ECHOGRAPHIC EXAMINATION IN EMERGENCY TELE-OPERATED USING A ROBOTIC ARM. APPLICATION TO ABDOMINAL & CARDIOVASCULAR PATHOLOGY AND OBSTETRICS.

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Abstract: As human will stay for long duration in isolated sites like ISS there will be a need to perform quick and reliable diagnosis to evaluate the gravity of the clinical symptoms. Many pathological situations (abnormal heart rate, cholecystis, renal lithiasis, phlebitis...) may occur even if all the astronauts are absolutely normal and healthy preflight. Ultrasound echography and Doppler are non invasive methods easy to use in space and very well adapted and used in routine for such diagnosis during clinical investigations at the hospital. The objective was to design a system which allows to control the echographic or Doppler examinations performed in an isolated place from an expert center. Three possibilities were evaluated: a) The operator in the isolated site is guided by vocal and video information in real time sent by the expert center. I the case of echography this system allows to identify the organ but not to find the appropriate incidence required for the diagnosis. b) A real time 3D system is available in the isolated site and the operator has just to collect the images in a volume that includes the organ to be investigated. The 3D systems are still under development and are expensive, energy consuming and larges. c) We designed a robotic arm fixed to the echographic probe and which reproduces exactly the movement of the hand of the medical doctor who guides the examination from the expert center. At the expert center the medical doctor moves the joystick of a computer (n°1) which simulates the echographic probe, the movement information are transferred by sattelite link to the ISS computer and the robot. A prototype have been build up by the institut of robotics (Bourges) and tested on 90 patients in our hospital (ISDN lines) and between main and secondary hospital and between a military hospital and a rescue ship of the navy (Satellite lines).

Key Words: echography, emergency, robot, Telemedicine.

I - Introduction: As human will stay for long duration in isolated sites like ISS there will be a need to perform quick and reliable diagnosis to evaluate the gravity of the pathology in presence of clinical symptoms. Many pathological situations (abnormal heart rate, pericardic collection, mitral prolaps, cholecystis, renal lithiasis, normal and ectopic pregnancies, ovarian cyst, acute appendicitis, phlebitis...) may occur even if all the astronauts are absolutely normal and healthy preflight. Ultrasound echography and Doppler are non invasive methods easy to use in space and very well adapted and used in routine for such diagnosis at the hospital.

The objective of the present project was to design a method that guarantee a reliable echographic diagnostic in an isolated site (space station or earth site) by a Medical Doctor located at the expert site that should be the Nasa control center for ISS. It is supposed that there is only a non sonographer person in the isolated site and that the transmission system (audio, video, numeric..) is the only link between the 2 sites. Two options are proposed: (a) The operator in the isolated site is guided by vocal and video information in real time sent by the expert center. I the case of echography this system allows to identify the organ but not to find the appropriate incidence required for the diagnosis. (b) A 3D realtime acquisition echograph that can record quickly all the echos of a volume containing the organ suspected to have a lesion [1-3], all these echo information being sent to the ground and processed by the ground experts (Fig 1), (c) A robotic arm that hangs the echo probe in the isolated site tele-operated (through sattelite network) from the ground by an expert in clinical ultrasound. [2] (As the expert moves the joystick of his ground computer the robotic arm reproduces the same movements on the probe) (Fig 2-3).

II - Material and method

The 3D realtime acquisition: The 3D system (Model 1 from 3D Volumetrics USA) is a realtime 3D acquisition system which probe consits of a matrix of
2Mhz transducers. This probe insonates the whole organ volume (heart, kidney..) and collects the whole backscattered ultrasound echo from this volume in realtime within one cardiac cycle. The system scans twenty two 64x64 degree pyramidal volumes per second at 15 cm depth. Each pyramidal volume (pyramid of insonation) contains 4096 scan lines that are spaced approximately 1 degree apart in azimuth and in elevation. (von Raum et al 1990). The ultrasound information (echos) collected within 1 cardiac cycle are stored as a pyramidal volume into the active memory of the device and can be replayed in a cineloop mode in realtime. This volume stored into the memory can then be cut out in 2D plans of any chosen orientation by moving a set of cursors which change the intersection of the 2D plan with the limits of the pyramidal volume (Fig 1).

The Robotic arm: The Laboratoire Vision Robotique from Bourges (France) developed a robot according to our concept and technical requirement (UMPS – Tours – France). This robot consisted in a motorized support hanging the echo probe, and able to orientate the probe in most of the directions requested for an echographic examination. The present system has 3 degrees of liberty: the robotic arm reproduces on the probe, rotating movement around the probe axis, tilting of 50 degrees around the axis perpendicular to the skin, and circular movement around the vertical axis on any tilting angle. (conic movement). Micro electrical engines controlled by a PC computer allow to select and induce progressive probes movements. The robotic arm fixed to the echographic probe (in the isolated site) will reproduce exactly the movement of the hand of the medical Doctor who guides the examination from the expert center. At the expert center the medical Doctor moves the fictive probe of a computer (n°1) which simulates the echographic probe. This computer (n°1) send the coordinates changes related to the fictive probe movement to the computer (n°2) of the isolated site. The computer n°2 reproduces the same movement on the robotic arm to which the ultrasound probe is fixed. Presently the system cannot translate the probe by his own. Only the operator in the isolated site can translate the robot-probe support on the basis of the audio information of the expert (Fig 2, 3,4,5,6).

Results: The system was tested on 90 patients using ISDN lines. In all cases the expert was able to perform the main views (longitudinal, transversal) of the liver, gallbladder, kidneys, aorta, pancreas, bladder, prostate and uterus as during direct examination on the patient. The cardiac 4 chambers and spleen were not visualized in two and four out of the 20 cases respectively. The main fetal views were collected in all cases below 37 weeks of gestation, but in 80% of the cases after 37 weeks. The mean duration of the robotized echography (28+/6 min for three to four organs) was approximately 50% longer than in direct echography of the patient. Using satellite communications the system was also tested between ground centers (University Hospital and secondary clinical center at 60 km) (Fig 6) and between a military hospital and a rescue ship of the navy at 100 km on the see.

The preliminary validation show that the robotized echography allow to make 80 to 100% of the case a diagnostic similar to the one provided by direct echography on the patient. One of the reason is that echography is operator dependent, which means that only the hand of the expert can find easily the incidence required for the diagnostic. Because some degree of angulation or rotation of the probe can change a bad incidence (no organ view, no diagnostic) into a good one sufficient to make the diagnosis, we believe that the robotic arm system is the most adapted system. The possibility to tele-operate the ultrasound examination from the an expert center (via the Robot) will provide to any isolated patient the same diagnostic performances as at the Hospital (fig 7). The 3D capture of images could be an alternative but it requires a higher level of practice for the operator in the isolated site and more expensive and sophisticated echographic devices which are not usually present in isolated sites.

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References:
Figure 1. (a) 2 Dimensional echographic probe, investigating a sector field. (b) Matrix probe investigating a pyramidal volume. (c) Transverse and apical views obtained from the pyramidal volume echo data.

Figure 2: The concept of the tele-echography based on the use of a robotic arm.
Figure 3: View of the Robotized arm (echo probe inside) maintained on the abdomen of the patient by the operator of the isolated site.

Figure 4: (a) Fictive (expert center) and (b) real echographic (isolated center) probes. The grey box close to the fictive probe allow to determine the coordinates changes of this fictive probe. The movements of the fictive probe (tilted, precessed, rotated) are applied to the real probe thank’s to the electrical engines of the blue robotic arm.

Figure 5: (a) Isolated site with the patient, robot, PC computer “2” for driving the robot, echograph and visio-conf (b) The expert, fictive probe, PC computer “1” sending movement informations to PC “2”, echographic view and a visio-conf camera.

Figure 6: Expert center at Toulouse « La Grave Hospital ». The robot seen on the left screen is at “Mazamet city Maternity” (30 miles away). The echographic view of the fetus is displayed on the right screen.
Figure 7: examples of Normal and pathological echographic views

(a) Normal Gall Bladder (black inside means liquid and no Lithiasis, thin bright contour mean no inflammatory process)

(b) Bladder (larger circle) and ovarian cyst on its left (*).

(c) Normal kidney (ovale): Central part bright and contour dark, cavity not seen.

(d) Kidney with dilated cavities (*). Black means liquid => urine stagnation due to downstream obstruction by a lithiasis.