MULTI-MODALITY IMAGE SIMULATION WITH THE VIRTUAL IMAGING PLATFORM: ILLUSTRATION ON CARDIAC MRI AND ECHOGRAPHY.

A. Marion, S. Camarasu-Pop, P. Clarysse, T. Glatard , H. Liebgott, K. Moulin, S. Specovius, D. Friboulet

Université de Lyon, CREATIS; CNRS UMR5220; Inserm U1044; INSA-Lyon; Université Lyon 1, France

ABSTRACT

Index Terms— Image simulation, medical, multi-modality, cardiac, magnetic resonance, echography.

This document materializes deliverable D3.4.1 of French ANR project ANR-09-COSI-03, "Virtual Imaging Platform". As specified in the project proposal, it consists of 3D simulated heart images for segmentation evaluation, which are available online [1]. This document details how they were produced. It is presented as a 4-page abstract that will constitute initial input material for a publication in 2012.

1. INTRODUCTION

Medical image simulation has become an essential tool to improve the understanding of biological processes, pathology diagnosis and treatment. Wide-scale availability of simulated medical images would greatly help to design new image acquisition techniques, developing realistic physiological models and validating image analysis procedures. However, using simulators remains complex, requiring significant technical skills and access to computing resources. For example, simulating the acquisition of processes such as the beating heart can require a month of CPU time.

The Virtual Imaging Platform (VIP) is an open platform targeting these problems. The framework provides access to an easy-to-use interface for the simulation of ultrasound (US) imaging, magnetic resonance imaging (MRI), positron emission tomography (PET) and computed tomography (CT). The simulators currently integrated in VIP are Field-II [1], Simri [2], Sorteo [3] and Sindbad [4].

In this paper, we propose a simulation framework dedicated to simulate multimodality medical images from a wide set of models. This is implemented as a workflow taking as input a biological model described in a pivot format, representing the model within the simulation scene, generating physical parameters (*e.g.* magnetic properties such T1) and finally simulating images.

Here we use the ADAM 4D cardiac model [9] and we focus on ultrasound and MRI simulation. The ultrasound simulated data are used in the project to help design a specific beamforming method called Transverse Oscillations [5][6]. The MRI simulated data are used for evaluating segmentation algorithms.

We provide details about the model and the simulation methodology in Section 2. Sections 3 and 4 present the simulated images produced by the platform. Section 5 concludes the paper.

[1] At `http://vip.creatis.insa-lyon.fr` in menu "VIP → Gallery → {Ultrasound,MRI}"

2. MATERIAL AND METHODS

2.1. Model content

The IntermediAte Model Format (IAMF)[7] is used in VIP to describe a model for multimodality medical image simulation. IAMF models are zip file bundles containing one or several of:

- `mhd/raw` files for labeled voxelic representation,
- `vtp` files for mesh representation,
- `text` files for lookup tables giving correspondence between labels and matters,
- and `xml` files for lookup tables giving correspondence between matters and physical parameters.

In addition, the user can directly define physical parameter information attached to the model and providing:

- `mhd/raw` files with physical parameter values for each voxel
- and/or `vtu` files containing a list of scatterers used in ultrasound simulation.

An annotation file describes in more details the semantic content of each file. These files are processed by an object preparation workflow to transmit proper files to simulators.

2.2. Design of the simulations

2.2.1. Definition of the simulation scene

The first step to design a new simulation consists in positioning the model with respect to the acquisition system to produce several cardiac views such as apical or parasternal in US

imaging. Obtaining these views is a tedious task. One can use a binary program or script to apply a 3D transformation and verify that the view is correct. However, cardiac views are not orthogonal to the well known axial, coronal and sagital planes and therefore finding the proper orientation becomes rapidly time consuming. As shown on Fig. 1, VIP includes a 3D interface to define the simulation scene. First, the user selects a model from the database. The model is opened and visualized in the platform using webGL[2] technology. Simulators of CT, MR, PET and/or US can then be selected. The model and selected simulators can be translated and rotated using spinners. This interface returns transformation matrices between simulators and object to be simulated.

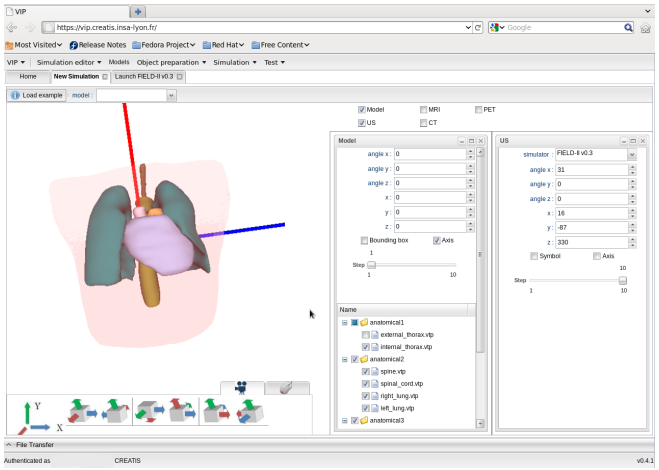


Fig. 1. Snapshot of the VIP simulation scene interface.

2.2.2. *Ultrasound simulation*

The model is prepared for the US simulation to generate a set of scatterers and the probe parameters. Field-II relies on an acoustical model to simulate propagation. The medium is represented by a set of scatterers defined by 3D positions and scattering coefficients.

The position for each scatterer is defined by 3 values x, y and z. A scattering coefficient is assigned to each scatterer according to the intensity of the signal backscattered by the tissue it belongs to. Position and scattering values are generated from statistical distributions (*e.g.* uniform for position, Gaussian for scattering coefficient) that are tissue-dependent. A density parameter is also used to define the number of scatterers per voxel. US simulation consists of a set of radio-frequency (RF) lines that are assembled to produce the final image.

If scatterers are already present in the IAMF model, they are directly transformed to the geometry defined by the simulation scene. The simulation is then launched on distributed computing resources. Each computing job receives one RF line to simulate. RF lines are accumulated in an RF matrix as soon as they are produced. Once the matrix is complete, a B-mode image is obtained from envelope detection and cartesian reconstruction.

If scatterers have to be generated, the voxel representation file, the LUTs and the transformation are used to generate the scatterers according to Algorithm 1. Once the scatterers are generated, they are transformed to the simulation scene and only the ones included in a slice defined by the azimuthal size of the PSF are extracted.

Scatterer generation is memory-intensive and can produce important amounts of data as the model size grows.

For performance reasons, scatterer generation is included in the simulation computation jobs. Thanks to the randomness of this step, the simulation can be considered a Monte-Carlo process and dynamic load-balancing among computing resources can be used, as detailed in [8]. Each computing job iteratively generates a few scatterers from a unique random seed, computes their contribution to the simulation and reports to a central master which updates the total number of computed scatterers. When the desired number of scatterers is reached, jobs are stopped and the simulation completes.

Algorithm 1 Generation of scatterers.

// in: labeled volume (vol) - dimensions (D)- sampling rate (S) - physical parameter LUT (LUT) - number of scatterers (Nd)
// out: scatterer positions (pos) and amplitudes (amp)
for i in LUT **do**
  tissueVox(i) = find(vol==tissue(i))
end for
nb_scat = createVector(1,$\sum_{i=1}^{N} n_i * d_i$)
// n_i is the number of voxels corresponding to tissue i, d_i is density of tissue i and N the number of tissues
for p in Nd **do**
  e = random(nb_scat)
  ind = find((e-nb_scat)$\leq$0)
  ind_vox = (e-nb_scat(ind-1))/d_{ind-1}
  voxCoord = tissueVox(i)(ind_vox)
  pos(p) = voxCoord*N + N*random(0,1)
  amp(p) = LUT(ind-1).physParam
end for

2.2.3. *MRI simulation*

Simri is based on Bloch equations to simulate magnetic resonance images. For Simri a medium is represented as a labeled volume (or image) associated to a LUT linking labels to materials and a LUT giving physical parameters for each material. It is possible to set the main magnetic field B_0 and the sequence used to for the simulation, *e.g.* gradient echo, spin echo, *etc*. The minimum physical parameters necessary for the simulation are the proton density ρ, T1, T2 and the susceptibility χ.

[2] http://www.khronos.org/webgl/

The step after the simulation scene definition for MRI simulation with Simri is to prepare a `zip` archive for each slice to be simulated. This archive contains the data files, the parameter file and the LUTs. Simri will then read these files and perform the simulation on VIP to produce a `raw` image. Simri was parallelized using MPI (Message Passing Interface).

2.3. Implementation

2.3.1. The ADAM model

The model used for simulation is the heart-beating and thorax-breathing ADAM model (A Dynamic Anthropomorphic Model of the thorax and heart) [9]. It consists of the pericardium, the left and right ventricles and atria, the aorta, the lungs, the spine, the spinal cord and the inner and outer thorax. It is defined as a collection of triangular meshes.

Figure 2 shows the model at 4 instants of the cardiac cycle. Systole is defined as the phase when ventricles are contracting while diastole corresponds to the phase when blood travels from atria to ventricles.

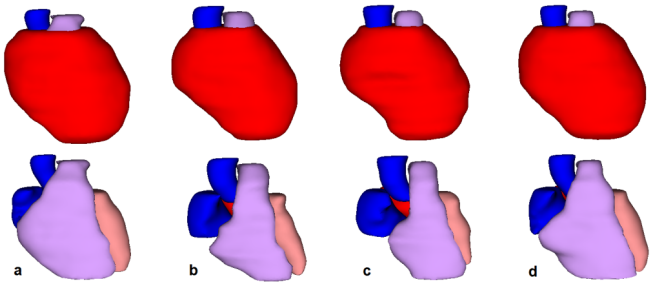
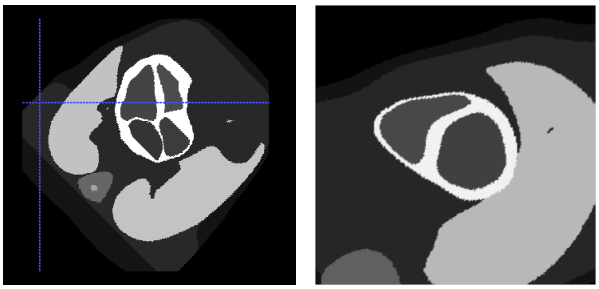


Fig. 2. *4 instants of the heart dynamic model - end diastole (a), half-systole (b), end systole (c), half-diastole (d).*

Figure 3(a) shows an apical view obtained after 3 rotations and Fig. 3(b) contains a short-axis view described by the plane orthogonal to the apical one.



(a) Apical view. The horizontal blue dotted line represents the short-axis slice in 3(b)

(b) Short axis view.

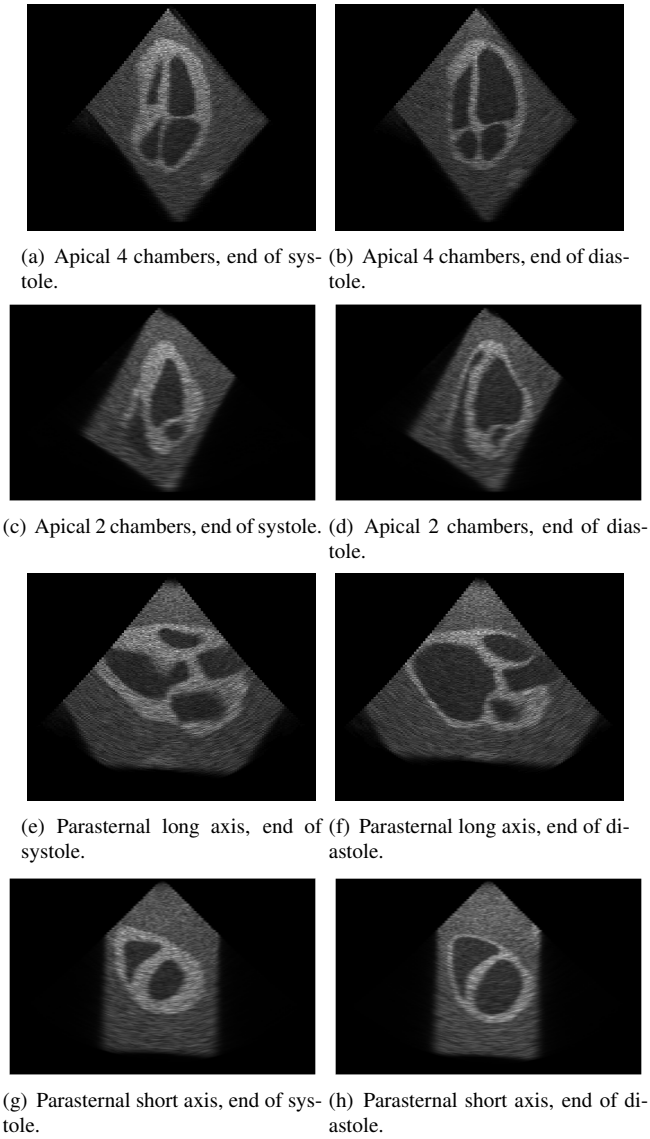
Fig. 3. Cardiac views on ADAM.

2.3.2. The simulators

As mentioned before, 4 simulators are currently implemented in the Virtual Imaging Platform: Field-II for ultrasound, Simri for MRI, Sorteo for PET and Sindbad for CT. Simulators are usually considered as legacy codes and so parallelization was performed on data to avoid code modifications.

3. RESULTS

Simulation results with Field-II are presented in Fig. 4. It represents simulated apical 4-chamber views at end of systole and end of diastole in Fig. 4(c)-4(d). We also show parasternal long axis views in Fig. 4(g)-4(h).



(a) Apical 4 chambers, end of systole.

(b) Apical 4 chambers, end of diastole.

(c) Apical 2 chambers, end of systole.

(d) Apical 2 chambers, end of diastole.

(e) Parasternal long axis, end of systole.

(f) Parasternal long axis, end of diastole.

(g) Parasternal short axis, end of systole.

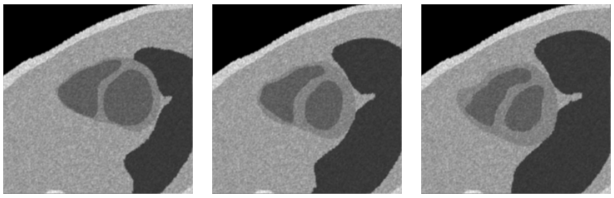
(h) Parasternal short axis, end of diastole.

Fig. 4. Simulated echocardiographic data.

For MR, we extracted from the heart model a 2D short-

axis slice at 15 instants over he cardiac cycle (Fig. 3(b)) to simulate a dynamic 2D image sequence of the beating heart. Figure 5 shows 3 simulated MRI slices obtained with Simri. We extracted a complete cardiac cycle, i.e. 15 instants at a given depth (see Fig. 3(b)) to simulate a dynamic sequence.

They correspond to 3 different instants during the cardiac cycle.



(a) Instant 0. (b) Instant 3. (c) Instant 6.

Fig. 5. Simulated MRI short axis views.

The simulation time of ultrasound simulation depends on the density of scatterers. With a density of 10 scatterers by voxel, the simulation represented a total of 750 CPU hours. In VIP it was computed in about 22 hours giving a 34 speed-up ratio (Tab. 1). One MR image simulated with Simri was computed on 16 CPU cores with a speed-up ratio of 7.

	FIELD-II	SIMRI
CPU time (s)	2,700,000	1456
Elapsed (s)	79,200	203
Speed-up	34	7

Table 1. Performance of the benchmark simulations on EGI.

4. DISCUSSION

The realism of simulated images could be improved in several ways. A first limitation is the ADAM model. Indeed, it does not have enough details (layers of fat, structure of the tissue) to be realistic. Starting from a CT image as done by Shams et al. [10] would bring more classes. A second limitation in US is that scatterers are too homogeneously distributed. For example, borders should receive more scatterers to mimic specular reflexion in ultrasound. Besides, the simulator itself ignores some physical phenomena like non linear behaviour.

However VIP was designed as an evolutive platform. New models could be easily integrated to use the same simulation workflow. Using other simulators such as the one proposed by Varray et al. [11] that integrates non-linear propagation could also be envisaged.

5. CONCLUSION

We presented the Virtual Imaging Platform dedicated to multimodality medical image simulation. We used a cardiac model to compute ultrasound and MRI simulated images. Using more detailed models could improve the realism of the simulated images.

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