3D FREEHAND ULTRASOUND:
RECONSTRUCTION AND FEATURES EXTRACTION IN LOWER LIMB MUSCLE

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ABSTRACT

Ultrasound systems can be enhanced to combine 3D data and corresponding spatial information. This approach, called 3D freehand Ultrasound (3DFUS), uses ultrasound (US) images and the corresponding pose of the transducer with the purpose of reconstructing the 3D morphology for large anatomical parts. So far, this 3D reconstruction has only limited clinical use as the procedure is not widely accessible and features extraction is very time consuming. Our current work is aimed at developing a new tool for image reconstruction and to optimizing the features extraction process in 3DFUS.

INTRODUCTION

- Morphological properties such as muscle volume and length are relevant to quantify pathologies, and to evaluate and compare medical treatments [1];
- The pose (rotation and translation) of the US image with respect to a global reference allows for proper allocation in 3D each image [2]. This leads to the reconstruction of large anatomical parts (Fig.1);
- The few existing applications have at least one of the following disadvantages: i) not open-source; ii) support data streams from a limited number of ultrasound or pose devices; iii) they are written in low-level languages;
- 3DFUS has only limited clinical use as the procedure is not widely accessible, and the features extraction process to outline the muscle border is very time consuming [1].
- **<u>Study aim</u>: 1) to develop a pure Python library that solves all the above issues**

  2) to extract clinical features (muscle length and volume) in a group of typically developing children.

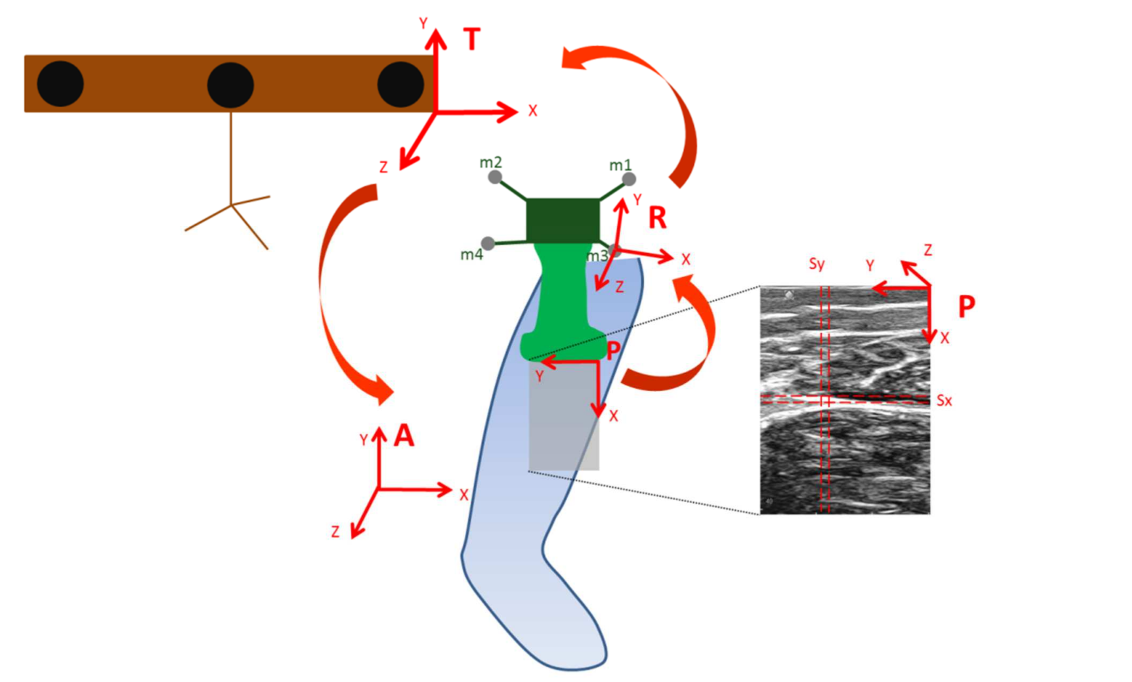

Fig.1 The different reference frames involved: US image (P), markers attached to a probe (R), optoelettonic system (T) and anatomical frame (A).

MATERIALS AND METHODS

1. RECONTRUCTION

- A library, called Py3DFreeHandUS, is developed in Python 2.7 to be able to process data acquired simultaneously by US and pose devices, being input as DICOM and C3D files, respectively;
- Intensive vectorization allowed to achieve reasonable computation speeds;
- Inputs are independent to ultrasound systems and pose devices.

The library performs the following operations:

1) Estimation of the pose of the US image wrt the cluster of markers (calibration as in Fig.2, [2]);
2) Estimation of the calibration quality by calculating Distance Accuracy and Reconstruction Precision [3];
3) Creation of the 3D voxel-array (Fig.3) containing the US images repositioned in 3D space;
4) Filling of empty voxels among slices by using Voxel Nearest Neighbour or Weighted Distance algorithm [4];
5) Exportation as VTI file (VTK) for later visualization (e.g. Paraview, MeVisLab.

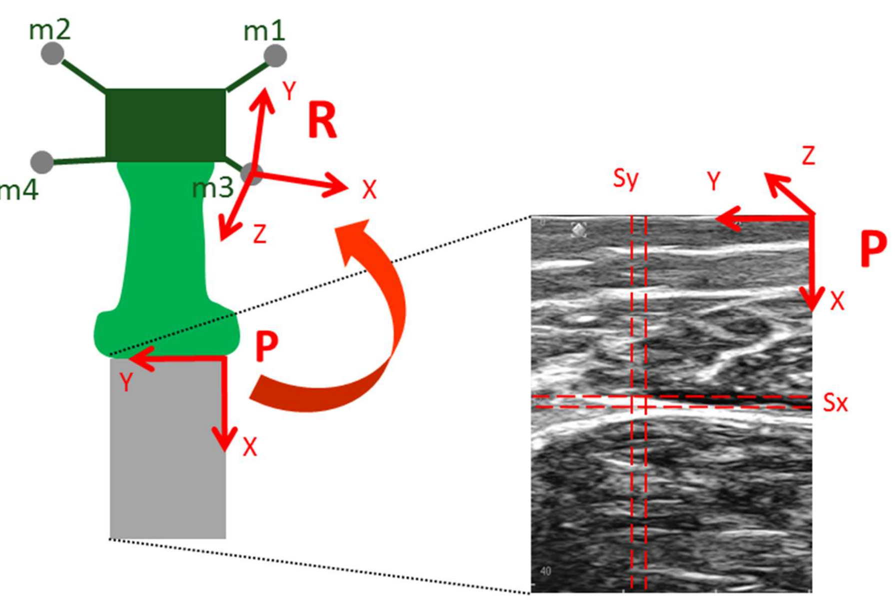

Fig.2 marker-based cluster reference frame (R) and US image reference frame (P).

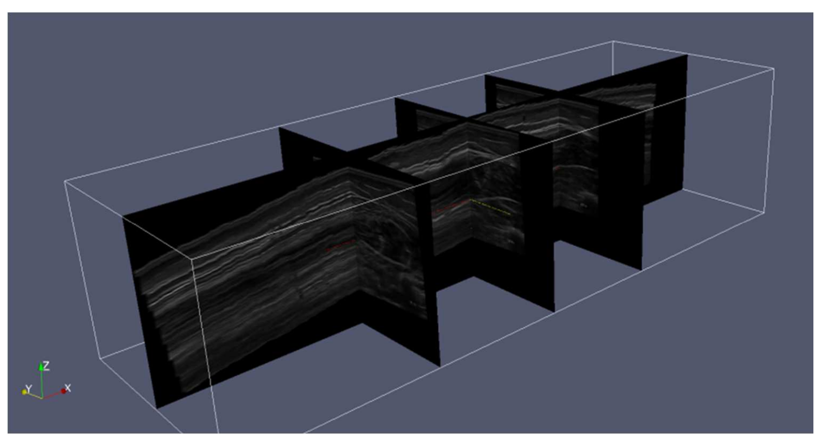

Fig.3 Three transversal and one longitudinal section of a reconstructed 3D voxel-array

2. FEATURES EXTRACTION

- The medial gastrocnemius muscle was imaged in 5 typically developing children (8.6±3.8 years) while lying in prone position;
- US scanner with a linear transducer (Telemed, Lithuania), and a portable optical motion analysis system, with 3-integrated cameras at 120Hz (Optitrack NaturalPoint, USA) were used;
- 4 reflective markers rigidly attached to the US transducer (Fig.4);
- A stack of US images (scan) was acquired by manually moving the US transducer over the muscle in a transverse orientation at a steady speed (Fig.1). Each muscle per child was imaged 3 times.

Fig.4 Cluster of 4 markers attached to the probe.

- This was then processed in MeVisLab (www.mevislab.de) for clinical feature extraction by sequentially applying:

A) Semi-automatic segmentation for certain images using edge features (Fig.5);

B) Interpolation of the outlined borders for all the images acquired (Fig.6);

C) creation of the 3D muscle model.

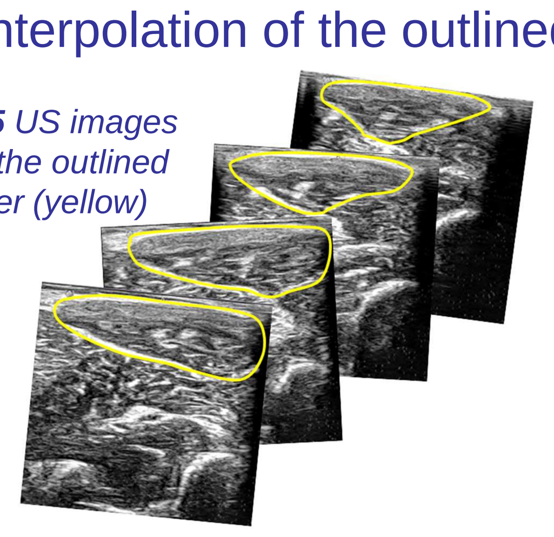

Fig.5 US images with the outlined border (yellow)

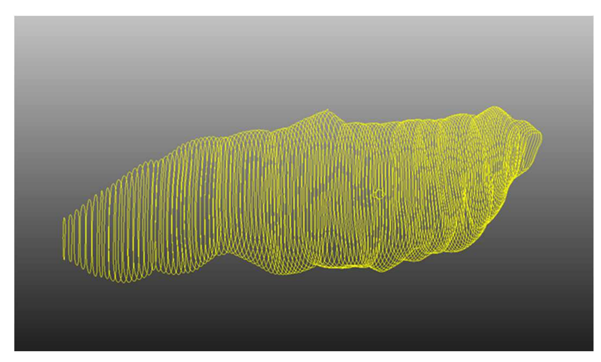

Fig.6 US images with the outlined border (yellow)

- Muscle volume and length was computed per scan and the reliability investigated by intra-class correlation coefficients (ICC), single measures.

RESULTS

- The present library is downloadable (https://github.com/u0078867/Py3DFreeHandUS);
- The calibration quality assessments were 1.9 mm and 3.9 mm for the distance accuracy and reconstruction precision, respectively. In Figure 3, a 3D reconstruction is showed. The average data processing time for each reconstruction was 5.9 min;
- The average muscle volume and length of all subjects and scans were 65.9 ± 29.4 mL and 159.9 ± 26.8 mm, respectively. The corresponding ICC values for comparing muscle volume and length during 3 scans with 3D freehand US were 0.98 and 0.95 with intra-scan variability of 2.5 mL and 5.7 mm, respectively.

DISCUSSION

- Py3DFreeHandUS implemented state-of-the-art procedures for voxel-array reconstruction by using an open-source and high-level language such as Python;
- The quality assessment revealed satisfactory results but these could be improved using different objects and methods for calibration procedure;
- Preliminary results in typically developing children showed that this novel method for image reconstruction and segmentation has reliability and efficiency in retrieving clinically-applicable data of muscle morphology comparable to the literature;
- A more advanced segmentation method will be explored to obtain an automatic procedure for features extraction;
- Further validation of the technique will be to seek a comparison to a gold-standard method, such as MRI.

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