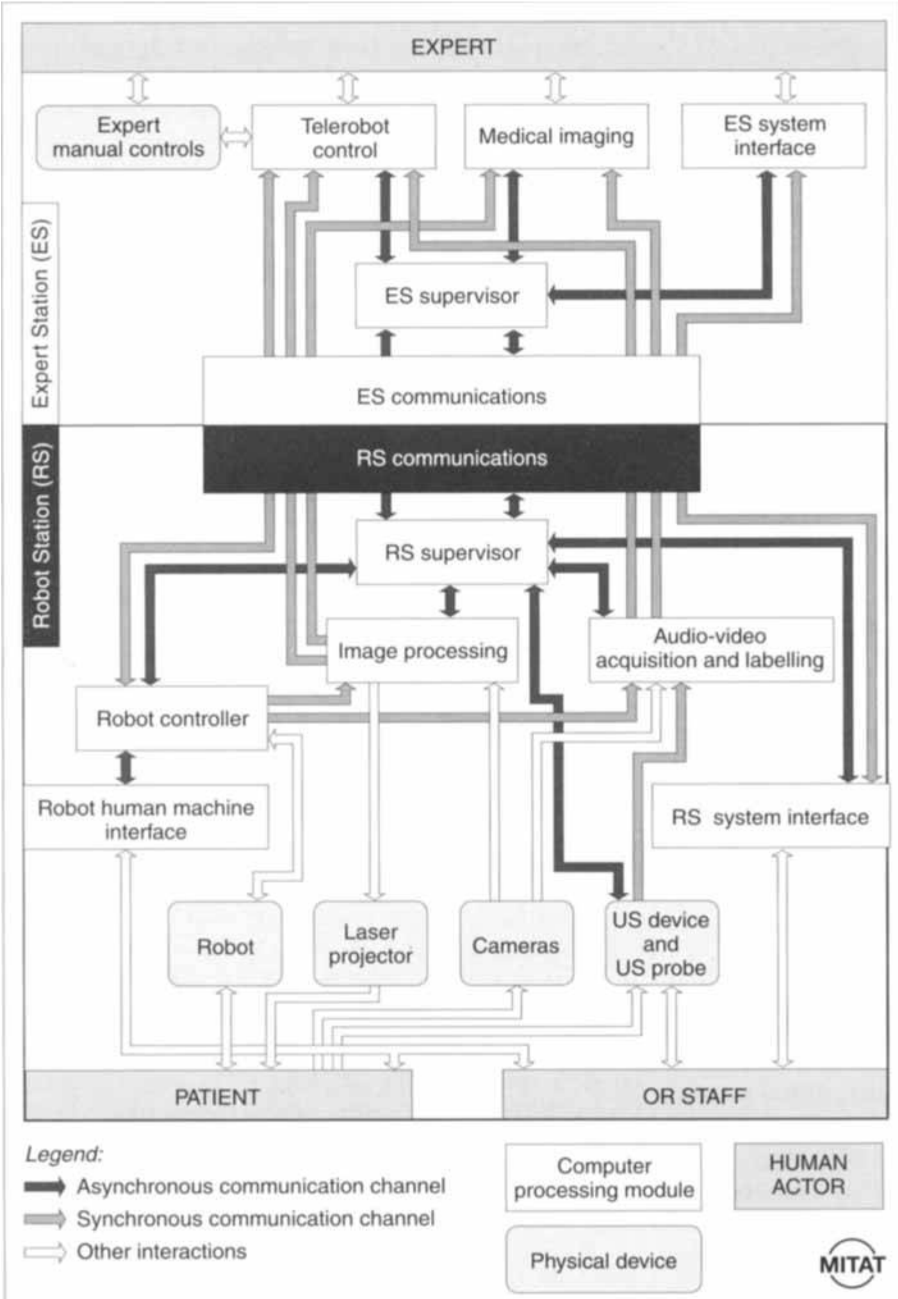

Figure 4. Overall functional architecture of the demonstrator [6].

- Human–computer interface (Centre Etude Nucleaire Service Teleoperation et Robotique, CEA).
- Telecom (Telecom Italia).
- Security and safety (Finsiel Consulenza e Applicazioni Informatiche).

The clinical partners, co-ordinated by the University La Sapienza of Rome (Angelini, Lirici), are responsible for the user needs work-package and all clinical validation and testing. The penultimate phase will end in June 1998. For that date, a live demonstration, involving a deep biopsy in a phantom, has been scheduled. The robot station will be located at the 'Ocean Expo' in Lisbon (Portugal), while the expert station will be located at the Rome Convention Centre, where the 6th World Congress of Endoscopic Surgery will be held. The two stations will be connected via the ATM European Network link.

Discussion

Interventional US procedures and intraoperative laparoscopic US investigations represent a 'delayed delivery' of an existing technology, in the sense that the requirements and needs are growing at a much higher speed than the availability of competence.

The results of Work-Package 1 (user needs), which has already been completed, clearly support the above statement [8, 9]. In the hospitals involved in this research programme — all leading academic centres — the number of physicians routinely performing interventional US-guided procedures ranges from only one to four. In four out of the five hospitals, laparoscopic US scanning is perfomed by the surgeon himself, and in two out of these five hospitals, a US expert assists the surgeon. Moreover, the number of radiologists or US specialists who routinely perform all interventional US-guided procedures is high in countries like the UK, Germany and The Netherlands, while it is low in Italy and Portugal. In three out of the five participating institutions, patients are referred from other hospitals to undergo interventional US-guided procedures; in these three institutions, the number of patients referred from other hospitals is as high as up to 20% of the overall number of patients treated in this way. On the other hand, there is a wide range of situations where the need for an interventional US procedure is sporadic, varied and difficult to plan (emergency unit, ICU, operating room, etc.). Similar problems arise in particular communities, such as jails, charitable institutions, remotely located industrial settlements, etc. In all these places it is economically prohibitive to provide a 24 h service of interventional US, considering that the cost of the equipment is almost negligible compared with the cost of the personnel needed.

The same concept of optimisation of the service regards the need for an intraoperative US examination, eventually completed with biopsies, during laparoscopic surgery. Laparoscopic US often requires the presence of an expert, other than the surgeon, at the operating table, to perform the examination and make a correct diagnosis. The possibility of using a single workstation to run US probes in a number of operating theatres will pre-dictably result in cost-containment, while maintaining quality and accessibility.

The social and economic impact of telerobotics applied to interventional and laparoscopic US may be summarised as follows:

- Improved ability to double-check and supervise.
- Enhanced service for patients in remote areas. Certain areas of the EU are so thinly populated that not everybody is within easy reach of a local hospital. Examples are the Greek islands and the north of Scandinavia. Outside the EU, a classic case is Australia, where 20% of the population have no access to a hospital other than by air ambulance. The extension of telemedicine facilities to include teleinterventional procedures would allow the patient to receive highly specialised treatment immediately and cost-effectively, without the need for an expensive and clinically undesirable ambulance journey [7].
- Ability to extend specialist treatment to local centres (traditional local general hospitals, jails, industrial settlements, etc.), avoiding the need to transport patients over long distances.

The reason for choosing ATM as the transmission technique to be used within this project has been previously explained. Nevertheless, broad use of ATM is still limited, due to both its cost and its incomplete network. Special agreements with the National Hosts have dramatically decreased the costs of ATM link among the MIDSTEP partners.

Legal and safety issues related to the application of telematics and robotics to medicine and surgery are of paramount relevance. Each and every medical and surgical treatment performed must partake of the following prerequisites: information, consent, confidentiality and safety. Information and consent are strictly interconnected, in as much as the patient must be informed of the diagnostic/therapeutic procedures they will be undergoing and give informed consent in writing. Safety has two aspects [7]: maintenance of confidentiality regarding the medical services and the patient's personal data, as well as the guarantee of their being preserved, unaltered and undamaged, during any possible transfer. The second aspect regards the dependability of any technology possibly employed during a medical treatment. Guarantees must be given of its correct functioning and suitability for the treatment requested and performed.

Finally, we would like to emphasise that MIDSTEP is in line with the trend in health care management which limits hospitalisation both in terms of the number of admissions and length of stay to situations of real necessity.

Acknowledgements

The following scientists involved in the MIDSTEP project besides the authors are acknowledged: Gerhard Buess, Alfred Cuschieri, Antonio M. D'Amico, Marcello Ferraro, Patrick F. Finlay, Raymond F. Fournier, Tim Frank, Philippe Gravez, Mike Halliwel, David J. Hawkes, Jack J. Jakimowicz, Emilio Ripani, Marc O. Schurr, Arauho T. Teixeira and Peter Wells.

References

1 Chimiak WJ, Rainer RO, Wolfman NT, Covitz W. An architecture for a high-performance tele-ultrasound system. In: *Proceedings of SPIE Medical Imaging* 1996.

2 Chimiak WJ, Kuehl KS, Hayes WS, Khanafe N, Lo SCB, Karr S *et al.* The effects of motion-jpeg compression of the diagnostic quality of paediatric echocardiograms. In: *Proceedings of SPIE Medical Imaging* 1997.

3 Miller EM, Kreder KJ, Siebes M. Design and development of an electromechanical ultrasound probe holder for urodynamics testing. *J Biomech* 1996; **29** (10): 1361–4.

4 Baumann B, Jacob AL, Messmer P. Direct referentiation of the AO/ASIF surgical drill for interactive navigation in CT-guided percutaneous fixation. University Hospital Basel (personal report).

5 Gravez P. MIDSTEP *Preliminary system functional specification*. April 1997.

6 Gravez P. MIDSTEP *Intermediate system architecture specification*. July 1997.

7 Multimedia Interactive DemonStrator TelePresence Proposal (MIDSTEP). European Commission DG.XIII, 2nd ACTS Call for Tender. July 15th 1996.

8 Lirici MM. MIDSTEP *End Users Preliminary Document.* September 18th 1996.

9 Lirici MM. MIDSTEP *WP01 Final Document on User Requirements*. October 8th 1996.