17th International Conference on Space Operations, Dubai, United Arab Emirates, 6 - 10 March 2023.

SpaceOps-2023, ID # 453

Autonomous uLtrasound Image improvement SyStEm (ALISSE) for guiding astronauts to take clinically valuable images in future long manned Space missions

**PhD. David Miraut[a], Gabriel Reale[a], Carlos Illana[a]*, Arnaud Runge[b], MD. Rebeca Tenajas[c],
PhD. MD. Áurea Diez[d], MD. Rodrigo Alonso-Gonzalez[d], PhD MD. María Luz Parra-Gordo[d],
MD. Silvia Ossaba[d], PhD. MD. Milagros Marti[d], PhD. MD. Gonzalo Garzón[d]**

[a] *GMV Innovating Solutions, 28760 Madrid, Spain, cillana@gmv.com*
[b] *European Space Agency—ESTEC, 2201 AZ Noordwijk, The Netherlands*
[c] *Área de Salud Oeste Madrid. Centro de Salud Arroyomolinos. 28935 Arroyomolinos, Spain*
[d] *Servicio de Radiología. Hospital Universitario La Paz, 28046 Madrid, Spain*
* Corresponding Author

Abstract

Deep Space is a very hostile environment for human body. Ultrasonography is currently utilised on ISS for monitoring research purposes. In addition to being non-invasive, it offers a number of other advantages, including providing real-time functional/dynamic information, having a low harm profile, and supporting numerous clinical and research applications in terrestrial medicine. Moreover, ultrasonography devices are already portable, and the size and power requirements of these devices continue to shrink. As such, it is likely that ultrasonography will be the preferred conventional imaging modality capable of meeting the constraints of future exploration missions.

Despite its many advantages, however, a significant limitation of ultrasonography is its inherent dependence on a skilled operator to capture images of sufficient quality for diagnostic purposes. Ultrasound imaging modality requires years of training for each scanned organ in order to be able to implement the full diagnostic capabilities of the technique. As a result, all ultrasonography activities to date that have been conducted during space missions have included direct participation and/or real-time guidance from ground-based experts via videoconference.

Planning future long manned Space missions requires the development of new solutions in the healthcare field. Medical support in Space exploration must be reconsidered to provide much more autonomy to crews because of communication delays, the limitations in terms of medical systems can be available for the crew as well as the difficulty to execute evacuations during the missions, among other technical factors.

ALISSE (Autonomous uLtrasound Image improvement SyStEm) system is an *ongoing* TRL-4 European Space Agency (ESA) project that will improve computer-assisted ultrasound acquisition workflow, by detecting clinically-valuable ultrasound planes and by providing clear indications for moving the probe while scanning key organs and acoustic views, which have been prioritized by ESA medical operations (MEDOPS) team. ALISSE system integrates the latest advances in Deep Learning architectures to drastically reduce the slope of the learning curve in ultrasound imaging, in the context of space missions beyond low Earth orbit (LEO), with a practical point of view and the spirit of expanding its application to a wider market on Earth. The AI-based guidance will help astronauts and technicians without radiologic expertise to follow standard protocols, and to take images than can be easier interpreted to avoid diagnostic errors. This Space technology will have a nice impact on Earth, as portable ultrasound will be as popular as stethoscopes for all physicians as soon as its learning curve gets flatten.

Keywords: ultrasound, space medicine, artificial intelligence, smart ultrasound

Acronyms/Abbreviations

AI	= Artificial Intelligence
ALISSE	= Autonomous uLtrasound Image improvement SyStEm
EPSRC	= Engineering and Physical Sciences Research Council
ESA	= European Space Agency
ISS	= International Space Station
LEO	= Low Earth Orbit
MBRSC	= Mohammed Bin Rashid Space Centre
MEDOPS	= Medical operations
POCUS	= Point of care ultrasonography
PULSE	= Perception Ultrasound by Learning Sonographic Experience project
t-SNE	= t-distributed Stochastic Neighbor Embedding

UK = United Kingdom
US = Ultrasound

1. Introduction and motivation

Astronauts need to be kept safe inside a spacecraft or spacesuit to be protected against the effects of vacuum and extreme temperature variations. However, while their habitat can provide them with enough breathable air, water, food, acceptable temperature and pressure, the limited habitable closed volume, the exposure to high levels of radiation and weightlessness remain very challenging for astronaut's physiological systems, in particular for abdominal organs, the cardiovascular system and the musculoskeletal system. Such conditions may indeed lead to balance disorders, fluid shifts, visual alterations, cardiovascular deconditioning, decreased immune function, muscle atrophy and bone loss, which are fortunately for most of them recoverable upon return on Earth.

The success of human spaceflight is therefore intrinsically linked to the health and safety of crewmembers. To achieve this, the European Space Agency (ESA) and other Partners of the International Space Station (ISS) Program employ a range of risk mitigation strategies before, during and following flight. For instance, in-flight, a range of countermeasures is routinely applied. Specific medical equipment (and associated training) is also provided to manage off-nominal and emergency operations and/or to support scientific experiments allowing to better understand the behavior of the human body during space missions. For this purpose, medical imaging is key. Non-invasive imaging is a standard component of modern-day medical diagnostics and will likely be a critical component of the medical capability for future space exploration missions beyond Low Earth Orbit (LEO), where more complex, invasive approaches will be extremely difficult, if not impossible.

The ultrasound imaging modality stands out for its safety, portability, non-invasive nature, and comparatively low cost. However, ultrasound imaging exam is particularly subject to errors, more than any other diagnostic imaging technique; indeed, the misinterpretation of images should be considered as a significant risk in ultrasound-based diagnosis. Ultrasonography is highly operator-dependent, making it essential that the sonographer is properly trained in order to be able to implement the full diagnostic capabilities of the technique.

This combination of low cost, portability and very specialized training has leaded to a situation where ultrasound imaging is a medical image modality that is atomized among a large amount of medical Services at any Hospital. So, for example, a cardiologist is used to perform very detailed ultrasound exams of the heart, but they do not know how to deal with other organs because of their extreme specialization.

The steep learning curve in ultrasound imaging is mainly caused by the next factors:

- The operator must place the transductor on the patient's body surface at very precise locations, to allow the signal to reach the desired organ and bounce back to the sensor. Bones (such as ribs) and certain organs (such as the lungs) are opaque to pressure waves, so they must be avoided in order to reach the target organ.
- Both the exact location of the acoustic windows and the force to be exerted with the probe slightly depend on patient's morphology and gravity conditions.
- In conventional two-dimensional (2D) ultrasound imaging, the user acquires a series of images of the region of interest while moving the ultrasound transducer by hand. Based on the content and the motion patterns used, he/she then performs a mental 3D reconstruction of the underlying anatomy. As far as most quantitative information is lost (distances between anatomical structures, exact locations relative to other organs, etc.), physicians have defined a set of protocols to obtain standard views that contain most of the relevant features in the 2D cutting plane of the organ. But, such views are not easy to be located for a person with limited training.
- Ultrasound images are noisy, and they are affected by signal dropout, attenuation, speckle, and acoustic shadows. So, one does not always perceive the anatomy as clearly as one would like. Moreover, a soft-textured image, free of noise due to excessive filtering or incorrect gain settings, is useless from a clinical point of view.

Astronauts would need years of radiology training to grasp all the anatomic and pathological subtle features in blurry, noisy and operator-dependent 2D plane cuts of ultrasound images, much beyond any gamificable learning process. Even the crew medical officer (CMO) cannot afford to spend such amount of time and effort in an already crowded schedule for their space mission preparation.

As a result, all ultrasonography activities to date that have been conducted during space missions have included direct participation and/or real-time guidance from ground-based experts via videoconference. That is, one radiologist on Earth does supervise the ultrasound scanning process by dictating instructions to two astronauts, the one who is scanned and the one who is scanning in the spacecraft, while the radiologist watch both a video recorded from a camera where the probe and body part to be scanned are exposed and the captured screen of the ultrasound device. By these means, the radiologist can figure out how the probe is located and the anatomical features shown by the ultrasound signal, to provide indications to the patient (like holding the breath or performing some voluntary movement) and to the operator (like rotating, tilting, or sliding the probe in some relative direction).

Space missions beyond LEO put new unique challenges on the table. Digital communications cannot be considered instantaneous anymore. Even in the Moon orbit at 1.5 seconds light, an audio or video signal needs around 10 seconds to be transmitted to Earth and viceversa, because of the satellite communication repeaters. For a hypothetical Mars mission, the crew will be from 54 to 402 million kilometres away, making return to Earth for medical treatment unfeasible. Telemedicine and remote guidance interactions will not be effective, at least in their current form (i.e. real-time interactions). Ideal radio communication signal (at light speed) may require up to 20 min to reach Mars from Earth.

As far as communication latency prevents Earth-based doctors to guide astronauts or robots to perform the exploratory protocols, **GMV proposes a new modular system that will help and guide** CMO (or any other crew member with basic US training) **to obtain clinically relevant -implying sufficient quality- ultrasound images from selected organs and their standard views through the acoustic windows, without real-time assistance from Earth**. Once ultrasound images are taken, they could be studied on board or sent to Earth in order to have a shared diagnostic opinion.

In non-emergency situations, it will still be feasible to transmit to the ground a limited number of the captured images for expert analysis, but those images must already be of sufficient quality for diagnostic purposes. As far as communication latency prevents Earth doctors to guide astronauts or robots to perform the exploratory protocols, the ALISSE consortium proposes a new modular Deep Learning system that will help and guide any crew member to autonomously (i.e. without human real-time assistance from Earth) obtain clinically relevant ultrasound images from the key organs and their standard views through the acoustic windows. Once ultrasound images are taken, they could be studied on board or sent to Earth in order to have a shared diagnostic opinion.

Then, in the context of ALISSE project, our main challenge in ultrasound examination is related to **reduce its dependence on the operator skills**, so we explore how to **improve the efficiency and autonomy in the acquisition workflow of this image modality for non-expert users by helping them with artificial intelligence (AI)-based guidance**.

From an image processing point of view, ultrasound medical modality is specially challenging: recognition systems must deal with organ deformation (depending on exerted pressure), many image artefacts (exploited by radiologists to diagnose pathologies), speckle noise, shadows, echoes, moving elements inside the body, blurry and noisy images, domain adaptation among devices from different vendors, very low signal to noise ratio (SNR), unknown post-processing settings… such features are far from the statistics of natural images where conventional convolutional neural networks perform well.

ALISSE AI-based guiding system is the visible peak of the iceberg in this data-driven project. Our AI-guiding system relies on large, high-quality curated datasets. As far as there are no public datasets for standardized ultrasound standard views available among the scientific community, we had to develop a myriad of modules and tools to help radiologists and scientists create the dataset of fully-anonymized labelled ultrasound images to train the neural networks and transfer their knowledge to our system.

As previously said, ALISSE is a TRL-4 *ongoing* project. At the moment of the presentation of SpaceOps conference, ALISSE is in the middle of its implementation phase, far from the final prototype and the later rigorous clinical validation process in the final stage of the project.

In this paper, we describe a portion of our in-house keystone tools to assist the radiologist team to label a vast image dataset, which are specially designed to improve their efficiency, and some very preliminary results in AI-based organ and clinically-valuable plane recognition in real-time ultrasound video.

2. Structure

After discussing related work in Section 3, we give an overview of the effects of the spacecraft environment on the human body, and the importance of monitoring the urinary system in Section 4. We then describe our strategy to build the dataset and the developed software solutions to help radiologist to label images in Section 5. We discuss some of our preliminary experiments and their results in Section 6 and end with a discussion and conclusion in Section 7 and Section 8.

3. Related work and impact on Earth

Abnormal fetal development is a leading cause of perinatal mortality in both industrialized and developing countries. Currently, most developed countries offer at least one routine ultrasound scan at around mid-pregnancy between 18 and 22 weeks of gestation. However, detection rates remain relatively low. For example, it is estimated that in the UK approximately 26% of fetal anomalies are not detected during pregnancy. Detection rates have also been reported to vary considerably across different institutions which suggests that, at least in part, differences in training and skillsets may be responsible for this variability.

On one hand, the diagnostic accuracy is limited due to poor signal to noise ratio and image artefacts such as shadowing. On the other hand, guiding the transducer to the correct scan plane through the highly variable anatomy and assessing the often hard-to-interpret ultrasound data are highly sophisticated tasks, requiring years of training [1]. At the same time, there is also a significant shortage of skilled sonographers, with vacancy rates reported to be as high as 18.1% in the UK [2]. This problem is particularly pronounced in countries of the developing world, where the World Health Organization estimates that many ultrasound scans are carried out by individuals with little or no formal training.

Ultrasound obstetric scans typically involve imaging a number of standard scan planes on which biometric measurements are taken (e.g. head circumference on the transventricular head view) and possible abnormalities are identified (e.g. lesions in the posterior skin edge on the standard sagittal spine view). Furthermore, it is far from trivial to obtain a clear image of a desired view if the fetal pose is unfavourable. Even identifying the relevant structures in a given standard plane image can be a very challenging task for certain views, especially for inexperienced operators or non-experts.

A significant portion of academic works on Smart Ultrasound [3] follow the wake of large-scale research projects in United Kingdom (UK). We highlight two, which have a long scientific trajectories: iFIND project aims to improve the accuracy of routine 18-20 week screening in pregnancy, by bringing together advanced ultrasound imaging techniques, robotics and computer aided diagnostics. It was founded with more than £10 million by the Wellcome Trust and the Engineering and Physical Sciences Research Council (EPSRC). PULSE (Perception Ultrasound by Learning Sonographic Experience) project, is prospective study of routine fetal ultrasound scans performed in all trimesters by accredited sonographers and fetal medicine doctors at the maternity ultrasound unit, Oxford University Hospitals NHS Foundation Trust, Oxfordshire, that was funded by EU with 2.4 million euros.

ALISSE stands on the shoulders of such giant projects. Our priority is guiding astronauts to take good ultrasound images with clinical value and identify the right standard planes in real-time.

We think ALISSE project will also have a positive impact on the time-consuming and repetitive tasks for medical practitioners, because the “smart” guidance for assisted scanning will simplify their job, increase their productivity, reduce costs, and improve the efficiency of the workflow. And, its impact on Earth can be even bigger, if we are able to provide assistance and to reduce the level of necessary expertise during the scanning; for example, many women in developing countries do not receive a single ultrasound examination throughout their pregnancy due to a lack of skilled operators [4]. Living conditions would improve in these remote regions if ultrasound scanning could be performed by anyone with a system like ALISSE, so only selected ultrasound images with clinical value would be sent to radiologist experts to be evaluated (independently of doctor’s place of residence).

4. The effect of the spacecraft environment on the human body

There is an extensive literature on the lack of adaptation of humans to the space environment and the changes that occur in the astronauts' bodies [5]. If we consider that they are kept inside a spacecraft, where they have enough breathable air, water, food, acceptable temperature and pressure, we can ignore[*] the effects of vacuum and extreme temperature variations that are fatal in a very short time.

However, the limited habitable room, the exposure to high levels of radiation and the absence of gravity make the interior of the spacecraft a hostile environment for humans, quite aggressive for internal organs. Such small living space with low gravity conditions may lead to balance disorders, fluid shifts, visual alterations, cardiovascular deconditioning, decreased immune function, muscle atrophy and bone loss.

---

[*] Although, other factors appear because of the small closed living environment, like CO2 levels, water and food, toxicology and microbiology related issues.

In fact, without the influence of gravity, the **musculoskeletal** system no longer has the function of maintaining posture and the astronauts execute alternative movements to terrestrial locomotion in order to move around within the spacecraft.

On the one hand, in this type of environment, the astronauts hardly exercise or carry any weight on the **muscles** of the back, nor on the muscles of the legs to stand up. As a result, these muscles weaken and quickly atrophy [link]. On the other hand, when other groups of muscles are used in daily tasks, their development changes. Thus, the slow-contracting (more resistant) fibers used to maintain posture are replaced by fast fibers that are not as strong. Therefore, it seems logical to monitor their evolution, beyond other possible problems derived from accidents that can be observed with ultrasound images.

Bone metabolism changes too. Normally, the bone develops in the direction of mechanical stress caused by the upright position in gravity, however, in an environment of microgravity there is almost no stress. In space, there is an increase in osteoclast activity compared to osteoblast one. This causes a loss of bone tissue [link] [6], especially in the lower vertebrae, hip and femur. Because of the drastic change in bone density, prolonged stays can lead to bone fragility similar to osteoporosis.

The increase in calcium in the blood, largely caused by the mechanism of bone atrophy described above, promotes the calcification of soft tissues and the formation of stones in the **kidney**, which can move to the **bladder.** The lack of gravity greatly complicates their expulsion.

Stones are a quite serious problem in space [7], not only because of the extreme pain of renal colic and its impact on human performance, but also because of the complications (such as haematuria, infection and hydronephrosis) that may require evacuation of the spacecrew.

Although some gallstones have no symptoms, they can cause a blockage within the bile duct or **gallbladder** that can lead to severe pain and inflammation (cholecystitis) requiring surgery. Because it is not an essential organ, astronauts are advised to have it removed (along with the appendix and wisdom teeth) before going into space [8]. Further, the diet on spacecraft is adapted to try to reduce its occurrence.

Fortunately, both types of calculi are opaque to ultrasound signal and can be easily characterized.

The body consists mainly of water, both intra-vascular and intra-cellular. In microgravity, the fluids tend to quickly spread to the upper body, causing the face to swell and causing a nasal congestion [link] that can remain throughout the trip.

In the case of the **main vessels** in the absence of gravity, the redistribution of fluids causes the **jugular and carotid** to have a much greater volume of blood than is usual on Earth, and their widening can have negative effects and produce damage. Although astronauts do not usually have fatty plaques due to arteriosclerosis, calcifications due to the increased dissolved calcium in the blood can have an equivalent effect. In addition, the possible presence of clots should also be monitored with ultrasound imaging, as has been shown recently [9].

Abdominal cava and aorta pose a different challenge due to two factors. On the one hand, they are located deeper inside the body, so it is needed a much lower frequency ultrasound probe to visualize them. Without specific probes for this task, the image is quite noisy, which makes it difficult to follow them and determine its width. And, on the other hand, the increase in astronauts' flatulencies, makes think that there is also an increase in the amount of air / gas in the digestive tract, which may be an additional complication to visualize these vessels.

Because there is a decrease in the amount of blood in circulation and the **heart** does not have to "fight" gravity to pump the blood through the body, the heart tends to shrink and weaken, which lowers blood pressure.

It is also interesting to monitor the possible appearance of thrombi that are temporarily trapped in the heart chambers. For this purpose, the measurement of the size of the chambers and the volume ejected during the beat, can be good indicators of their evolution, but requires large expertise on echocardiology to pose the ultrasound probe in the right locations of the acoustic windows. The influence of deep-space radiation on the heart is probably not visible in the short term or with this medical imaging modality, although it has been demonstrated its devastating long-term influence [10].

Because weightlessness increases the amount of fluid in the upper body, astronauts also experience a noticeable increase in intracranial pressure. The pressure at the back of the **eyes** also increases, which changes their spherical shape and slightly presses on the optic nerve [11][12]. The intense mechanical forces, the astronauts are subjected to, during take-off and can have fatal consequences for the retina, which can become detached. Exposure to ionising radiation can lead to the development of cataracts [link]. All these space travel phenomena on eyes can be studied using ultrasound imaging.

Cosmic radiation has a very negative impact on the **spleen** and the immune system, which is weakened by the reduced creation of T-lymphocytes. The creation of erythrocytes (red blood cells) is also decreased. Finally, it has been shown that in Space, there is a deterioration of **liver** function, because it becomes fatty and a process of fibrosis begins [13].

Many of these conditions can be detected at an early stage and their evolution can be followed by the use of ultrasound imaging. But such examinations require to follow non trivial medical protocols for each organ, each of these has a distinct set of acoustic views, and a set of clinical planes that are not trivial to obtain even for a physician who is not versed in the interpretation of this type of medical imaging modality of the target organs.

As far as ultrasound imaging is quite atomized among the different medical specialities, it is hard to find professionals who can deal with so varied organs at the same time. The **software developed in the ALISSE project tries to collect such diverse experience in order to support the CMO** (or any crew member with basic knowledge of ultrasound scanning) to carry out the ultrasound image studies in **accordance with the protocols for each organ**, and orientate him/her in real-time during the **search and identification of the corresponding standard views**.

Among the listed organs, the **urinary system** stands out. On one hand, its pathologies are quite common in Space. On the other hand, both kidney and bladder are excellent organ candidates to illustrate the performance of initial ALISSE prototypes. They are abdominal organs, located deep inside of the body with non-easy to find acoustic windows. Thus, they require a remarkable amount of experience to be scanned and to locate the standard planes in order to acquire clinically-valuable 2D images. Because of these reasons, we have focused our effort on these two organs in the first prototypes, we shall expand our developments to the rest of prioritized organs later.

5. Radiologist team, dataset design and in-house labelling tools

Most data scientists spend more time working on the data than on the algorithms. However, most research works are only focused on the algorithms. This Section addresses this typical gap in medical machine learning research; which has a particular relevance in Smart Ultrasound, as far as there is no public available labelled datasets of standard clinical planes.

Unlike robots in the movies, most of today's artificial intelligence cannot learn by itself; instead, it relies on intensive human feedback. Probably 99% of machine learning medical applications today are powered by supervised machine learning. Compared with the past, our intelligent devices are learning less from programmers who are hardcoding rules and more from examples and feedback given by physicians who do not have to code. These human-curated examples -the training data- are exploited to train machine learning models and make them more accurate for their given tasks.

Deep learning algorithms are voracious on computational resources and require enormous amounts of data to be trained. However, ultrasound medical data is hard to acquire, and even harder to annotate as a post process, because it requires large radiologist experience to interpretate the images without the corresponding clinical record.

As we introduced, ultrasound imaging is one of the core diagnostic imaging modalities, and is routinely used as the first line of medical imaging for evaluation of internal body structures. US has become a ubiquitous diagnostic imaging tool owing to several major advantages over other medical imaging methods such as computed tomography (CT) and magnetic resonance imaging (MRI). These key advantages include real-time imaging, no use of ionizing radiation, and better cost effectiveness than CT and MRI in many situations. In addition, as already indicated, US systems are compact and portable, require no shielding, and use conventional electrical power sources. They are therefore well suited to point-of-care applications and space mission applications. However, these factors combined with the difficulty in their interpretation have led to a strong organ-oriented specialization, making it difficult to find doctors capable of dealing with organs from different functional systems.

Radiology Emergency Service is an exception, as they have to deal with any urgent pathology. The manual acquisition of ultrasound standard planes heavily relies on clinical experience and is also very laborious. Their time is precious and they usually have to be focused on saving patients' lives, so they are used to perform fast exams to discard problems and look for the origin of patient's trauma or disease. Therefore, extra ultrasound scans to cover additional organs in order to create a nice dataset may not be possible in their stressing work. Furthermore, in COVID crisis ultrasound examinations are performed with less frequency, as they require a close contact between doctors and patients.

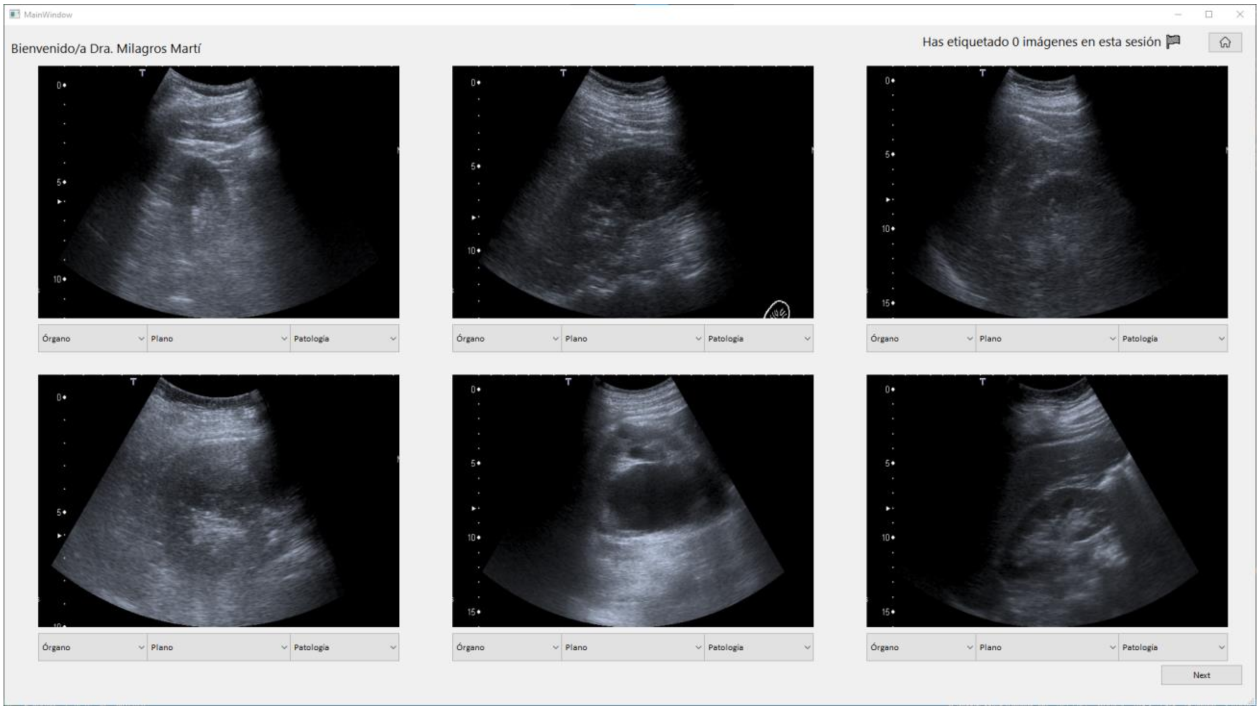
ALISSE project consortium is composed by GMV Advanced Healthcare Technologies department, the Nuclear Physics Group in the Faculty of Physical Sciences at University Complutense of Madrid and the Emergency and Urgency Radiology Service at La Paz Hospital. La Paz has been the biggest Hospital in Spain for more than 60 years, the Radiology Service is well known for being the main reference in our country, gathering the most outstanding professionals in many lines of research, among which the use of advanced ultrasound excels. Therefore, it is a privilege to have the opportunity to learn from them in the mysterious world of ultrasound examinations and pathology diagnosis.

ALISSE budget did not allow us to perform a large prospective data collection, as opposed to how it was done in iFind or PULSE UK research projects. Instead, we have taken advantage from the huge amount of ultrasound normal examinations that are stored in Hospital PACS along decades. Images in PACS have great value: they are perfect examples of real clinical planes for the targeted organs, more than 50% corresponds to pathological cases in several degrees of severity (which provides robustness to a system that is going to be deployed in Space, where astronauts will face unknown challenges and medical conditions), and gathers images taken with more than 40 different ultrasound devices models and vendors (which implements different image formation and postprocess algorithms).

On one hand, ALISSE is fed with the best curated annotated images, thanks to La Paz Radiology Emergency Service. But, on the other hand, this Service has suffered a lot of pressure during the pandemic. Therefore, such high workload persists nowadays, because of strikes and complex Spanish Public Healthcare situation in 2022 and 2023. So, the Radiologist Team is striving and making an additional great effort to help us in this project in spite of hard times and difficulties.

Therefore, radiologist time is one of our scarcest and most precious resources.

We developed special labelling tools implement to help radiologists to be more efficient. Our tools strictly anonymize the ultrasound images and display them in order to be labelled in an intuitive way. So, the radiologist time is spent in annotating the images instead of search for them.


MainWindow

Bienvenido/a Dra. Milagros Martí

Has etiquetado 0 imágenes en esta sesión

Fig. 1. One of the in-house tools for annotating organs and planes from PACS' US cone images

Our automatic selection process of the PACS images discards around a 98% of the images, mainly because they show other organs. The other 2% of the images represent 2D cuts of the urinary system, which were taken with a multitude of ultrasound devices.

As a result, the growing curated dataset contains full-resolution anonymized images of ultrasound clinical planes of kidneys from more than 50.000 different patients, and bladders from more than 17000 patients, taken along several years. Data belongs to all kind of patients, without any distinction of gender, age, race, or pathologies, because our strict anonymization process avoids any bias. Such diversity provides robustness to a critical system for astronauts.

We expect the dataset to grow at least twice the current size during the current implementation phase.

A significant portion of these images have been already labelled by the Radiologist Team. In the next section we describe some preliminary real-time organ-plane recognition experiments with an undisclosed neural network architecture.

6. Preliminary Experiments

The initial ALISSE prototype has a simple modular physical architecture, composed by three elements:

1. A medium-end POCUS certified ultrasound device. We chose a Canon Xario 100G, as an example of a versatile machine which can scan all affected organs in Section 3. This element could be swapped by other similar product with minimal changes in setup. We think the selected model is a bit more advanced than the ones that have been used in the International Space Station, because this kind of technology moves forward quickly. It is important to highlight that this vendor and model combination is not present among the large variety of devices in La Paz Radiology service, so there are no identical ultrasound image formation mechanisms among the images we use for training in the preliminary experiments.
2. A high-end framegrabber, which is connected to the digital video output of the POCUS ultrasound device, it captures and translates the image that is displayed in the screen so we can copy each frame in other computer via USB port. This is a high-cost component in comparison with similar products in the market, and cannot be easily changed. Besides, we chose a vendor and model that has been previously used in International Space Station in order to ensure flight considerations.
3. A high-end gaming laptop. That is, a portable computer with more processing power than a usual computer, as far as we want to run complex and very parallel algorithms (like the deep learning ones) in interactive times while displaying the ultrasound images in the patient examination.

A similar hardware configuration has been successfully used in numerous prototypes published in scientific journals and conferences. It allows great flexibility in designing algorithms that do not exploit the raw signal of ultrasound pressure waves, instead we deal with the recognition of organs or elements in the already shaped images, as is the case in ALISSE project, to ensure interoperability with many possible POCUS certified ultrasound devices.

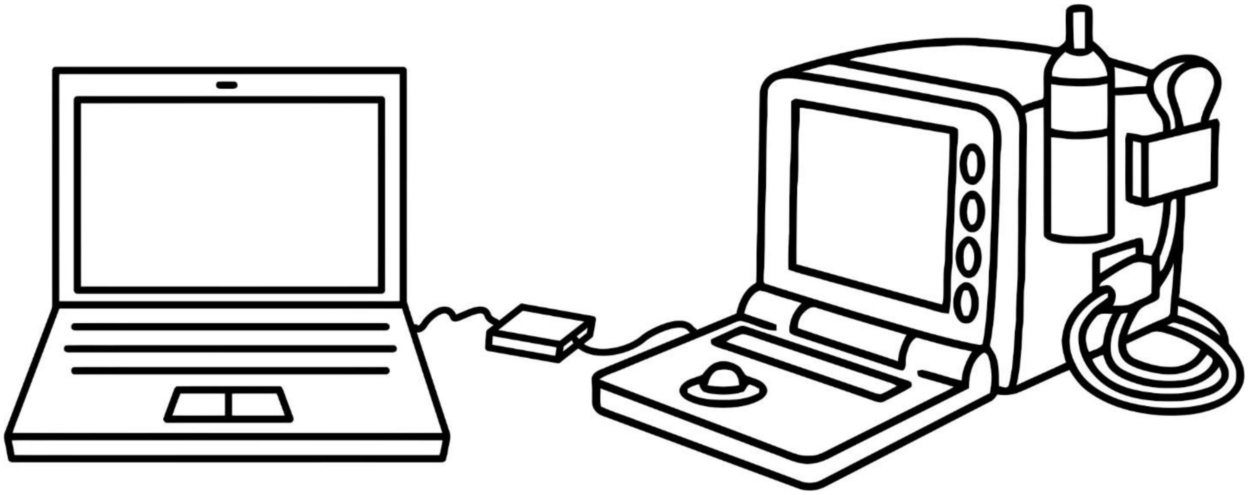


Fig. 2. ALISSE HW modular setup: ultrasound device with transductor connected to a gaming laptop via digital video output with an external framegrabber

This modular design allows us to prototype in an agile way without being tied to a specific model of ultrasound image acquisition device during development (it is possible to change this hardware component for another device model easily), nor to be limited by computational power in inference. Since the images must be evaluated in real time, to provide feedback while the astronauts are performing the scan.

The first consideration has been a challenge, because -as already noted- neural networks are prone to learn the features of the image formation in combination with the anatomical ones. There is no standardisation in image formation procedures. Different manufacturers use different algorithms to generate the image from the measurements of the reflected acoustic waves. Therefore, the AI solutions for plane identification and guidance that other research groups have created only work for the ultrasound device model they have considered. And their neural network models give incorrect results when we introduce images acquired by other equipment [14][15][16]; as it is easy to check in those models that have been released by the scientific community.

The architectures of our earliest neural networks for organ detection and diagnostic planes have been designed with five key drivers in mind:

- **real time inference**: low consumption of computational resources
- **generability**: we cover a wide range of age, race and diseases with very robust detection
- **domain adaptation**: the system is able to run on ultrasound devices that we don't even have images to train on (which will be a significant improvement in comparison with previous works)
- **modularity:** we can change "software pieces" and combine with new ones easily, to experiment and improve features quickly
- **explainability**: we have developed our own tools to check how training evolves and how the stages of each network are performing (at neural activation level), to validate the refinements that are introduced in each design.

It is not possible for us to give details of the structure of the network that yields the best results in the preliminary experiments. As it is a GMV industrial secret.

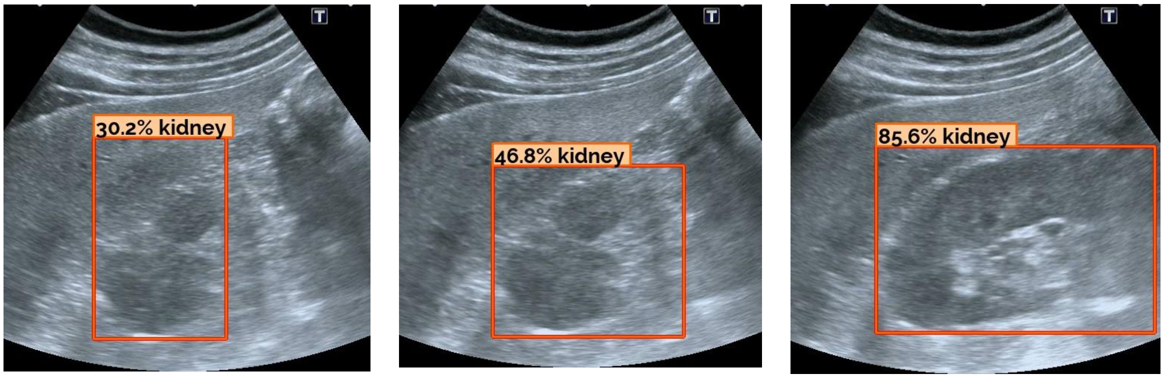
The network is moderately resource-intensive (in memory and processor consumption), it performs frame-by-frame inference in 15.6ms (±2ms) on an nVIDIA 2060GTX GPU. This performance would allow to carry out the analysis at sustained 60 FPS, which is more than sufficient compared to the framerate of ultrasound equipment (which samples around 20FPS in abdominal scanning).

We have focused our initial efforts on kidney scanning, as it is a key organ in urinary system and the list of Section 3. we show some of the initial results of the most promising design in organ detection mode and plane detection mode.

6.1 Organ detection mode

The initial prototype has two modes of operation.

Once the user places the probe over the corresponding acoustic window, an initial scan is performed to locate the organ of interest. Our network allows the target organ to be identified in a simple way, so the user can centre the organ in the cone of the ultrasound image. Once the organ is well centred and images are acquired with a high-quality score, the application switches to the second mode of operation to guide the user while fine-tuning the probe placement to obtain the ideal diagnostic planes of interest.



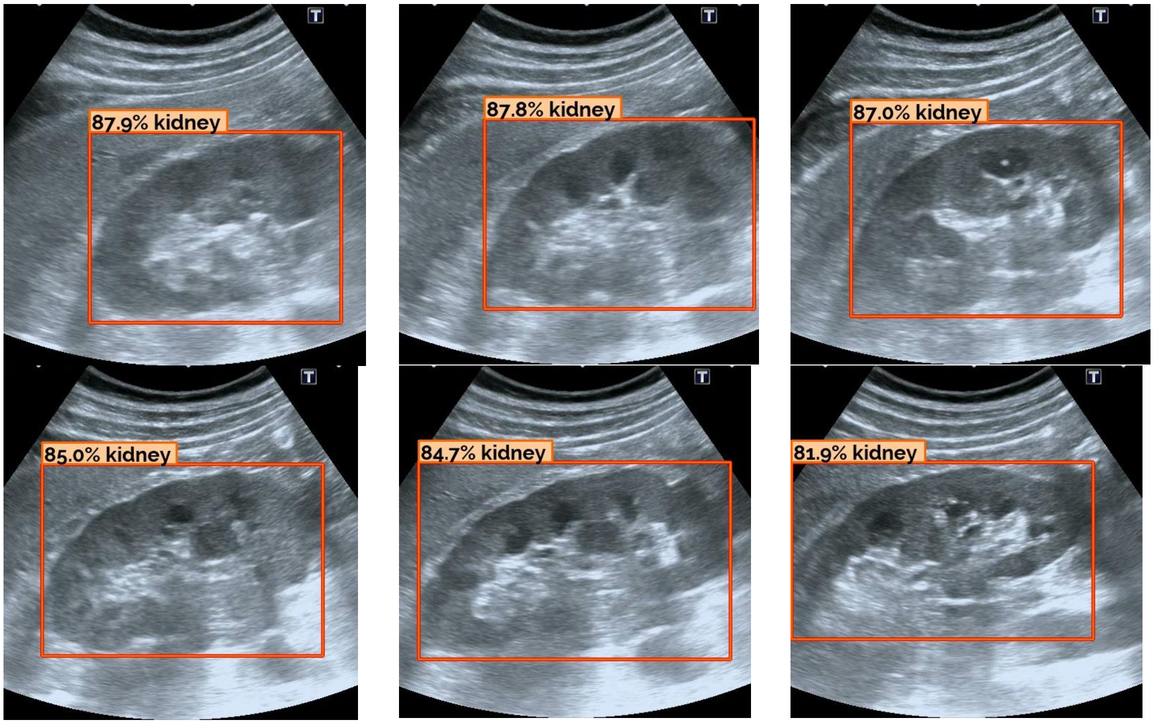


Fig. 3. Sequence of subsampled frames during the detection organ exploration

In this first mode, the image quality score integrates several criteria, including the presence of the organ of interest, the sharpness of internal structures, noise, how blurred the image may be (typically due to motion blur when operator slides the probe), the presence of acoustic shadowing, and so on.

Figure 3 shows a sequence of subsampled frames showing how a user centres the kidney on the cone image according to the system feedback.

Instead of displaying saliency maps in overlayed colours, which can distort the image for diagnostic purposes, we preferred to display the location of the visible organ with a containing box.

6.2 Clinically-valuable plane detection mode

Once the target organ is centered on the cone, the user is encouraged to perform gentle tilt, rotate and pan movements to locate the plane of interest according to the system guidance instructions. In the case of the kidney, the longitudinal plane is first located with the help of the score, which becomes larger the closer the image is to the academic clinical plane. Once the image has been acquired in this plane, with the organ centered, it is easy to locate the transverse plane by simply rotating the probe 90° following the ALISSE guidelines.

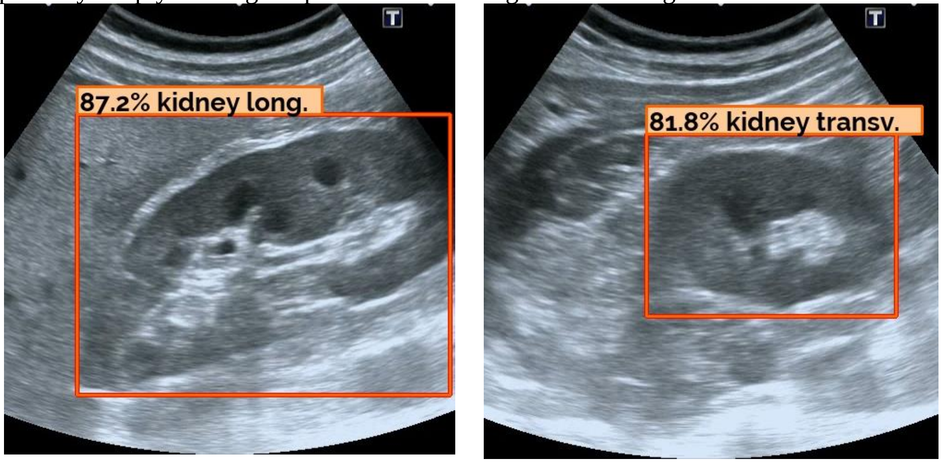


Fig. 4. Examples of clinical planes with high quality score, but not perfect ones.

Figure 4 shows two examples of these planes, taken by an inexperienced user with no medical training or knowledge of this medical imaging modality. They are examples of clinically valuable images, but they are not perfect. Both are a bit blurry because of probe movement and the inner structures are not so well defined as a radiologist would like. User would be encouraged to get a better score in both cases, before saving and sending the ultrasound images to Earth.

7. Discussion and future work

This paper describes ALISSE project, and it shows an illustrative subset of preliminary results in the middle of the implementation stage. Organ identification can be considered quite mature. Plane exploration is already an experimental feature in progress, although initial results are surprisingly good in precision, accuracy, and speed.

The team of radiologists are labelling the vast database indicating the corresponding plane for each image. On the one hand, the diversity of ultrasound devices, varying degrees of diseases and large numbers of patients are key factors that help to obtain a more robust model, capable of distinguishing cases where the condition is very advanced, and the organ is virtually unrecognizable for a person without large experience in ultrasound radiology. On the other hand, PACS images often contain intermediate planes, because clinicians are more interested in pathologies than in academic canonical planes. They are extremely valuable for detecting diseases in Space, thus they are more clinically-valuable than pure standard planes.

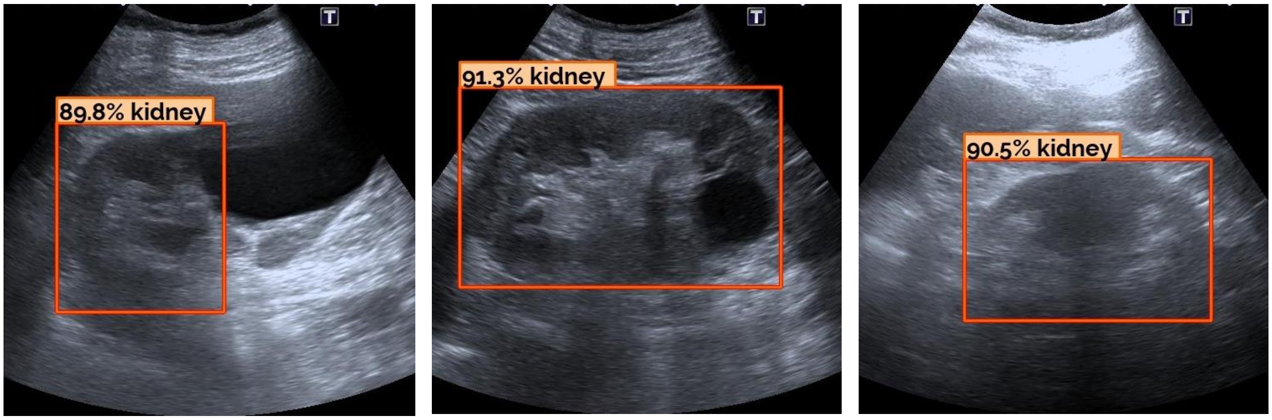


Fig. 5. Three randomly chosen examples of kidney with cysts (pathological cases) from the test set

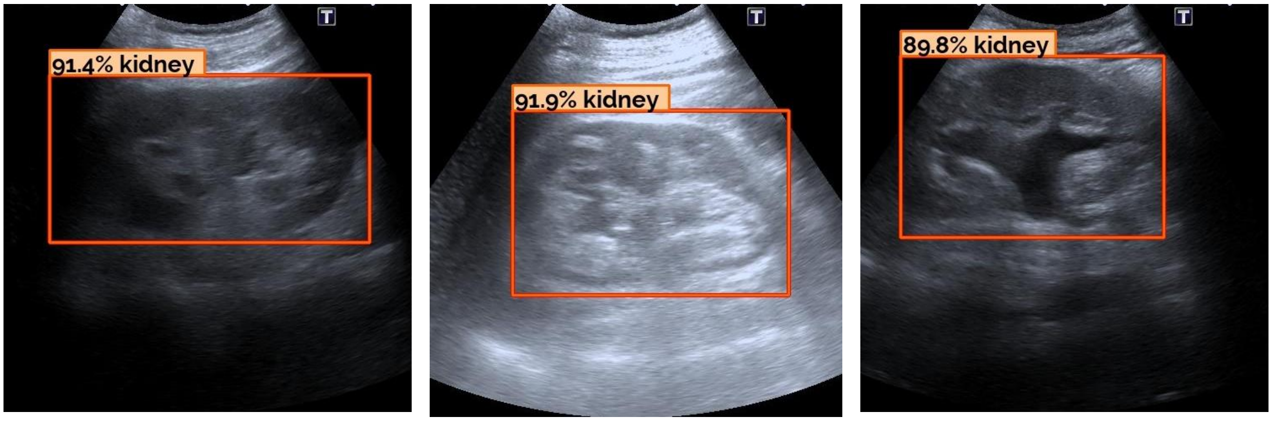


Fig. 6. Three randomly chosen examples of urinary track dilation in kidney (pathological cases) from the test set

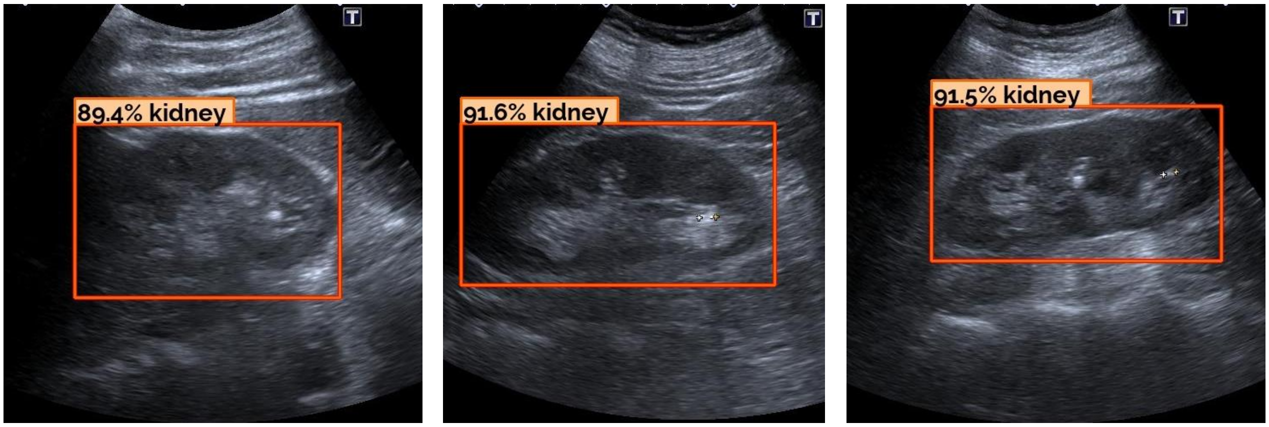


Fig. 7. Three randomly chosen examples of kidney lithiasis / stones (pathological cases) from the test set

Figures 5 to 7 show some examples of pathological kidneys. The initial ALISSE prototype can locate the organ even when the inner structures are misshaped or broken because of the patient's condition.

As a consequence, the intermediate planes provide robustness to the network and allow us to cover a large number of pathological cases of interest. But, at the same time, they dilute the differences between the classic academic planes, typically the longitudinal plane and the transverse plane in the case of the kidney. Figure 8 shows a representation of a subset of test images (randomly sampled) that represents their relative spatial position in the latent space of our network, using a non-linear projection that reduces their dimensionality to just 3 [17]. This representation demonstrates that the images labelled as longitudinal planes are more common in the PACS and that they occupy a clearly differentiated area (red points) from the images corresponding to the transverse planes (blue points) in this projected space. However, there is a fuzzy border where some images are halfway between one zone and the other. At present, we are considering different possible guidance strategies to improve these preliminary results and to help astronauts acquire the most valuable (preferably academic) planes for further diagnosis.

Once the kidney case study is successful, it will be adapted to guide the user to obtain the planes of interest in the bladder, as well as other organs that must be frequently monitored in space missions.

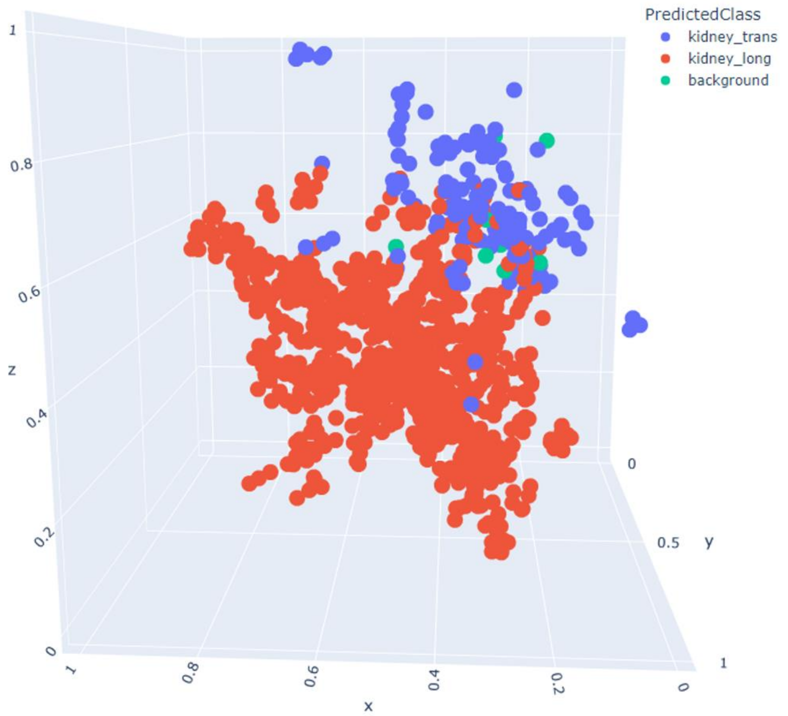


Fig. 8. 3D t-SNE projection of a random sampled subset of ultrasound image's features in latent space

8. Conclusions

Diagnostic imaging plays a critical role in healthcare, serving as a fundamental asset for timely diagnosis, disease staging and management as well as for treatment choice, planning, guidance, and follow-up. Among the diagnostic imaging options, ultrasound imaging is uniquely positioned, being a non-ionizing and cost-effective modality that offers the clinician an unmatched and invaluable level of interaction, enabled by its real-time nature. Its portability and cost-effectiveness permit point-of-care imaging at the bedside, in emergency settings, rural clinics, **and spacecrafts** with limited space and energy restrictions. Ultrasonography is increasingly used across many medical specialties, spanning from obstetrics to cardiology and oncology, and its market share is globally growing.

However, ultrasound imaging is highly operator-dependent, making it essential that the sonographer is properly trained in order to be able to implement the full diagnostic capabilities of the technique. ALISSE AI-guiding system will help to reduce the steep learning curve in ultrasound scanning by assisting astronauts in Space to perform full examinations in a much more autonomous and easier way. We expect this technology to be also applied on Earth, in order to democratize ultrasound examinations' procedures. In a near future, physicians, nurses, and technicians will use AI-guided ultrasound devices so proficiently as they use stethoscopes today.

References

[1] S. Shah, B. A. Bellows, A. A. Adedipe, J. E. Totten, B. H. Backlund y D. Sajed, «Perceived barriers in the use of ultrasound in developing countries,» Critical ultrasound journal, vol. 7, p. 1–5, 2015.
[2] N. Thomson, Sonographer workforce survey analysis, Society and College of Radiographers, 2014.
[3] R. Tenajas, D. Miraut, C.I. Illana, R. Alonso-Gonzalez, F. Arias-Valcayo, J.L. Herraiz, «Recent Advances In Artificial Intelligence-Guided Ultrasound Scanning», Applied Science, MDPI. 2023 (submitted)
[4] S. Shah, B. A. Bellows, A. A. Adedipe, J. E. Totten, B. H. Backlund y D. Sajed, «Perceived barriers in the use of ultrasound in developing countries,» Critical ultrasound journal, vol. 7, p. 1–5, 2015.
[5] N. Kanas y D. Manzey, «Basic issues of human adaptation to space flight,» de Space psychology and psychiatry, Springer, 2008, p. 15–48.
[6] P. Cabahug-Zuckerman, D. Frikha-Benayed, R. J. Majeska, A. Tuthill, S. Yakar, S. Judex y M. B. Schaffler, «Osteocyte apoptosis caused by hindlimb unloading is required to trigger osteocyte RANKL production and subsequent resorption of cortical and trabecular bone in mice femurs,» Journal of Bone and Mineral Research, vol. 31, p. 1356–1365, 2016.
[7] P. A. Whitson, R. A. Pietrzyk, B. V. Morukov y C. F. Sams, «The risk of renal stone formation during and after long duration space flight,» Nephron, vol. 89, p. 264–270, 2001.
[8] C. G. Ball, A. W. Kirkpatrick, D. R. Williams, J. A. Jones, J. D. Polk, J. M. Vanderploeg, M. A. Talamini, M. R. Campbell y T. J. Broderick, «Prophylactic surgery prior to extended-duration space flight: is the benefit worth the risk?,» Canadian Journal of Surgery, vol. 55, p. 125, 2012.
[9] P.L. Arbeille, «Index of Reflectivity of Ultrasound Radio Frequency Signal from the Carotid Artery Wall Increases in Astronauts after a 6 mo Spaceflight,» Ultrasound in Medicine & Biology, 2021.
[10] S. M. Auñón-Chancellor, J. M. Pattarini, S. Moll y A. Sargsyan, «Venous thrombosis during spaceflight,» New England Journal of Medicine, vol. 382, p. 89–90, 2020.
[11] M. D. Delp, J. M. Charvat, C. L. Limoli, R. K. Globus y P. Ghosh, «Apollo lunar astronauts show higher cardiovascular disease mortality: possible deep space radiation effects on the vascular endothelium,» Scientific reports, vol. 6, p. 1–11, 2016.
[12] L. A. Kramer, A. E. Sargsyan, K. M. Hasan, J. D. Polk y D. R. Hamilton, «Orbital and intracranial effects of microgravity: findings at 3-T MR imaging,» Radiology, vol. 263, p. 819–827, 2012.
[13] K. R. Jonscher, A. Alfonso-Garcia, J. L. Suhalim, D. J. Orlicky, E. O. Potma, V. L. Ferguson, M. L. Bouxsein, T. A. Bateman, L. S. Stodieck, M. Levi y others, «Spaceflight activates lipotoxic pathways in mouse liver,» PloS one, vol. 11, p. e0152877, 2016.
[14] Blaivas M, Blaivas LN, Tsung JW. «Deep Learning Pitfall: Impact of Novel Ultrasound Equipment Introduction on Algorithm Performance and the Realities of Domain Adaptation.» J Ultrasound Med. 2022 Apr;41(4):855-863. doi: 10.1002/jum.15765
[15] Blaivas M, Blaivas LN, Campbell K, Thomas J, Shah S, Yadav K, Liu YT. «Making Artificial Intelligence Lemonade Out of Data Lemons: Adaptation of a Public Apical Echo Database for Creation of a Subxiphoid Visual

Estimation Automatic Ejection Fraction Machine Learning Algorithm.» J Ultrasound Med. 2022 Aug;41(8):2059-2069. doi: 10.1002/jum.15889.
[16] Crockett, D., Kelly, C., Brundage, J., Jones, J., & Ockerse, P. «A Stress Test of Artificial Intelligence: Can Deep Learning Models Trained From Formal Echocardiography Accurately Interpret Point-of-Care Ultrasound?. » Journal of Ultrasound in Medicine, 41(12), 3003-3012. 2022.
[17] L. Van der Maaten, & G. Hinton. «Visualizing data using t-SNE.» Journal of machine learning research, 9(11). 2008.