CT Scan Merging to Enhance Navigation in Interventional Radiology Simulation.

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Abstract. We present a method to merge two distinct CT scans acquired from different patients such that the second scan can supplement the first when it is missing necessary supporting anatomy. The aim is to provide vascular intervention simulations with full body anatomy. Often, patient CT scans are confined to a localised region so that the patient is not exposed to more radiation than necessary and to increase scanner throughput. Unfortunately, this localised scanning region may be limiting for some applications where surrounding anatomy may be required and where approximate supporting anatomy is acceptable. The resulting merged scan can enhance body navigation simulations with X-ray rendering by providing a complete anatomical reference which may be useful in training and rehearsal. An example of the use of our CT scan merging technique in the field of interventional radiology is described.

Keywords. Interventional Radiology, CT scan, X-ray rendering

Introduction

Some medical procedures involve a significant portion of navigation through the patient's anatomy to reach the desired region of interest. Often this entire navigation length of the patient is not scanned completely since it would expose the patient to additional radiation, require multiple imaging scans, not be cost or time effective. As a result, imaging scans are focused on a particular localized region of interest and does not capture the remaining supportive anatomy that a physician has to navigate through. We propose to enlarge a patient-specific scan by merging a second scan from a different patient onto the original primary patient scan so that a more complete anatomical environment is available. With patient-specific simulation receiving increasing focus from the research and clinical communities, there is a need for larger training datasets which could be accomplished by permitting allowances outside the primary area of interest. Thus, targeted patient scans could be augmented with approximate supporting anatomy in the regions which are less critical. Our simulated CT scan will not interfere with the soft tissue simulation, but will facilitate navigation thanks to the inclusion of additional anatomical landmarks.

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One such medical field which requires lengthy navigation through a significant potion of a patient is interventional radiology where femoral arterial needle puncture is performed so that catheter/guidewire pair can navigate to apply therapy to the patient's brain or to their heart. Interventional radiology methods, such as transcatheter drug delivery and mechanical extraction of blood clots, have substantially improved outcomes for patients. With this image guided therapy, skillful instrument navigation and complete understanding of vascular anatomy are critical in order to avoid irreversible complications. Often, a CT angiography scan is done before a procedure so that interventional radiologists can identify any pathologies that are impeding the patient's blood flow. Traditionally, the best training environments these techniques has been actual patients since porcine and canine animal models have dissimilar anatomy. This recognition of the unacceptable risks of learning on patients has placed a new emphasis on creating realistic, accurate simulations. A real-time high-fidelity interventional radiology simulator [1] has been developed with accurate anatomical representations, fluoroscopic rendering, and physics-based device models with collision detection, physiology subsystem with fluid dynamics, simulation of contrast agent propagation and a tracking device. For anatomical models, a corresponding CT and CTA datasets are used to segment and reconstruct the targeted vascular system [2] while the same CT scan is used directly for the fluoroscopy rendering of the supporting anatomy surrounding the vascular network. Often, this supporting anatomical space is not captured in the initial patient scan so we have developed a technique to enlarge this supporting anatomy environment by merging a second scan from a different patient onto the original primary scan so that a larger supporting anatomical environment is available for training.

This paper first describes the registration preprocessing, then details of the non-rigid registration itself. The two registration techniques presented here are: an automatic method based on FEM and a manual one using landmarks. The end result is the use of a non-linear registration on a second CT scan to align it with the first CT scan so that a continuous whole body CT scan can be created. Lastly we will show our method applied with the datasets from the Visible Man and Woman projects [3].

1. Method

1.1. Registration Preprocessing

Data first need to be preprocessed in two steps: matching and rigid registration. As a preliminary step, the slice from the second CT scan which matches the best with the final slice of the first CT scan must be found. This is done manually using a visualization tool. Figure 1 shows the slice which was chosen to match our patient's final CT slice. In order to have the two datasets in the same coordinate system, a rigid registration is applied. It is a similarity transform, which can be seen as a composition of rotations, translations and uniform scaling. It preserves angles and maps lines into lines. This transform is implemented from a rigid 2D transform with an additional scale parameter.

1.2. Non-rigid Registration

Once the data have been prepared, the non-rigid registration can be applied. After testing various 2D non-rigid registrations techniques (B-Spline [4], FEM [5], Demon [6] ...)

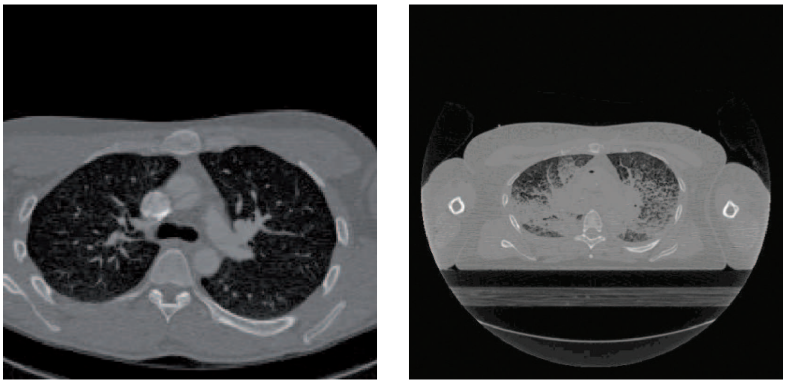

Figure 1. Common slices: last slice from the first CT scan (left) and the best matching slice from the second CT scan (right)

without successful results, we chose two methods: the Finite Element Method and a landmark based registration [7].

The Finite Element Method (FEM) applied in this type of application can be thought of as warping the image as a piece of rubber. It is not physically based so the tissues properties associated with the image are not relevant. The "forces" are based on derivatives of image metrics in blocks of pixels that surround the FEM grid nodes. Therefore the magnitude of these forces are not measured in any physically consistent unit, but in the units of the image metric divided by units of pixel spacing. The values used for the Young modulus and Poisson ratio are based on the magnitude of the image metric derivatives. In our case, Young Modulus has been fixed at E=2.5e5 Pa. The computing time is approximately an hour on a Intel Pentium M 2.00GHz 2.0GB RAM @ 599MHz.

The landmarks-based registration is a transform kernel which computes dynamically the displacements associated to a deformation field. A 3D point's displacement value is computed by interpolation from the vectors defined by a set of source landmarks to a set of target landmarks. Those landmarks are chosen by the user and can take approximately a few minutes to set 20 landmarks. A B-Spline interpolation kernel is then used to compute the deformation field. Figure 2 below shows the landmarks used in our example. The computing time for this landmark registration is approximately 5 seconds on the same machine.

The result from both non-rigid registrations is a deformed image and a corresponding displacement vector field. Applying this vector field to every slice of a dataset, the entire CT scan can be deformed. Figure 3 shows the lateral and frontal slices of a resulting 3D CT scan generated from our merging technique. The following section analyses our result.

2. Results

The resulting final dataset is a volumetric CT scan dataset with a 3D matrix of density values that can have some discontinuity on the transition zone between the first and the second CT scan sections. The FEM registration approach (Figure 3 (*top*)) yields good

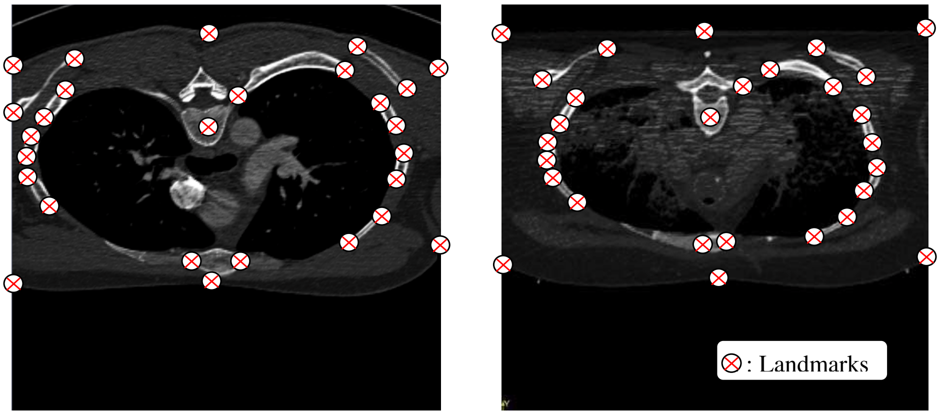

Figure 2. Landmarks positions. left: first CT scan, right:Second CT scan

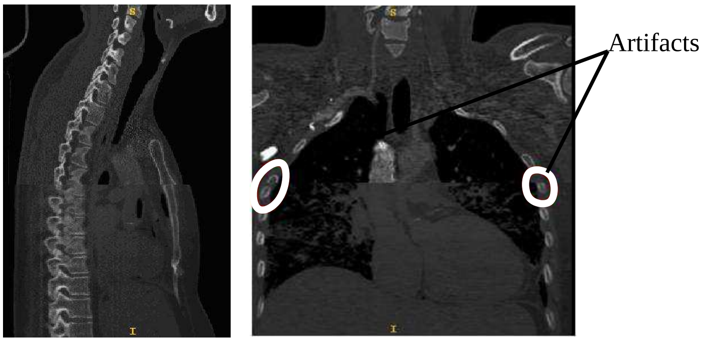

Figure 3. Result of FEM registration. *left*: spine view and *right*: rib view

results. For instance, the spine is continuous, there are right numbers of vertebra and overall the transition between both dataset is smooth. There are some discontinuities at the interface junction: first with the skin on the left, and also with the ribs as shown in Figure 3 (*bottom*) labeled as Artifact. In the same way, we can also see a skin problem on the left image.

These kinds of artifact do not appear with the landmark method. This method is less automatic than the FEM method but gives more accurate results. Our first aim is to provide the training environment software with at least two whole CT scan data, whatever the computing time is.

Density values are not very convenient to watch and even more complicated if one wants to check the continuity. To fully analyze the 3D CT scan dataset and correct this, we can reconstructed these two anatomical sections (skin and bone) in 3D. An isosurface is generated with a basic threshold segmentation for the two structures. These two parts are the easiest to segment and to use to check the continuity. The results are shown in Figure 4 (*left*) which shows the result of this reconstruction. The application of our technique has also been applied to The Visible Man dataset as well. Using the same segmentation method and highlighting the continuity is shown in Figure 4 (*right*). Finally,

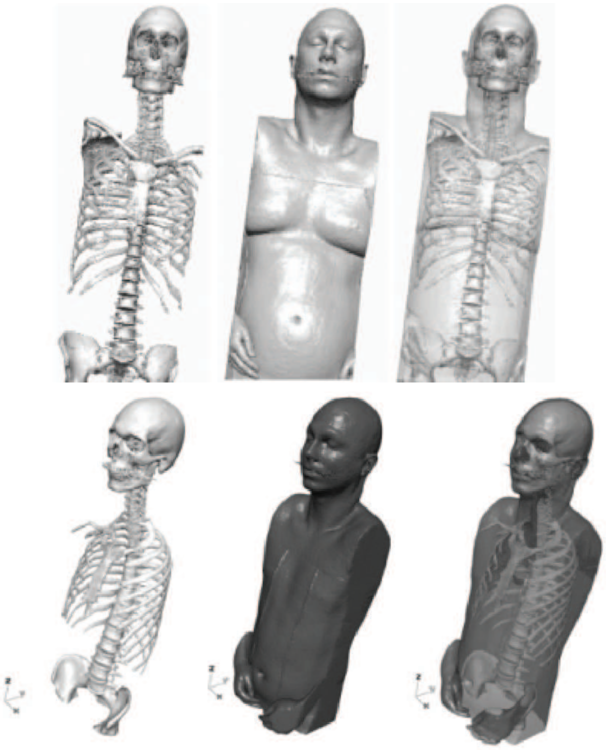

Figure 4. 3D Reconstruction from the resulting CT scan : bones, skin and both. *Top*: visible woman, *bottom*: visible man.

both final full body 3D CT man and woman data sets have been incorporated into the interventional radiology simulator. Figure 5 shows a screen image from the simulator using a male patient head scan merged with the body of the Visible Man scan. Also on the image is the vascular model is segmented from the patient scan and a heart motion field for the physiology module.

Conclusion

A method has been presented to supplement a patient CT scan with another to provide supporting anatomy. Our technique is a 4 step process: dataset preparation, registration prepossessing, non-rigid registration and merging. This includes resampling, normalisation, CT scan concatenation, rigid and non-rigid deformations. The results of the landmark method are acceptable, even though the transition is slightly noticeable. Possible future work includes optimising the entire process to be as semiautomatic as possible. The merged CT scan discussed in this paper is currently used inside the simulator presented in [1] and a second dataset will be soon available.

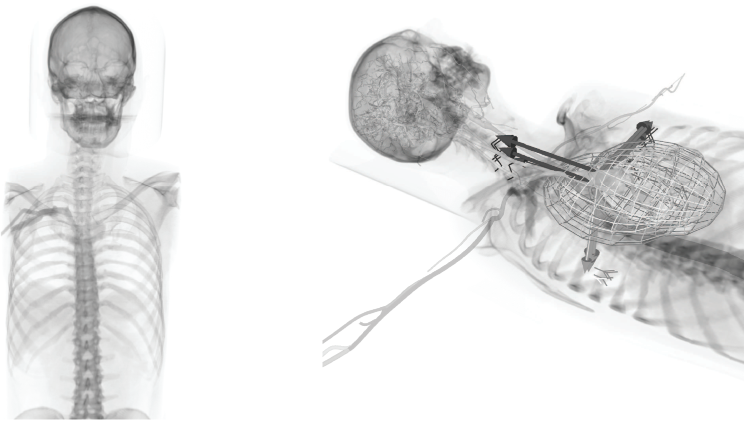

Figure 5. Merged 3D radiography dataset with segmented vascular model and heart physiology field controller.

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