Demonstration and Validation of a complete Tele-Echography Solution

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<td>Digital Video Broadcasting - Return Channel Via Satellite</td>
</tr>
<tr>
<td>ECG</td>
<td>ElectroCardioGraph</td>
</tr>
<tr>
<td>ESA</td>
<td>European Space Agency</td>
</tr>
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<td>ESTEC</td>
<td>European Space Research and Technology Centre</td>
</tr>
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<td>GSP</td>
<td>General Studies Programme</td>
</tr>
<tr>
<td>HME</td>
<td>Human spaceflight, Microgravity and Exploration</td>
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<td>IPEV</td>
<td>Institut Polaire Français - Paul Emile Victor</td>
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<td>PNRA</td>
<td>Programma Nazionale Ricerche in Antartide (National Antarctic Research Programme – Italy)</td>
</tr>
<tr>
<td>pQCT</td>
<td>Peripheral Quantitative Computed Tomography</td>
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<td>SoW</td>
<td>Statement of Work</td>
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<td>UMPS</td>
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Part 1: General Background of the Activity

For medical diagnosis onboard human spacecraft, ultrasonography (more generally known as “echography”) has been identified as an essential first step in terms of medical imaging capability, both for current flights (especially on long-duration missions) and future exploration missions to the Moon and Mars. The interest of this technique emanates from the numerous advantages it offers. Its main interest is based on the fact that ultrasonography gives medical practitioners access to a lot of anatomical and functional information in real-time while being non-invasive and harmless for the patient. In addition, its implementation and use are today quite straightforward partly because ultrasound scanners have become user-friendly, compact and lightweight systems, compared to other medical imaging tools such as MRI (Magnetic Resonance Imaging) or X-rays based computerized tomography systems. Last but not least, ultrasonography is more affordable than other medical imaging techniques. For all these reasons, it is widely used today and particularly appreciated for the diagnoses of a wide range of pathologies and for emergency situations where fast diagnosis is required.

While ultrasound scanners can be adapted to space-flight requirements, the expertise to use these systems and carry out examinations is a key issue to envisage ultrasonography on an operational basis during space missions. Analysing ultrasound images and positioning the ultrasound probe on the patient’s body involve significant professional skills. Since at least one year of extensive training is required to gain acceptable ultrasonography expertise, alternatives to classical ultrasonography methods have to be found. This problem also exists on Earth in some areas where the access to ultrasonography is limited or even non-existent (e.g. regional hospitals and isolated healthcare centres) because of the geographical isolation of populations (e.g. in French Guiana, underdeveloped regions, or on some islands), the lack of experts, or their inappropriate geographical distribution.

To overcome the distance issue, telecommunications between the medical expert and the site where the patient is located can be used in association to suitable tools and services to remotely carry out examinations (See Figure 1). This concept commonly called tele-echography or tele-sonography has been developed in different forms depending on whether scanning is transmitted in real-time or off-line, and whether the consultations are carried out live in video or audio-conferencing, or exchanging electronic clinical files in asynchronous mode.

Figure 1: various contexts of use for tele-echography
Demonstration and Validation of a complete Tele-Echography Solution

As of today, the tele-echography type that has shown to be the most promising and convenient is the one where the medical expert gives instructions to an operator to set the probe on the patient’s body and remotely visualizes the images from the ultrasound scanner and the operator’s movements. Widely used on Earth, this type of tele-echography has also been successfully tested on the ISS. Although answering to the need, this solution is not optimal and has a significant drawback: it relies on subjective oral instructions given by the medical expert, who must give comprehensive and easily understandable instructions to describe the movements he/she would intuitively perform while the operator must translate these instructions into movements. This procedure leads to approximations and slowness in performing medical acts. Results were acceptable when the subjects performed examinations on themselves only. In addition, body areas that could be examined were very limited.

Taking these limitations into account, two ideas have arisen and led to the development of:

- Robotic tele-echography where the radiologist handles the probe through a remotely controlled robot;
- Automated 3-dimension scanning echography where the radiologist gets a 3-dimension reconstitution of the part of the body he/she wants to investigate (automatically scanned by the echograph).

Practically, such a tele-manipulation system requires:

- One “expert” station, i.e. sub-system positioned where the medical expertise is located;
- One “isolated” station, i.e. sub-system positioned where the patient and a medical assistant are located;
- Bidirectional telecommunications means in order to connect the two stations.

Particularly for real-time operations, the provision of tele-echography service relies on the availability of a sufficiently fast communication channel. This can be provided almost everywhere on Earth making use of existing satellite communications. Several systems and services based on open standards such as the DVB-RCS (developed in Europe through a number of activities in the frame of the ESA ARTES Programme) can be selected to support the tele-echography service. The opportunity of using European satellite communication products and services will be actively exploited in the course of the proposed activity.

Each “expert” station is composed of:

- One fictive probe, enabling the medical expert to manipulate the tele-echography robot;
- The dedicated command unit of the fictive probe,
- One laptop computer to display echographic pictures,
- One additional flat screen enabling the medical expert to have visual contact with the isolated site;
- One videoconference system integrated in the computer.

The “isolated” station is composed of:

- One robotic arm referred to as the “probe-holder robot”, which mimics the movements of the medical expert;
- The dedicated command unit of the probe-holder robot;
- One laptop computer
- One videoconference system integrated in the laptop computer.
Figure 2: illustration of the robotised tele-echography system

Figure 3: example of “expert” and “isolated” stations in a mobile context
2.1 Tele-echography across the world

Several projects\(^1\) have been launched worldwide in order to develop tele-echography.

- **LOGINAT**
  
  LOGINAT is a project based on a multi-centres visio-conferencing concept and has been experimented since 1993 for inter-hospital perinatal care. Initially providing real-time transmission of echographic sequences, the project was then limited to the transmission of static post-examination images because of networking limitations. Such a system is now only used for weekly videoconferences or tele-consultations (advice on some emergency pathological cases) between a few maternity hospitals.

- **TeleInVivo**
  
  The objective of the TeleinVivo European project was to develop a portable station to allow echographic exams in isolated regions. With a 3D ultrasound probe, a volume of data acquired by the operator close to the patient could be sent to a remote expert who, using a virtual ultrasound sensor, could examine the data in much the same way that he would examine a patient.

  For both these projects, operators still have to perform the examination on the patient even if he can be guided by a remote medical expert; moreover the expert has to perform the diagnosis on a purely visual basis.

- **HIPPOCRATE**
  
  HIPPOCRATE is a hybrid force-position controlled robot for assisted echographic diagnosis. The robot holds an ultrasound probe and can either be used for echography teaching or for measurements.

- **MIDSTEP (Multimedia INteractive DemonStrator TElEPrEseNce)**
  
  MIDSTEP system consists of 2 tele-surgery demonstrators (one for local tele-manipulations via Local Area Network - LAN, one for remote tele-manipulations via Wide Area Network - WAN) working in asynchronous transfer mode. Both demonstrators use a robot able to manipulate an ultrasound probe remotely controlled by a medical expert who will guide the surgeon located close to the patient.

- **SALCUDEAN echography robot**
  
  This robotic system was developed to provide assistance for echography diagnoses of carotid arteries and can be manipulated by a remote expert. The main idea was to suppress the discomfort felt by medical experts during such examinations. The system is made of a master unit, controlling remotely the position of the ultrasound probe via a haptic mouse, and of a slave unit reproducing the mouse commands and also acting as probe holder. The robot can be controlled in position or in force.

- **MASUDA system**
  
  The MASUDA tele-echography system was developed to carry out remotely controlled ultrasound examinations. A robot controlled by two joysticks (the first one controls its position while the other one controls its orientation) is positioned on the patient and detects the contact force between the ultrasound probe and the patient’s skin via force sensors. This information is used to enable a permanent contact between the skin and the probe, as well as for safety reasons (force

\(^{1}\) From “TER: a system for robotic tele-echography”, Lecture Notes in Computer Science and (see 2.4.1)
threshold). Different communication networks have been investigated (LAN, 128 Kbytes ISDN). The system is completed by a videoconferencing tool.

- **RUDS (Remote Ultrasound Diagnostic System)**

The RUDS system has been designed to carry out shoulder examinations. This system is based on a master/slave concept. The master unit whose structure is close to a manipulating arm enables the medical expert to feel the force exerted by the probe attached to the slave unit on the patient’s skin. This system has been tested with an ISDN network (3 ISDN lines are mandatory: 1 for the robot control, 2 for the transfer of medical images and videoconference capabilities).

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<td>Tele-echography</td>
<td>Satellite</td>
<td>Clinical use</td>
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<td>HIPPOCRATE</td>
<td>Robotic assistant for echography</td>
<td>I</td>
<td>Clinical validation</td>
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<td>Robotised tele-echography</td>
<td>LAN / WAN</td>
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<td>RUDS</td>
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**Table 1: Overview and development status of tele-echography projects**

Most of these systems are still under development and have been only partly validated, while the technology supported by ESA is more advanced technically and is nearly ready for a pre-commercialisation phase, once the operational infrastructure has been set up.

### 2.2 Experience of ESA in tele-echography & domains related to remote diagnosis

The European Space Agency, continuously aiming at improving its experience in monitoring and preserving human beings’ health, wellbeing and performance, is therefore very much involved in activities involving technology for monitoring, diagnosis and treatment of different pathologies either for use on the ISS, for future crewed exploration, missions or for European citizens.

ESA’s strength in activities such as developing services of remote diagnosis via tele-echography comes from its ability to bring together technical multi-sided competences and organisational skills (e.g. bringing together and managing industrial and scientific partners, collaborative work between directorates to merge their expertise). ESA holds indeed a key position in Europe combining expertise in science and technology as space infrastructure developer (See 2.3). ESA’s telemedicine activities involve the integration of various areas of expertise. Regarding satellite communications, ESA is promoting and supporting innovation through R&D activities enabling European businesses in associated Member States to develop world-class products and services, helping European citizens to benefit from high-quality, cost-efficient telecommunications. In the domains of life and physical sciences, ESA is involved in the development of advanced sensor technology, remote monitoring of health parameters and building and/or provision of related equipments.
2.3 Specific experience of involved ESA Directorates

The multisided expertise required to successfully achieve the goals of this project is provided through cross-directorates' collaboration. It involves the experience of the following ESA entities:

2.3.1 HME-GAL

Activities and knowledge of HME-GAL mainly deal with the study of Human Life Sciences, especially physiology, psychology and biology, for the International Space Station or future exploration missions, as well as for terrestrial applications where similarities with space activities can be identified. HME-GAL thus possesses specific expertise in defining strategies, assessing needs and critical requirements for future equipment and technologies required to conduct Life Sciences experiments and to support the health and well being of humans in extreme environments.

Moreover HME-GAL has solid expertise in identifying terrestrial situations (e.g. remote, isolated and mobile contexts, harsh environments) where technologies and concepts developed for manned spaceflights could also be of interest. Many efforts are currently invested at the Concordia station† to assess the efficiency of these technologies such as tele-echography.

HME-GAL has supported research on robotized tele-echography through a Microgravity Application Programme (MAP) whose result is the development of a prototype, which demonstrated its operational capabilities in different situations (Hospital located on Cyprus island, medical centre onboard a ship). This robot has even been tested under microgravity conditions during several ESA parabolic flight campaigns. HME-GAL is now working in collaboration with TEC-MMG on the acquisition of advanced tele-echography systems.

HME-GAL also gained some expertise in leading telemedicine projects during the second phase of Telemedicine Alliance, a European Commission funded project. This phase called TMA-Bridge dealt with the interoperability issues of telemedicine systems, which should be of relevance for this activity.

2.3.2 HME-AP

HME-AP has been focusing since some years on integrating the commercial approach and strategy within projects that typically belong to an institutionally-driven environment, and leading/ pushing the commercial exploitation of products and services resulting from activities conducted on-board the ISS or other microgravity carriers.

Within the daily implementation of this ISS commercialization policy HME-AP has gained experience in developing business strategies, in defining business plans, and in matters like IPR, NDA, commercial contracts, and partnership alliances.

HME-AP has also developed good knowledge of promotion techniques with a commercial oriented content always protecting the ESA image and interests such as: Participation at conferences, organisation of workshops and promotion events, as well as the creation and maintenance of website targeting industry, potential partners, as well as final consumers.

† Located on an Antarctic high plateau, Concordia Station is jointly run by the French Polar Institute (IPEV) and the Italian Antarctic programme (PNRA). The crew lives in an extreme environment completely cut off during the winter and therefore has to be fully self sufficient. The extreme environmental conditions and complete isolation make Concordia Station an excellent analogue to a Mars or Moon base, in which human psychology and physiology can be studied and life support and telemedicine technologies tested. ESA has already initiated a research announcement and has started implementing some medical experiments of relevance to the polar institutes and ESA's life science programme.
2.3.3 TEC-MMG

TEC-MMG is providing support to the HME Directorate, especially for all kinds of instrumentation systems for Life Sciences. This section thus has special experience in the development of technologies for monitoring purposes, diagnosis or even treatment.

Regarding diagnosis via ultrasound, TEC-MMG is in charge of preparing the technological transition between the prototype and pre-commercial phase of the robotised tele-echography system and will very soon issue an invitation to tender for the procurement of three new-generation versions of the existing system.

TEC-MMG is, in addition, fostering technology research and development on alternative monitoring, diagnosis or robotics techniques, pillars of the aforementioned global long-term approach. Regarding imaging systems, studies on possible MRI, pQCT and X-rays applications for space activities are on-going or foreseen.

2.3.4 TEN-TSU

TEN-TSU is experienced in supporting innovation in satellite communications and promoting the exploitation of satcom-based technologies by various service providers and applications developers. TEN-TSU holds special skills in telemedicine via satellite systems, having launched in the last ten years 27 different contracts in the frame of the different elements of the ARTES Programme covering telemedicine and medical education via satellite. An extensive overview of TEN-TSU’s involvement in activities related to the one proposed in this proposal can be found under http://telecom.esa.int/telemedicine.

2.4 List of references

2.4.1 Tele-echography references


- “Tele-operated echography in parabolic flight using a robotic arm (TERESA)”, Description of the experiment run under microgravity conditions during an ESA parabolic flight campaign, ESA Erasmus Experiments Archive, available at the following URL: http://spaceflight.esa.int/eea/index.cfm?act=search.record&id=9105&search=echography

- “Future astronaut diagnostics for the ISS bring advances in technology for telemedicine”, ESA web news available at http://www.esa.int/esaCP/ESA3DQ7708D_Improving_0.html.


- “Robot à trois degrés de liberté et à un point fixe” (Robot with three degrees of freedom and one fix point), French patent n°9903736, from University of Orléans representing LVR (25 mars 1999).
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- “Safety Analysis of a Medical Robot for Tele-echography”, J. Guiochet - LESIA (France), A. Vilchis - TIMC/IMAG GMCAO (France).


2.4.2 References to related activities of the involved ESA Directorates

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<th>Related Domain</th>
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<td>Telemedicine</td>
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<td>TEC-MMG</td>
<td>Imaging Systems</td>
<td>TEC-MMG is currently carrying out some activities in the field of: • Tele-echography • MRI • X-Rays • pQCT References will be provided at the end of these activities.</td>
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<tr>
<td>TEN-TSU</td>
<td>Telecommunication via satellite</td>
<td>A quite extensive list of references affecting the work of TEN in the field of Telemedicine via Satellite can be found under: <a href="http://telecom.esa.int/telemedicine">http://telecom.esa.int/telemedicine</a>.</td>
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