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

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ABSTRACT

Medical image simulation is useful for biological modeling, image analysis, and designing new imaging devices but it is not widely available due to the complexity of simulators, the scarcity of object models, and the heaviness of the associated computations. This paper presents the Virtual Imaging Platform, an openly-accessible web platform for multi-modality image simulation. The integration of simulators and models is described and exemplified on simulated cardiac MRIs and ultrasonic images.

Index Terms— Medical image simulation, multi-modality, cardiac, MRI, echography.

1. INTRODUCTION

Medical image simulation is essential 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, to develop realistic physiological models and to validate image analysis procedures. However, using simulators remains complex and requires (i) availability of proper object models, (ii) significant technical skills to parametrize and run the simulators and (iii) access to computing and storage resources to support heavy simulations.

The Virtual Imaging Platform[1] (VIP) is an open web platform targeting the sharing of simulators and object models as well as their execution on distributed computing resources. It is designed to be extensible and currently includes simulators of ultrasound (US) imaging, magnetic resonance imaging (MRI), positron emission tomography (PET) and computed tomography (CT).

In this paper, we describe VIP features and show how it is used to simulate multi-modality medical images from generic models. Although realistic images can be simulated from *in vivo* images such as proposed in [1, 2], this paper considers a different approach where simulations are based on models of organ geometries and physical parameters. This approach enables model sharing for various image modalities in a common repository. It is also flexible since simulated images can be obtained directly from organ geometries and physical parameters, without any *in vivo* twin. For instance, model parameters can be varied to simulate individual populations or specific pathologies.

The integration of simulators and models in VIP is demonstrated on ultrasound and MRI simulations from the ADAM 4D cardiac model [3]. The model repository, integration of simulators and supporting infrastructure are described in section 2; cardiac imaging simulation implementation and results are reported in section 3.

[1] `http://vip.creatis.insa-lyon.fr`

2. PLATFORM DESCRIPTION

2.1. Simulator integration

To facilitate their integration, applications in the VIP repository are described as workflows of elementary activities from which launching and monitoring interfaces are automatically generated. Workflow descriptions also enable parallelization since they are parallel by nature. Parallelization exploits data parallelism so that simulators only require minor modifications (mostly parameter adjustments) to be integrated.

Most simulators produce images from an object model with modality-specific physical parameters and a parametrized representation of a scanner. A specific workflow template was defined for image simulation [4]. It consists of object preparation (conversion to simulator-specific format), parameter file generation from parameter values, core simulation and post-processing (e.g. reconstruction). For now, this template is only used to structure simulator integration and to facilitate interaction with platform tools. In the near future, it will be used as input of a semi-automatic simulator workflow designer [5].

Four image simulators are currently available: Field-II [6] for ultrasound, Simri [7] for MRI, PET-Sorteo [8] for PET and Sindbad [9] for CT. A GATE plugin is also available for radiotherapy simulations [10]. Other applications have also been integrated, including MR liver cartography, Mean-Shift image filtering and cardiac segmentation.

2.2. Model repository

Models in the VIP repository are annotated with the terms of an ontology of simulation object models that we proposed in [11]. Model files are annotated as physical parameters or as objects belonging to a geometrical, anatomical, pathological, foreign body or external agent layer. Layers allow to easily add/remove structures such as pathological objects or contrast agent to a baseline anatomy. When a simulation is launched, layers are flattened by object preparation workflows to produce simulator inputs. Physical parameters can be maps or look-up tables of magnetic, chemical or echogenicity parameters. Model files are also annotated with time information. Two time scales are considered: instants define a fine scale (e.g. movement) while time points are used at a coarser scale (e.g. longitudinal follow-up).

These annotations are used to structure the repository and for searching. Inference rules can also be applied on the annotations of a model to check if it has enough physical parameters to be used in a simulation of a given modality. More elaborated rules may be envisaged too. Annotations are also used by the workflows, e.g., to split the simulation in independent time-points and instants. Soon, they will also be used to annotate simulated results.

Models can be visualized in a webGL[2]-based 3D interface and scenes where image simulators can be positioned w.r.t the model can be defined. The model and selected simulators can be translated and rotated using spinners. This interface produces transformation matrices used by object preparation workflows. A screenshot is shown on Fig. 1.

Model annotations can describe files regardless of their type but interfaces and workflows only support limited file types, mostly based on VTK: `mhd/raw` files for labeled voxelic representation or physical parameter maps, `vtp` files for mesh representation, `text` files for lookup tables giving correspondence between labels and matters, `xml` files for lookup tables giving correspondence between matters and physical parameters, and `vtu` files containing a list of scatterers used in ultrasound simulation. Model files and annotations can be downloaded for local inspection or processing.

2.3. Infrastructure

Computations are performed on the biomed virtual organization of the European Grid Infrastructure (EGI-biomed)[3], which is openly accessible for non-commercial computations. This infrastructure is shared among approximately 1,000 users, but VIP can usually run some 2,000 concurrent tasks. Personal clusters can also be declared in the platform.

Data files containing object models, intermediate results or simulated data are stored on distributed storage sites of EGI-biomed where 1.65 PB is currently available. Although storage is not an issue, simulations can be hampered by the transfer time of large files or file collections. To cope with downtimes of storage sites, model files and simulation results are replicated on three sites with good availability history.

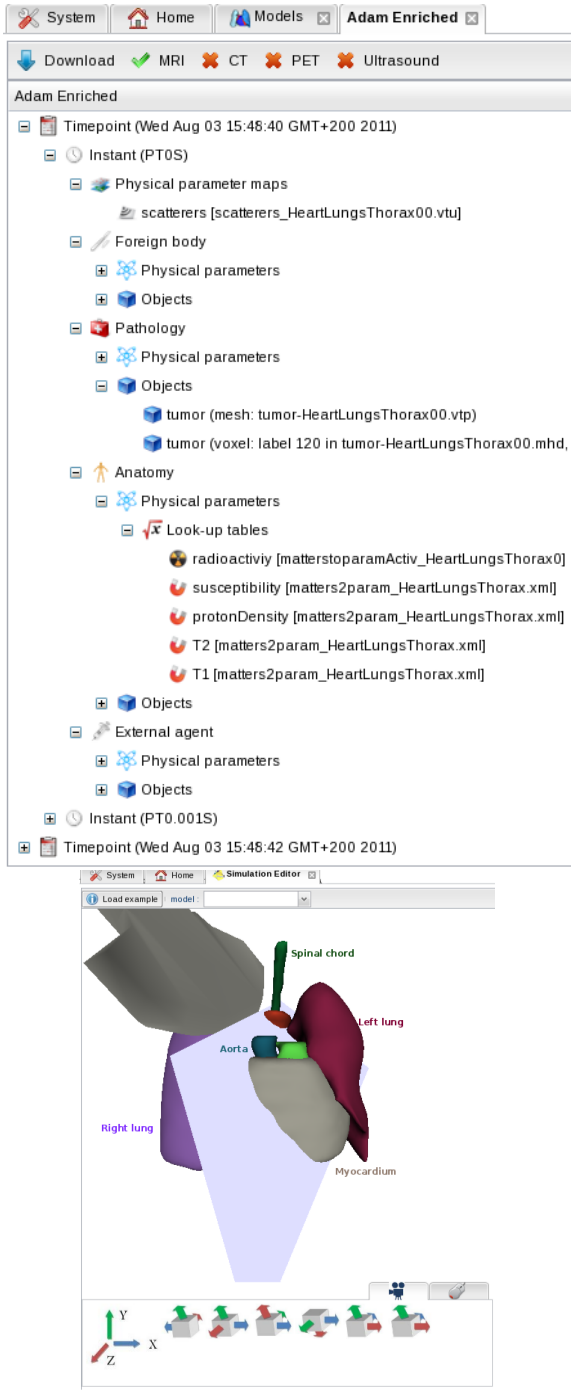


Fig. 1. Snapshot of the VIP interface. Top: model repository. Bottom: simulation scene interface showing a mesh representation of a cardiac model and an ultrasound probe.

[2] `http://www.khronos.org/webgl`
[3] `http://www.egi.eu`

3. CARDIAC IMAGE SIMULATION

The heart-beating and thorax-breathing ADAM model [3] is used in these simulations. 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.

3.1. Ultrasound simulation

Field-II is a widely-used ultrasonic simulator that relies on an acoustical model to simulate propagation. The model 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 tissue-dependent statistical distributions (*e.g.* uniform for position, Gaussian for scattering coefficient). A density parameter is also used to define the number of scatterers per voxel. US simulation consists in generating a set of radio-frequency (RF) lines that are assembled to produce the final image.

If scatterers are already present in the 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 those in a slice around the imaging plane are extracted.

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,∑_{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)≤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
```

Class	PD (%)		T1 (ms)		T2 (ms)		Scattering
	μ	σ	μ	σ	μ	σ	amplitude
Fat	73	7	754	70	68	7	0.5
Muscle	70	7	963	96	60	6	0.5
Blood	57	6	1600	160	100	10	0.2
Spine	54	5	350	35	49	5	1
Spinal cord	56	6	585	59	70	7	1
Lung	32	3	1199	120	56.5	6	0.5
Myocardium	70	7	1100	110	50	5	1.5
Air	0	0	0	0	0	0	0

Table 1. MR/US parameters for ADAM classes.

Here, scatterer positions were generated from a uniform spatial distribution with a density of 10 scatterers per voxel. Scattering coefficients were generated from centered Gaussian distributions with amplitudes reported on Table 1.

3.2. MRI simulation

Simri simulates MR images from Bloch equations and is parallelized using MPI[4]. A medium is represented as a labeled volume associated to LUTs. LUTs link labels to Gaussian distributions from which physical parameter values are randomly sampled. Physical parameters used for ADAM classes are reported on Table 1. A spin-echo sequence with TE=20ms and TR=400ms was simulated with $\mathrm{B}_0 = 3\mathrm{T}$.

3.3. Results

Fig. 2 shows US simulation results for different views and Fig. 3 shows 3 MR slices simulated over the cardiac cycle. Each simulated US view represents a total of 750 CPU hours, computed in about 22 hours on VIP. Each MR slice represents 24 CPU minutes, computed in 4 minutes on VIP.

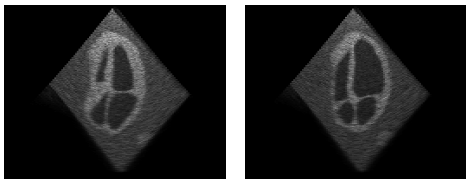
The realism of simulated images could be improved. Using more detailed object models or improving the distributions of physical parameters are the main axes for future work. For example, borders could receive more scatterers to mimic specular reflection in ultrasound.

4. CONCLUSION

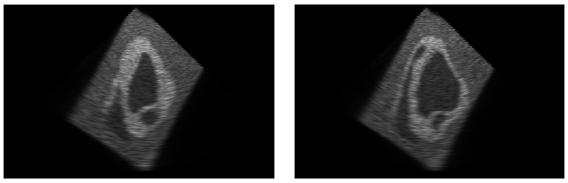
VIP is an online open platform for medical image simulation. Simulators of four imaging modalities are available and object models can be shared in a semantic repository. Simulations can transparently benefit from resources of the European Grid Infrastructure and local clusters.

We demonstrated how VIP was used to simulate cardiac ultrasonic and MR images from a geometrical model. Images simulated from generic models are less realistic than image-based simulations but allow more flexibility.

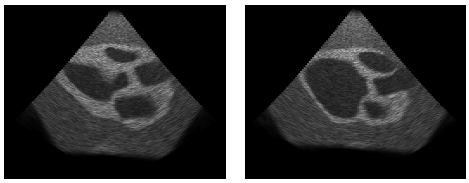
[4] http://www.mcs.anl.gov/research/projects/mpi



(a) Apical 4 chambers, at end systole. (b) Apical 4 chambers, at end diastole.



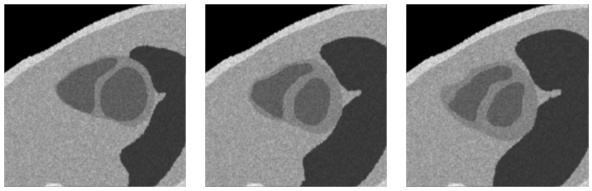
(c) Apical 2 chambers, at end systole. (d) Apical 2 chambers, at end diastole.



(e) Parasternal long axis, at end systole. (f) Parasternal long axis, at end diastole.

(g) Parasternal short axis, at end systole. (h) Parasternal short axis, at end diastole.

Fig. 2. Simulated echocardiographic data.



(a) End diastole. (b) Instant 3. (c) End systole.

Fig. 3. Simulated MRI short axis views.

VIP was designed as an extensible platform to support simulation-based research. Other simulators could also be integrated. Integrating more elaborated and diverse object models used in the same simulation workflow is also possible.

5. ACKNOWLEDGMENT

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[5] `http://www.france-grilles.fr`