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Real time exhibition of a simulated space tele-echography using an ultra-light robot

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Abstract

A new tele-operated robotic system, specifically designed to perform an echography at a remote site, will be simultaneously presented between Montreal, during i-SAIRAS 2001 conference, and Paris le Bourget during the international 2001 Aeronautics and Space Show. At the site located in Paris le Bourget, called the "expert site", a clinical expert will be set with a fictive probe equipped with a 3D magnetic tracker position. He will receive from Montreal (slave station also called the "remote site") the ultrasound images of the remote patient's anatomical structures. Combining the 3D sensor information, force information and the received images, he will control the slave robot, located in Montreal, to remotely perform an ultrasound examination. A videoconference system will complete the expert site display by showing the ultrasound examination room and the patient located in Montreal. At the i-SAIRAS exhibition center, a non-specialized personnel will hold the 4-axis ultra-light slave robot on the patient's body. This room will also be equipped with videoconferencing system transmitting in real time the expert site image located in Paris le Bourget.

1 Introduction

Ultrasound examinations, in particular echographies, are currently used to support space research in human physiology as well as space medicine. A 2-D ultrasound system, for example, will be part of the equipment on board the international space station. They are also of increasing importance in daily medicine. Current technology provides, in real time, high resolution images, competing in many applications with medical imaging techniques which use ionizing radiation. 2-D Ultrasound techniques are considered as non-invasive, with some exceptions, and are relatively affordable. Therefore, use of ultrasound in space and daily medicine will increase even more in the future.

The main drawback of ultrasound techniques is that the quality of the examination highly depends on the operator's skills. This operator dependant technique is especially critical for examinations in microgravity environment, where crew time, in space and during training, is strictly scheduled. It also becomes a strong limitation in daily healthcare, because many healthcare centers could benefit from ultrasound examinations, but do not have the required medical experts on hand when needed. Therefore, tele-echography protocols are currently being developed or used in many telemedicine centers.

Among the various types of scenarios, one where the examination is partly or fully remotely controlled by the expert has been tested within the framework of the ESA tele-sciences program. The main advantage of this scenario is that it does not need the presence of skilled personnel at the remote site. Examinations on ten subjects have demonstrated that reliable data can be obtained with untrained operators at the remote site, increasing the duration of the examination by about 50 per cent. This experiment demonstrated the feasibility of an assisted tele-operated echographic examination.

Several scenarios concerning the use of ultrasound techniques have been recently developed in Europe and in the USA. Some concerns the use of industrial heavy robots, others use standard communication facilities to transfer ultrasound data from one clinical expert to another with eventually videoconference links. In 1998, a laparoscopic system, MIDSTEP, was guided, using a virtual environment, by a tele-operated industrial robot holding an ultrasound probe [1]. The expert was located at a control desk and the patient was either in an adjacent room or in a different hospital connected via an WAN network. In 1998 also, videoconference was used between two experts, one of whom was performing the echography examination. Both experts could simultaneously discuss the obtained ultrasound image, and the expert, distant from the patient, could suggest a different probe orientation for better observation and analysis of the area of interest. In 1999, a seven degree-of-freedom (dof) spherical industrial robot equipped with a force sensor was controlled to maintain an ultrasound probe in contact with a patient's carotid [2]. During a necessary learning phase, the robot was guided along the carotid artery by the medical expert. During the second phase the robot was able to follow the same path at a chosen speed and ultrasound topography were recorded to evaluate the artery compliance, arterial diameter and to analyse eventual pathologies. A another type of probe holder robotic system was developed by [3] to perform similar ultrasound task. In 2000, the TeleInVivo European project proposed a different approach : the echography was performed by a clinical expert standing next to the patient; ultrasound data were sent via satellite to a data base station and processed to reconstruct a 3D representation of anatomical regions of interest [4].

However, most of these proposed systems either use heavy and industrial voluminous robotics systems to guide the ultrasound probe or require the presence of a specialist nearby the patient, or are merely telemedicine approaches (e.g. the LOGINAT project [5] based on a multi-centres visio-conferencing basis has been experimented since 1993 for inter-hospital perinatal care) were data are transmitted via communication networks.

2 Tele-echography via satellite

An improved variant of the tele-operated echography is the use of a tele-operated probe-holding robot at the remote site. This technology was successfully demonstrated through the SYRTECH project conducted in the summer of 1998 in the Himalayas by the Laboratory of Vision and Robotics (L.V.R) [6]. During this experiment a clinical expert based in Bourges (France) operated, via a simple joystick and satellite communication (Inmarsat B), a 3 degree-of-freedom slave robot (figure 1) holding an ultrasound probe on a patient based in Nepal (figure 2) [7]. Ultrasound images were transmitted from Nepal in real time back to the expert who performed heart and kidney ultrasound scans on the remote patient and proposed a preventive diagnosis. The patented mechanism (named the "slave system") that we have developed has the following characteristics [8, 9]: it is a serial robot with 3 degree-of-freedom that enables continuous contact between the ultrasound probe extremity and the patient's skin;

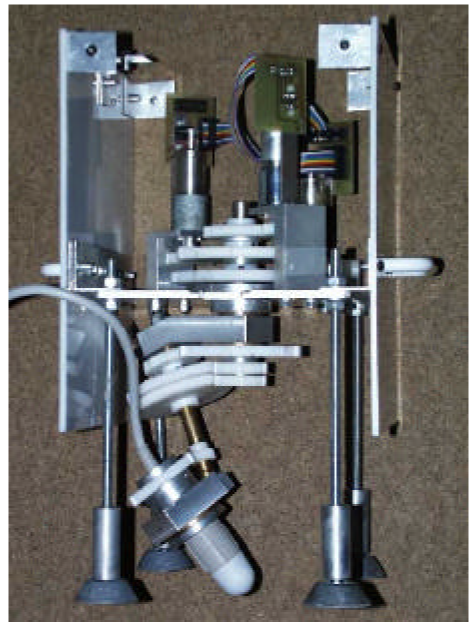
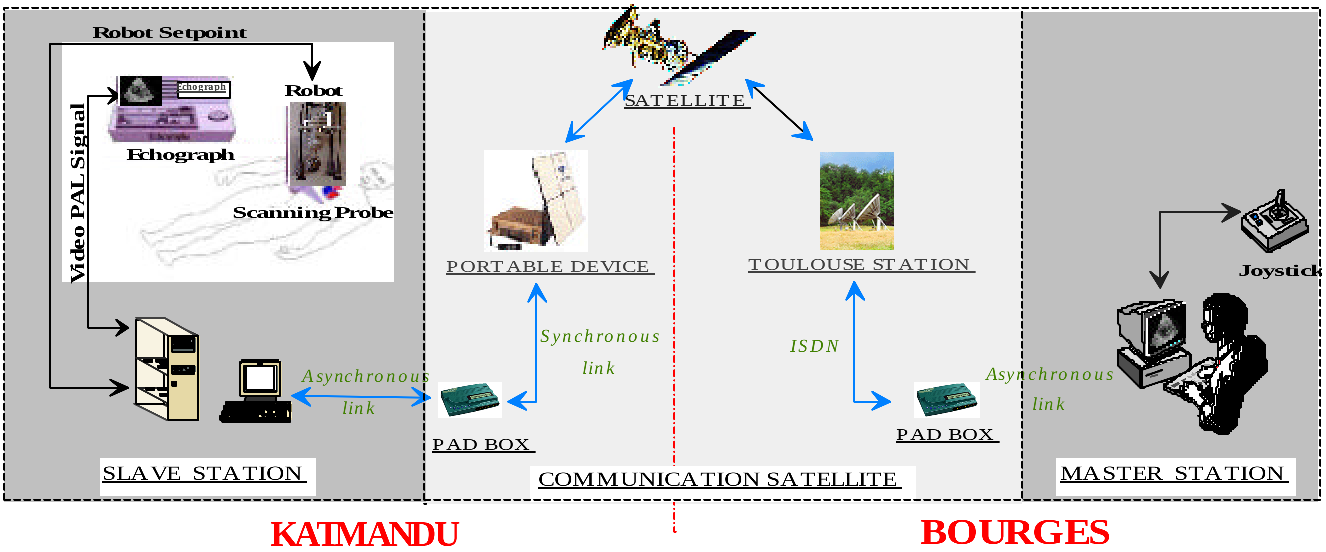


Figure 1 : Off the shelf 3 degree-of-freedom probe holder robot developed by the LVR for SHISHA 1998

the analysis of the clinical expert's hand movements enables the definition of the three Euler angles : the yaw for the choice between a cross section or a longitudinal cut, the pitch for a maximum angle of 45° with respect to the vertical axis, the roll to adjust the incidence of the ultrasound beam.

The results obtained from this SYRTECH project showed several areas for improvement for the tele-operated slave robot. First of all in the image transmission field : despite a strong image compression and a 56kbps flow rate, we only reached a 2 images per second rate. Secondly, the control/command of the slave robot by the clinical expert was then altered due to the communication link delay and the image flow rate. Furthermore, this experiment demonstrated that even being a non ultrasound specialist, the paramedical person seated next to the patient can operated the slave robot system. Also we demonstrated that its ergonomic structure is of a prime necessity to be accepted by the patient and to be handled with ease by the helper.



Finally, in order to improve his understanding of the scanned tissues or anatomical structures the expert needs, in addition to visual information about the distant scene, force feedback information for a precise vertical displacement of the ultrasound probe on the patient's skin.

3 Ultra-light robot demonstration

3.1 A 4 DOF mechanical structure

The continuity of the SYRTECH project is the concept of a new design including three degree-of-freedom dedicated for the rotational movements of the probe and one Z translation displacement to insure continuous contact between the ultrasound probe and the patient's skin.
This concept led to the development of a pre-industrial slave robot associated with its master system, financially supported by the European Space Agency (ESA) and with a collaborative effort between SINTERS company (Toulouse – France) and the Laboratory Vision and Robotics (LVR - Orleans University- France).

This tele-operated probe holder robot includes improvements mentioned above : a light weight and ergonomic structure for a better handling ; the probe-holder accepts a 3.5 MHz ultrasound probe. This type of probe should allow a specialist to perform several kind of investigations from abdominal, renal, cardiac to fœtal.
The actuators driving the robotics system have been chosen to give the best performances despite delays introduced naturally by communication links. Absolute encoders have been used to control the robot joints. In case of communication loss or perturbations during initialisation phase, these types of encoders allow the recovery of robot position control. They also permit accurate control of the mobile parts of the slave system. Control laws are conditioned by the kinematics and dynamics behaviour of the robotic system and the electronic real-time drivers. These laws should enable a fast and accurate positioning of the tele-operated probe-holder system.

Figure 3 : The 4 degree-of-freedom light robotic probe holder developed under contract funded by ESA 2000

In the tele-echography situation, when such a robot is remotely used by a tele-operator (in this case the clinical expert), it is desirable to communicate contact force information from the master to the probe handling system and back from the slave to the master station. The Z translation is combined with a force sensor, as mentioned above, to generate and evaluate the force exerted on the patient's body by the real probe.

3.2 The master station

In the tele-operated echography scenario, the expert will be remotely located from the patient bed and will entirely remotely controlled the medical act. Hence, the master station has to provide the clinical expert with a specific and ergonomic device with haptic feedback to ensure the rendering of the distal environment where the medical ultrasound act is being performed.

To accurately track the fictive probe displacements held by the expert's hand, a 3D magnetic sensor, the Flock of Bird (FOB) from Ascension Technology, was considered and affixed on the fictive probe (figure 4). This 3D magnetic tracker is a six degree-of-freedom measuring device that can be configured to simultaneously track position and orientation within a ± 130 cm range from the transmitter. The analysis of the clinical expert's hand movements during an ultrasound scan showed that the various orientations of the ultrasound probe refer to the three Euler angles (figure 5) :

- the yaw allows the choice between a cross-section and a longitudinal cut and reverse,
- the pitch angles the probe with a maximum angle of $\pi/4$,
- the roll adjusts the incidence of the ultrasound beam.

The medical act also shows that the probe has to have a continuous contact between its extremity and the patient's skin to avoid ultrasound signal loss.

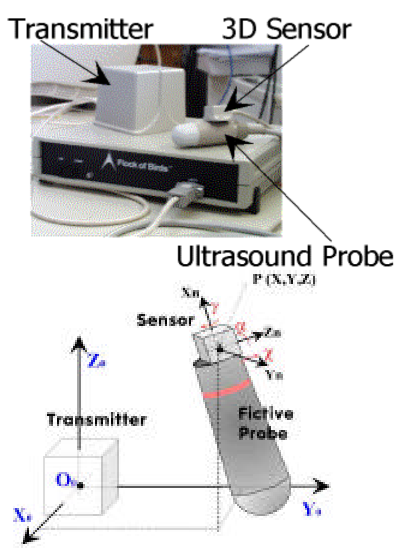


Figure 4:
a- Flock of Bird (FOB) 3D magnetic sensor and its transmitter (Ascension technology Co);
b- tele-echography Master system : fictive probe associated with the FOB

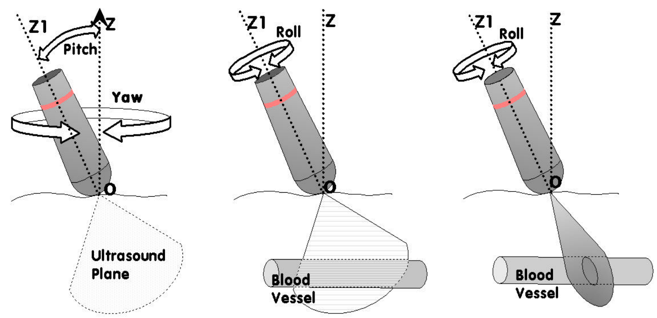


Fig 5a Fig 5b Fig 5c

Figure 5: Euler angles associated with the expert's hand movement. 5a : the pitch for a maximum angle of $\pi/4$ with respect to the vertical axis OZ; the yaw defines a rotation of the probe around the OZ axis with a continuous contact on the patient's skin, it adjusts the incidence of the ultrasound beam; 5b and 5c : the roll to choose between a cross section or a longitudinal cut

The position and angles data given by the FOB (figure 4b) are sent to the remote site located at i-SAIRAS 2001 conference center in Montreal (Canada) and analyzed via the reverse kinematic model of the slave robot. Simultaneously, patient ultrasound images are transmitted back in real time to the master site located at Paris Le Bourget Aerospace Show (France). These images will be used as a visual feedback control in order to help the expert to adjust the position and orientation of his fictive probe for a better analysis of the desired anatomical region of interest and to make for a pre-diagnosis.

As a first set up, the force information will be displayed on a dynamic bar graph, on the master station video system, to continuously assist the expert in the control of the applied force by the real probe on the patient's skin.

4 Communication link

During the real time exhibition between Montreal and Pairs, the tele-echography will be performed using two ISDN lines that will insure quality of service One line will be used to send audio/video data of the overall examination environment; the other line will be dedicated to send robot control data, haptic information and ultrasound images.

5 Conclusion

The tele-operated robotic system, presented during the exhibition, enable a medical expert to perform in real time, via an ISDN communication links, an echography on a patient remotely located. The tele-operated probe holder should bring accurate echographic and Doppler data required for the daily medical care of man in the micro-gravity environment and support for the research in extreme physiology of the cardiovascular system. This echography could be performed by astronauts with the sole handling of the "slave" light robot without heavy manipulation protocols.

Furthermore, echography is a widespread technique and is known by a large public. Tele-echography will have applications in many health ground sectors, for example:

- provide better access to healthcare in remote areas,
- allow the maintenance of local infrastructures (e.g. maternity units) supported by expert centres.

Another benefit of this industrial prototype would also be to lower the cost of ultrasound scan exams by performing examinations in local infrastructures, to reduce patient transportation costs to the expert center when it is not required, or the transportation of the clinical expert to the local infrastructure. From a professional point of view, this tele-operated ultrasound probe-holder could be used to demonstrate probe holding techniques to future clinical ultrasound specialists.

As a future study, the master-slave system will take into account haptic information in both directions. However, due to communication delays, one must face stability problems. Based on Niemeyer-Slotine [10] approach that considers the communication blocks as a lossless transmission line, we will optimize the transparency of the telemedicine chain by adjusting in real time the characteristic impedance, named the tuning parameter of the communication lines. This will enable a better rendering of the distant environment to the medical expert during the medical act.

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