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● *Technical Note*

REMOTE ECHOGRAPHY BETWEEN A GROUND CONTROL CENTER AND THE INTERNATIONAL SPACE STATION USING A TELE-OPERATED ECHOGRAPH WITH MOTORIZED PROBE

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Abstract—Echography is the most appropriate imaging modality for investigating astronauts. Unfortunately, it requires a great deal of training to perform ultrasound examinations, which can be difficult and time consuming, especially if the astronaut does not have a medical background. We designed a new echography system with motorized probes that allows for the majority of exam functions to be controlled by a ground-based sonographer. Using tele-operation, the sonographer controls the orientation of the transducer (tilt, rotation) and echograph settings (gain, depth, freeze) and triggers ultrasound functions (pulsed wave color Doppler, 3-D capture, radiofrequency data collection, elastography). With this system, astronauts are required to hold the motorized probe only at the locations indicated, with the remainder of the exam being conducted by the ground-based sonographer. During spaceflight, ultrasound imaging of the carotid artery, jugular vein, thyroid, liver, gallbladder, biliary tract and portal vein (2-D, 3-D, color, pulsed wave, radiofrequency) were successfully performed. (E-mail: arbeille@med.univ-tours.fr) © 2018 World Federation for Ultrasound in Medicine & Biology. All rights reserved.

Key Words: **Echography, Tele-operation, Motorized probe, Remote control, Space medicine, Astronaut, International Space Station.**

INTRODUCTION

Remote ultrasound investigations are highly beneficial for isolated medical centers on Earth as well as inflight investigations of astronauts. Several robotic systems have been developed and validated that use a robotic arm to hold the probe on the patient's body and allow the sonographer to remotely control the orientation of the probe (Arbeille et al. 2005; Avgousti et al. 2016a, 2016b; Boman et al. 2009; Otto et al. 2012; Vieyres et al. 2003). These systems allow for reliable echographic diagnoses (Georgescu et al. 2015), but are heavy and large, are difficult to manipulate and do not allow for tele-operation of the settings and functions of the echograph. Moreover, the robotic systems require a heavy mechanical support to hold the robotic arm (100 kg), which cannot be easily moved around the patient or over the patient skin and can be quite expensive (∼100,000€ plus ∼30,000€ for the echograph). Although effective for some clinical evaluations, logistically, the robotic system is not ideal for use during spaceflight.

To date, ultrasound evaluations onboard the International Space Station (ISS) were performed using the "remote guidance" method, in which a ground-based expert verbally assists the astronaut in orienting the probe and finding the expected view of the organs (Hamilton et al. 2011). This requires training of the astronauts performing the evaluations, which can often be limited, especially for astronauts without medical backgrounds. Consequently, during inflight examinations, the time to acquire each image is often long, the functions are not triggered at the right time and the quality of the image is not always of sufficient quality for evaluation, with some recordings completely missing the organ of interest. In many cases, optimizing imaging quality requires fine adjustments of the probe such as a

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2° or 3° tilt or movement of the probe by half a centimeter, which can often be difficult to communicate verbally.

With "remote guidance" the astronaut is required to (i) select the right preset of the echograph and enter his or her ID and session name; (ii) correctly locate the probe over the organ of interest; (iii) orient the probe to get a "perfect" long-axis or short-axis view; (iv) adjust the setting to optimize the image; (v) activate specific functions such as Doppler, time motion and 3-D; and (vi) freeze and store images and video. Therefore, the primary objective of the work was to design a new device for which most of the functions (i, iii, iv, v and vi) are controlled by the sonographer from the ground. With this system, the astronaut is only required to position the probe in the location indicated by the ground-based expert and hold the probe motionless for the duration of the examination. As the astronauts are not required to operate the ultrasound functions, they can focus on maintaining the probe in the proper location for the examination. It is anticipated that use of this new system will save crew time, as image acquisition and optimization are performed by the trained expert sonographer on the ground. Additionally, this system allows the sonographer to start functions at the appropriate time for better signal acquisition (Doppler, color, 3-D, freeze) and, therefore, better scientific data. Finally, this system does not require the assistance of additional ISS crew as the ultrasound functions are controlled from the ground, a task that astronauts would frequently recruit other crew members to assist with using the "remote guidance" technique.

In addition to spaceflight applications, this system could also benefit isolated medical centers on Earth that do not have an easy access to ultrasound imaging. Therefore, before being sent to the ISS, the tele-operated ultrasound with motorized probes was validated on patients in isolated medical centers (Arbeille et al. 2016). The following is an extension of this work reporting the preliminary results using this system on the ISS.

METHODS

Tele-operation of the ultrasound system was facilitated by modifying a commercially available echograph (Orcheolite TE, Sonoscanner, Paris, France) to be controlled through an Internet connection (TeamViewer GmbH, Göppingen, Germany) (Fig. 1c). Using a standard keyboard, the expert sonographer can adjust the settings (gain, depth, *etc.*) and trigger functions (Doppler, color, 3-D, *etc.*) of the echograph. The design and weight (6 kg) of the echograph were not altered from the commercially available system, but new analysis functions were added including elastography, 3-D reconstruction, panoramic display, radiofrequency (RF) display and parameter calculations associated with the previously listed functions.

Motorized probes, slightly larger and heavier (400 cm^3 and 430 g) but similar in appearance to 3-D probes (Vermon, Tours, France), allowed for the tele-operation of probe orientation. Two probes were developed specifically for this system; a convex array transducer (3.5−7 MHz) for deep organ examinations, and a linear array transducer (5−17 MHz) for superficial organs. The motorized components of the convex array transducer (Fig. 1a, d) tilted the transducer between +55° and −55° and rotated the transducer ±180° about the central axis. The linear transducer was also able to tilt between +55° to −55° and rotated ±90° about the central axis, with a precision of 1°. A dummy probe (Fig. 1b), connected to a computer using a USB connection, was used to tele-operate the motorized probes though custom software (Optimalog, St. Cyr-sur-Loire, France).

For image optimization, tilting and rotating movements of the probe transducer needed to occur in single-degree increments/decrements. In practice, the tilt and rotation direction and amplitudes were checked by the expert by placing the motorized probe head in front of the cabin camera. Additionally, the Optimalog software, used for probe movements, displayed four icons corresponding to the tilt and rotation (positive/negative) amplitudes so that the sonographer would know when the transducer reached the limit of each of these movements.

To be usable for spaceflight application, the system had to meet several technical requirements. The delay between the sonographer and the tele-operated system needed to be shorter than 3 s. Therefore, signals from the dummy probe and control keyboard needed to reach the tele-operated ultrasound in less than 1 s, with the corresponding images and function changes returned to the sonographer in a similar time frame (Fig. 2). This delay allowed the sonographer to make fine adjustments to the probe orientation and return to a previous orientation if necessary. Additionally, the minimum requirements for the video downlink were 1 Mbit/s with a frame rate of 10 frames/s to maintain a fluid video stream without imaging pixilation. A dedicated communication link between the ISS and the ground space center (CNES/CADMOS, French Space Agency) in Toulouse (with an end-to-end Teamviewer VPN encrypted based on the UDP protocol) was set up by ESA/NASA for use with this ultrasound system. On the ground, a domestic Internet was used (1 Mbit/s, approximately 12 frames/s, Teamviewer VPN encrypted, TCP protocol).

In the case of communication loss (where the sonographer was unable to tele-operate the system), a