Towards 4D Object Modeling

Aspects of defining **O**bjects, **S**tructure-systems, **V**isualizing & **A**nalyzing them

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Introduction

Digital Image processing has several applications. One such futuristic Medical Application is in Quantitative Radiology. Its goal is to build a body-wide fuzzy model of the human anatomy from image data from many normal subjects and to utilize this in recognizing automatically the anatomy from a given patient image and produce quantitative information.

This project is being engineered specifically for 'TIS' (Thoracic Insufficiency Syndrome) problem in small children (aged 6 to 13). The concept of 4th Dimension modeling techniques designed in this project, using Digital Image Processing tools, can help the doctor in planning an accurate surgical procedure on the child patient. At present, TIS problem does not have an exact solution; this project will eventually aid the doctors in deciding better for a correct diagnosis by taking into the child's growth (5th Dimension) using statistical measures. This is an ongoing project in collaboration with the '**CHOP'** (Children's Hospital of Philadelphia). The MRI Data-Sets used in this project are provided by CHOPs' Radiology section.

Our initial aim is to differentiate between normal and abnormal subjects. This is done by collecting Data-Sets of many normal subjects. By doing so, we will be in a position to define what normal is!! With this we can easily identify the abnormality on TIS subjects by comparing with normal. This is the underlying concept of this project.

This study aims to understand and analyze the dynamics of organs in thoracic region in close reference to the TIS. In this study we show the procedure to model lungs & diaphragm for calculating Lung Volume & Excursion Volume. This is one of the most important aspects in defining the normal function in the thorax.

There are many hurdles involved in modelling the complex behaviour of the organs in thoracic region. This is because, unlike the organs in the abdomen region, the organs in thorax are not stationary. Also, each organ in the thorax has its own frequency of motion which is independent of the other organs in the thorax. For example, motion of heart during pumping is quite different from the motion of lungs during breathing (inhalation/exhalation).

This study requires 2D MR Images as input. The goal is to convert the data from 2D to 3D to 4D to 5D, for analysis. Here, the 2D is simply an image on a plane. The 3D is obtained by stacking many 2D images one above the other. The 4D is obtained from the 3D volumes at various time intervals; here the 4th dimension is the breathing-time. The 5D is obtained from integrating various 4D statistical models; here the 5th dimension is the growth-time. In this study we have reached up to the 4D stage.

Goals

OVERALL: To segment Lungs and Diaphragm automatically and to obtain the corresponding 4D models for calculating Lung Volume , change in Lung Volume and Diaphragm Excursion Volume for TIS analysis.

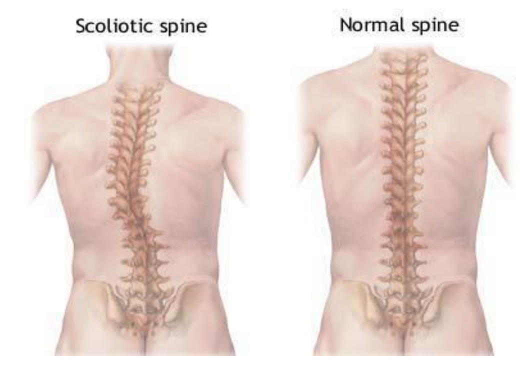
- ✓ To develop a method to Model Lungs and Diaphragm from 2D MR Images.
- ✓ To obtain a 4D movie animation of the Lung and Diaphragm motion.
- ✓ To calculate Lung Volume, change in Lung Volume and Diaphragm Excursion Volume of the subject.
- ✓ To develop an automatic method to segment the Lungs in the thorax. Techniques tried include :
  - Image Registration*
  - Shape Based Interpolation
  - Fuzzy Connectedness*
- ✓ Compare results of manual vs. automatic segmentation methods.*

Software Tools Used :

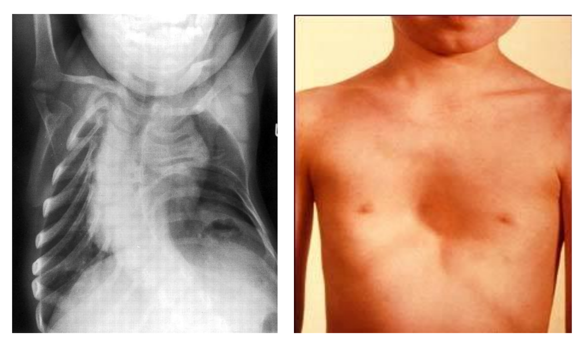
3DVIEWNIX — CAVASS — MATLAB

About TIS

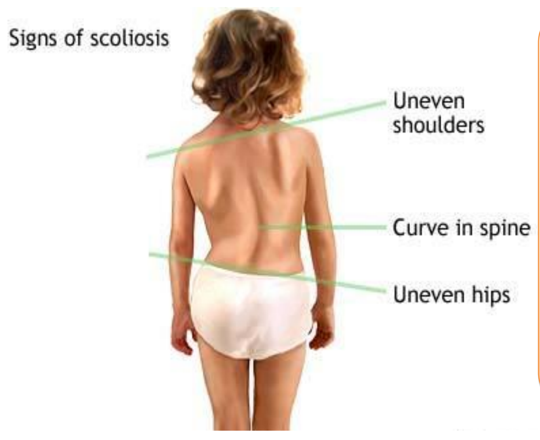
Thoracic Insufficiency Syndrome is the Extensive thoracic congenital scoliosis (curving of the spine) associated with fused ribs which may have an adverse effect on the function and growth of the lungs. It is the inability of the thorax to support normal respiration or lung growth. Traditional spinal surgery does not directly address this syndrome.



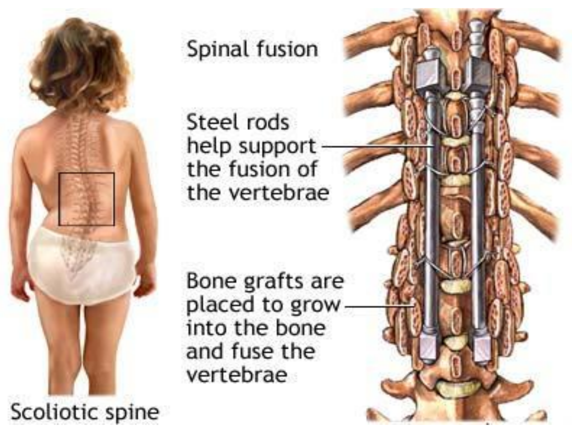
Scoliosis –
Abnormal curvature in the spine is known as scoliosis. It generally begins just at the onset of puberty and progresses during the period of rapid growth. Most junior high school students routinely screen for scoliosis because, if caught early, progressive spine curvature can be prevented. Scoliosis affects girls much more frequently than boys.



Progressive thoracic insufficiency syndrome due to three-dimensional thoracic deformity and dysfunction can be characterized on the basis of the respiratory history and the findings on physical examination, radiographs, computed tomography, and pulmonary functioning studies.



Treatment –
Depending upon the severity and responsiveness to other treatment surgery may be recommended for the scoliosis. Surgical correction involves correcting the curve (although not all the way) and fusing the bones in the curve together. Bone grafts are laid across the exposed surface of each vertebra. These grafts will regenerate, grow into the bone, and fuse the vertebrae together. The bones are held in place with one or two metal rods held down with hooks and screws, which also help to support the fusion of the vertebrae.



Ideally, treatment should restore thoracic volume and function and maintain these gains during growth. Traditional spine surgery with instrumentation achieves some correction of rigid congenital curves, but the mechanical advantage is too poor to effectively expand the lateral part of the rib cage constricted by rib fusion. Thus, the global three-dimensional thoracic deformity remains unaddressed.

Key Points

- Thoracic insufficiency syndrome is the inability of the thorax to support normal respiration or lung growth.
- The rare condition of fused ribs and congenital scoliosis may result in a three-dimensional thoracic deformity with adverse effects on thoracic growth and function with development of thoracic insufficiency syndrome.
- The normal thorax is defined by two characteristics: normal, stable volume and the ability to change that volume.
- Volume depends on the width and depth of the rib cage, and the thoracic spine provides height. The ability to change volume, termed *thoracic function,* is provided by the diaphragm and the secondary muscles of respiration.
- On radiographs, the loss of the vertical height of the lung of the concave, restricted hemithorax is defined by the percentage of space available for the lung.
- Spine rotation causes a windswept thorax, with both restriction of the volume of the convex hemithorax and restriction of the motion of the involved ribs.
- Constrictive three-dimensional deformity of the thorax may cause extrinsic, restrictive lung disease.
- Treatment of progressive thoracic insufficiency syndrome should provide an acute increase in the thoracic volume with stabilization of any flail chest-wall defects and maintain these improvements as the patient grows, without the need for spine fusion.

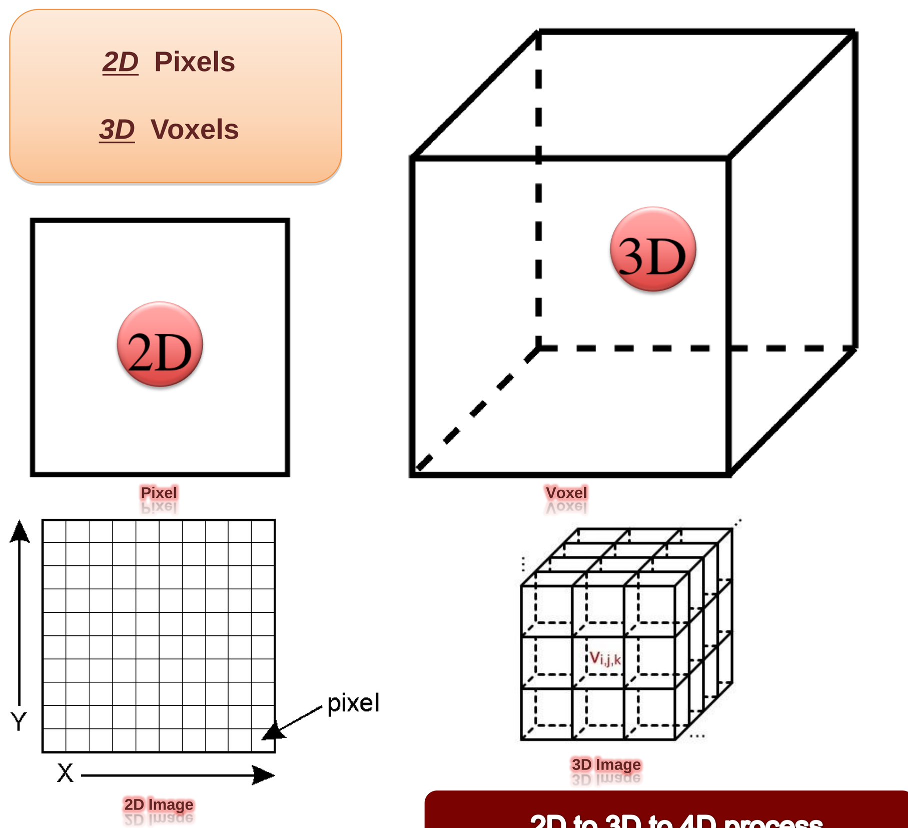
3D Image Processing

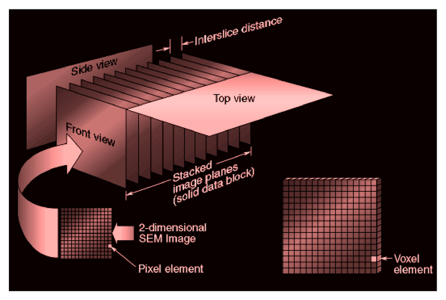
2D **Pixels**

3D **Voxels**

This project is concerned with digital image processing; in other words, image processing using computers.

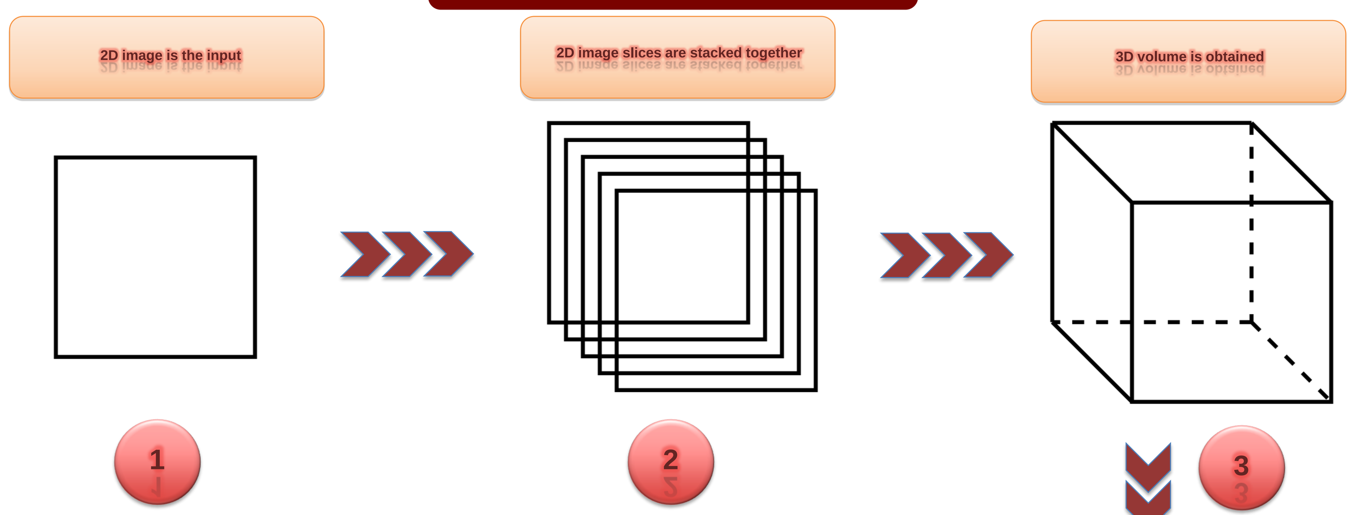
Our aim is to generate a 3D digitized image. By analogy with 2D images, the screen is split up into pixels and the intensity value of each is represented by a finite number of bits. The pixels are extended to 3D to obtain the density value and they are called *voxels*, the 3D equivalent of pixels. An image that has been digitized in such a manner is called a *three-dimensional digital image*, abbreviated as 3D image.



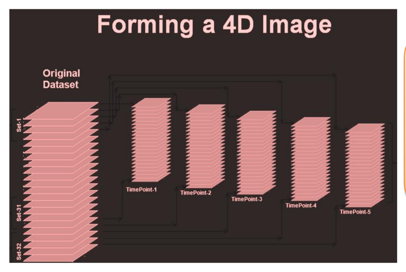


Pixel to Voxel Concept

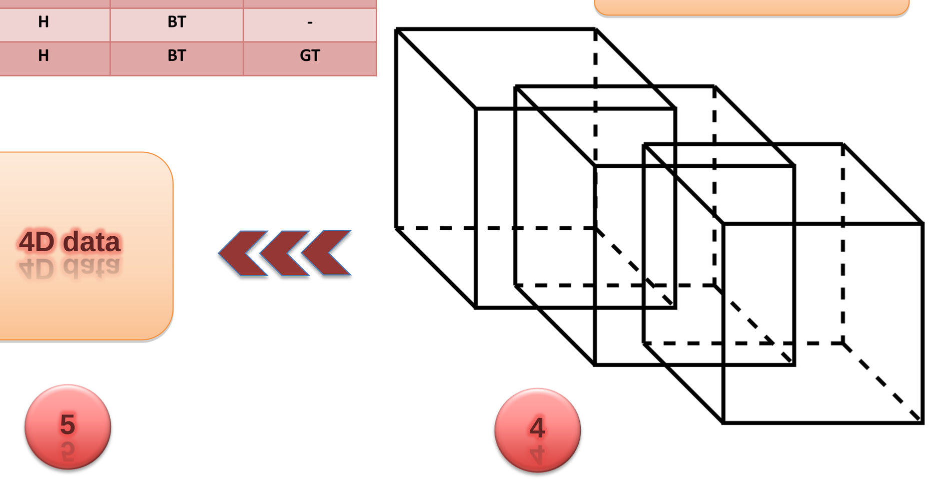
2D to 3D to 4D process



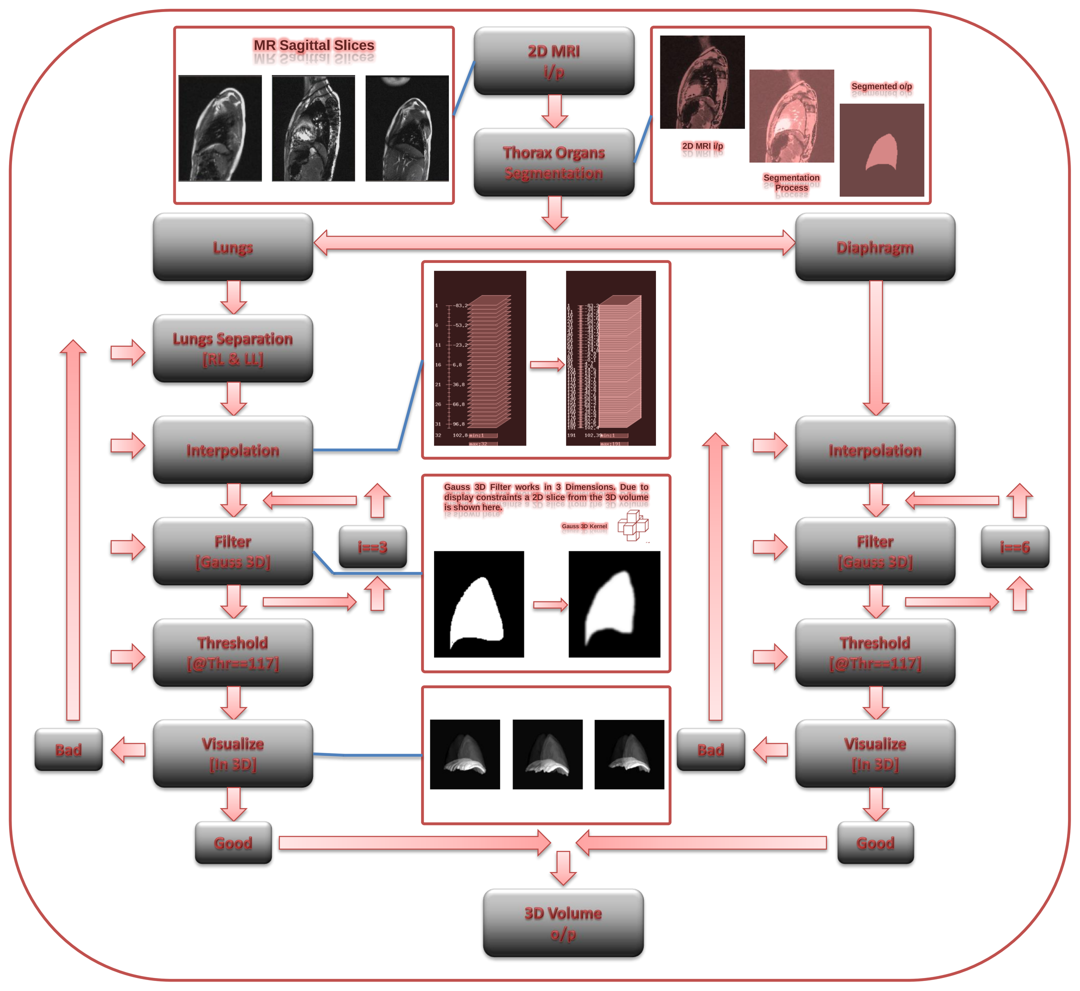
Dimension	Parameter				
	Length (L)	Breadth (B)	Height (H)	Breathing-Time (BT)	Growth-Time (GT)
2D	L	B	-	-	-
3D	L	B	H	-	-
4D	L	B	H	BT	-
5D	L	B	H	BT	GT



4D data



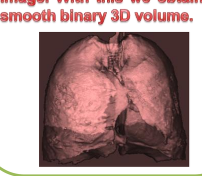
Process Flow

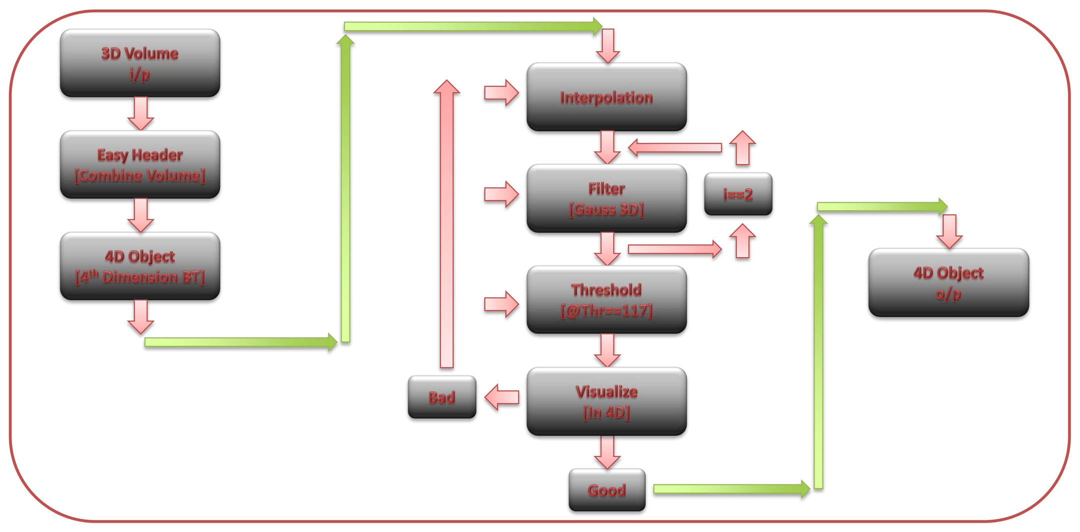


Stage 1

Here we take 2D MRI Data-Sets as input and obtain a 3D volume from it. The intermediate process from 2D to 3D has been shown in the flowchart.

- Manual Segmentation is performed on the 2D slices to segment out the Lungs and Diaphragm.
- Once the manual segmentations of Lungs and Diaphragm are obtained in binary form, we perform Shape Based Interpolation. This will result in more no. of slices in our 3D volume. This is mainly done to fill the large gaps in the 3rd Dimension and to make the 3D volume smooth.
- We use Gauss-3D filter on the 3D volume to further smoothen the image.
- We set a threshold of 117 grey-value on the filtered image. With this we obtain a smooth binary 3D volume.





Stage 2

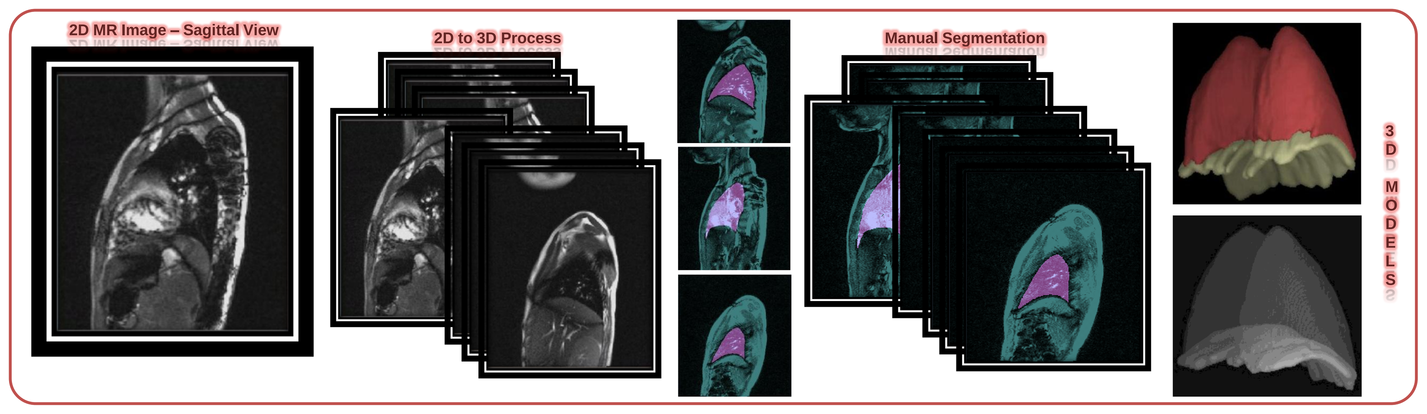
The 3D volumes at different time instant are the input. The intermediate process from 3D to 4D has been shown in the flowchart.

- Easy Header combines 3D volumes into a 4D object.
- We interpolate the 4D object to obtain intermediate 3D volumes for continuity.
- Gauss-3D filter is used to smoothen the 4D object.
- A threshold of 117 grey-value will result in a binary 4D object.

Results

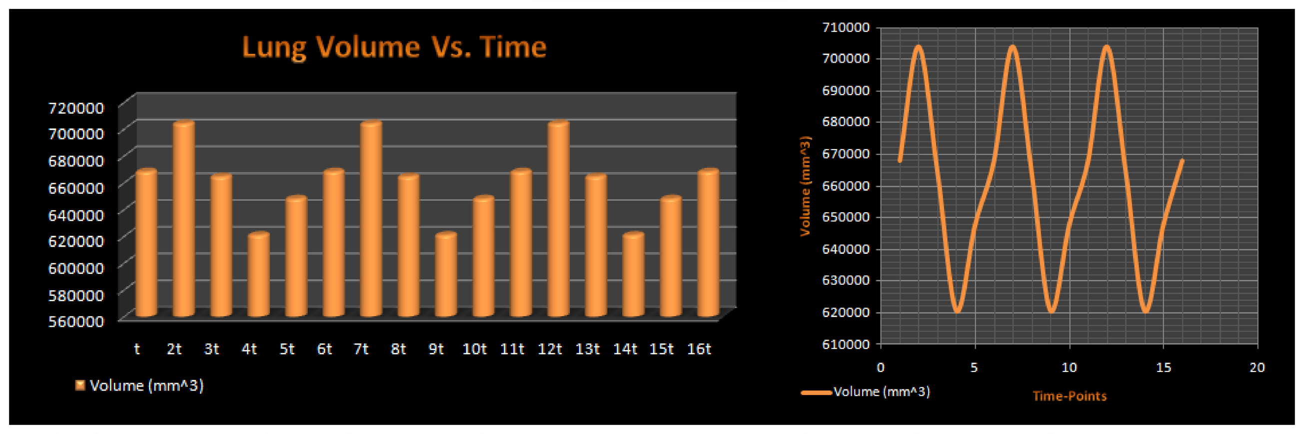
We tested the proposed methods on two data sets. The first data set consisted of 5 MRI time points of the thorax (in low quality), the objects of interest being the Lungs & Diaphragm. The second data consisted of 14 MRI time points of the thorax (in good quality).

Object Modelling

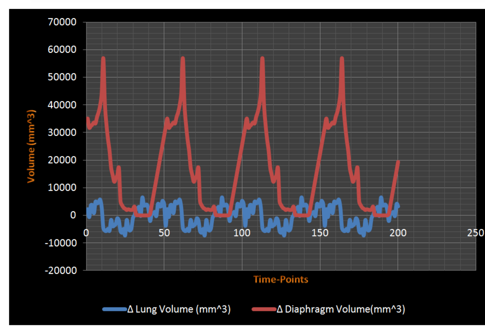


Quantitative Analysis

Lung Volume Graph



Diaphragm Excursion Volume Graph



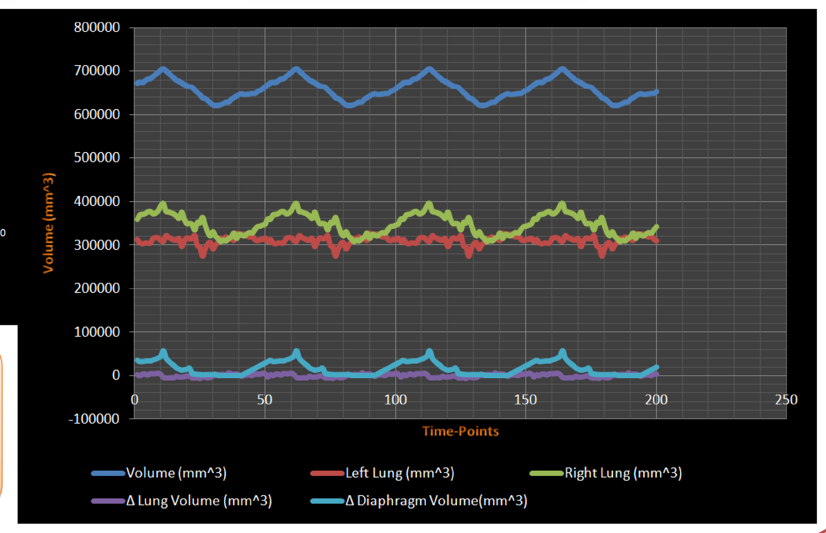
The Graphs are obtained from the models which was generated.

Actual Lung Volume = 579000 mm^3
Calculated Lung Volume = 660000 mm^3

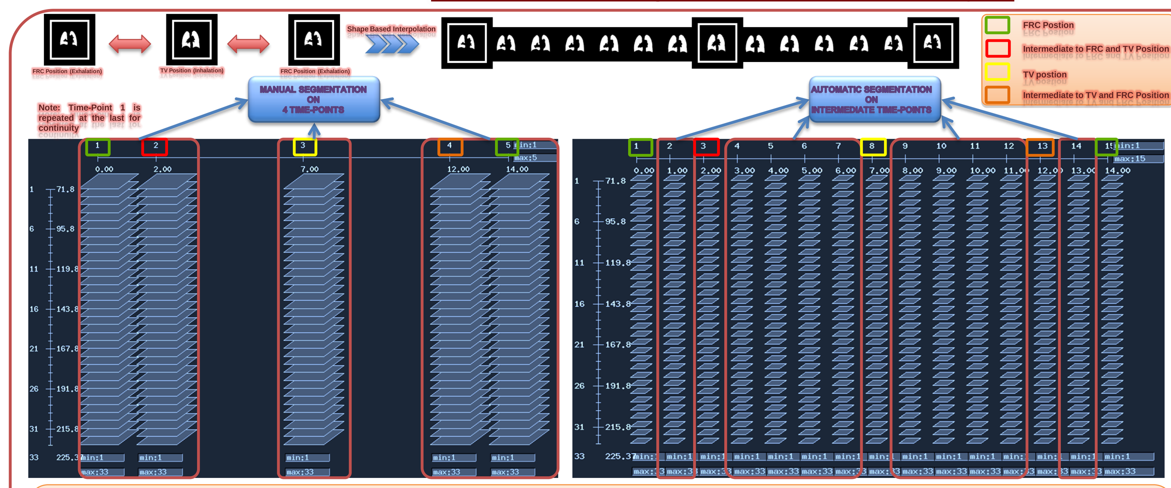
% Error = 12.27%

Optimization to obtain better results is being carried out.

Cumulative Volume Graph



Automatic Segmentation Technique



Shape Based Interpolation is used to segment out the Lungs from 14 time points of the MRI data set.
This is a semi-automatic segmentation technique. Here the segmentations of extreme lung positions are done manually. The intermediate time points are then segmented using Shape Based Interpolation automatically. This method has given us good segmentation results.

Conclusion

We have presented a method for modelling objects in 4D. We have calculated the Lung Volumes and Diaphragm Excursion Volume from our models for a normal subject. The results obtained have a close match with the accurate data obtained by measuring respiratory breathing volumes. We evaluated the accuracy of the generated models based on our results. Our evaluation indicates that the proposed method can be used to identify the abnormality in thorax with close reference to the TIS. Interestingly, this method can be automated. To do so, we have been working on automatic segmentation of the Lungs and Diaphragm. The shape-based interpolation technique is a semi-automatic segmentation technique for many time points. This has yielded good results. Other methods like fuzzy connectedness and registration are in their trial stage. These methods can completely automate the segmentation procedure involved for this analysis work.

References

1. George J Grevera & Jayaram K Udupa, "Shape Based Interpolation of Multidimensional Grey-Level Images", *IEEE Transactions on Medical Imaging*, vol.15(6), pp. 881-892, 1996.
2. Jayaram K Udupa, " Three-Dimensional Visualization and Analysis Methodologies: A Current Perspective", *Imaging & Therapeutic Technology*, vol.19(3), pp. 783-803, 1999.
3. George J Grevera & Jayaram K Udupa, "An Objective Comparison of 3-D Image Interpolation Methods", *IEEE Transactions on Medical Imaging*, vol.17(4), pp. 642-652, 1998.
4. H Rusinek, M E Noz, G Q MaguireJr., C Cutting, B Haddad, A Kalvin & D Dean, "Quantitative and Qualitative Comparison of Volumetric and Surface Rendering Techniques", *IEEE Transactions*, pp. 1531-1534, 1990.
5. Oliver Wirjadi & Thomas Breuel,"Approximate Separable 3D Anisotropic Gauss Filter", *IEEE Transactions*, 2005.
6. Jayaram K Udupa, Punam K Saha & Laszlo G Nyul, "Task-specific comparision of 3-D image registration methods", *Proceedings of SPIE,* vol.4322, pp.1588-1599, 2001.
7. Jayaram K Udupa, Punam K Saha & Robert A Lotufo, "Relative Fuzzy Connectedness and Object Definition: Theory, Algorithm, and Applications in Image Segmentation", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol.24(11), pp. 1485-1500, 2002.
8. Robert M Campbell, Melvin D Smith, Thomas C Mayes, John A Mangos, Donna B Willey-Courand, Nusret Kose, Ricardo F Pinero, Marden E Alder, Hoa L Duong & Jennifer L Surber, "The Characteristics of Thoracic Insufficiency Syndrome Associated with Fused Ribs and Congenital Scoliosis", *The Journal of Bone & Joint Surgery*, vol.85(A),pp.398-408, 2003.

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