Towards 4D Object Modeling for Thoracic Insufficiency Syndrome

Sudhish Kasaba Ramesh[a] and Manmeet Singh[b]

[a,b] B.Tech Candidate, DSP/ISP Division, School of Electronics Engineering, Vellore Institute of Technology.

Email: sudhish.rams@gmail.com, manmeet05@gmail.com

ABSTRACT

This study aims to understand and analyze the dynamics of organs in thoracic region with close reference to the "Thoracic Insufficiency Syndrome" (TIS).

In this study we show the procedure to model lungs & diaphragm, from 2D MR images, for calculating Lung Volume, Change in Lung Volume & Diaphragm Excursion Volume. These are the most important aspects in defining the normal function in the thorax. We have also obtained a 4D movie animation of the Lung and Diaphragm motion. There are many hurdles involved in modeling the complex behavior 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, the frequency of motion of heart during pumping is quite different from the frequency of motion of lungs during breathing. We have obtained Lung Volume to be 66000mm^3 from the 3D models generated. Also, we have calculated the correlation between the Lung Volume (at discrete time intervals) and Diaphragm Excursion Volume, and have obtained a result of 0.89224 for a normal subject. To automate the segmentation process we have been trying techniques such as Registration & Fuzzy-Connectedness. With Shape-Based Interpolation technique we were able to segment intermediate time-points semi-automatically.

***Index Terms*—** TIS, MRI, 3D-Imaging, Image Segmentation, Interpolation, 3D-Filtering, Image Registration, Fuzzy-Connectedness.

I. INTRODUCTION

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 [1]; 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).

This study uses 2D MR Images as input (provided by CHOP - Radiology section). The goal is to convert the data from 2D to 3D to 4D to 5D, for analysis. 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. 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 the normal. This is the underlying concept of this project. We have used 3DVIEWNIX [2], CAVASS [3] and MATLAB software tools for this work.

A. About TIS

Thoracic Insufficiency Syndrome (TIS) is the Extensive thoracic congenital scoliosis (curving of the spine), shown in Fig.1, 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.

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.

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, shown in Fig.2 and Fig.3, 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.

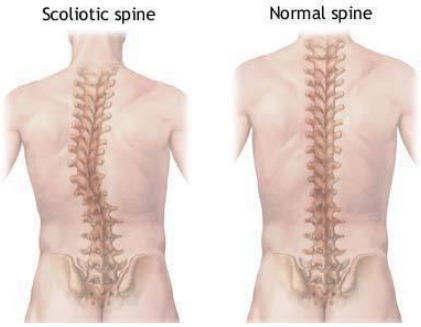


Fig. 1. Abnormal curvature in the spine is known as scoliosis, and generally begins just at the onset of puberty and progresses during the period of rapid growth. Most junior high school students routinely screen for scoliosis because, if caught early, progressive spine curvature can be prevented. Scoliosis affects girls much more frequently than boys.

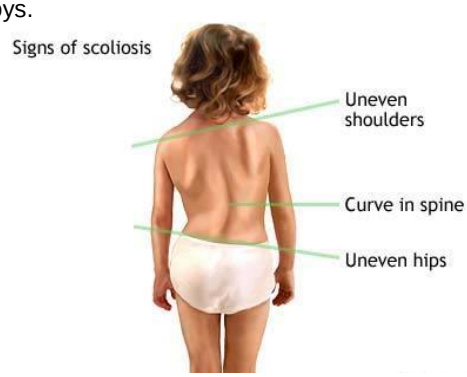


Fig. 2. Scoliosis may be suspected when one shoulder appears to be higher than the other, there is a curvature in the spine, or the pelvis appears to be tilted. The treatment of scoliosis can involve the use of a brace or surgery. Treatment is determined by the cause of the scoliosis, the size and location of the curve, and the stage of bone growth of the patient.

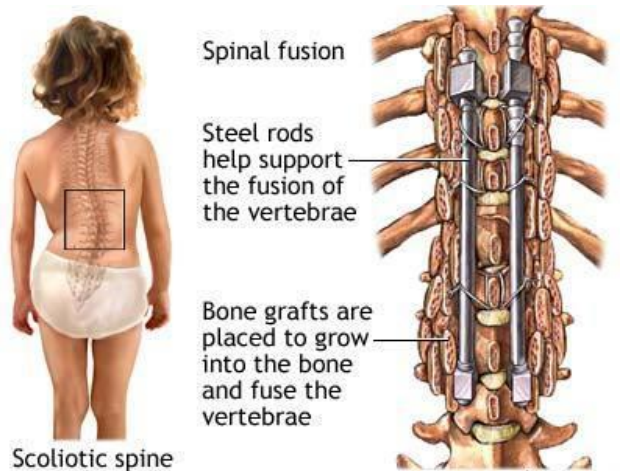


Fig. 3. Depending upon the severity and responsiveness to other treatment surgery may be recommended for the scoliosis. Surgical correction involves correcting the curve (although not all the way) and fusing the bones in the curve together. Bone grafts are laid across the exposed surface of each vertebra. 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.

B. Thorax Function & Deformity

The thorax includes the spine, the ribs, and the sternum and should be considered as a dynamic chamber of respiration. It passively supports primary respiration by providing a stable wall for lung expansion by the diaphragm, and it actively enables secondary breathing through upward excursion of the ribs by the secondary muscles of respiration [1]. It provides for growth of the underlying lungs by symmetrically enlarging itself through rib and spine growth throughout childhood and adolescence. The normal thorax is defined by two characteristics: normal volume and the ability to change that volume. Normal volume depends on adequate thoracic height, width, and depth. The height of the thoracic spine defines the height of the thorax, while the rib cage provides the width and depth. The rib cage must be stable for the volume to be normal.

The ability to change volume, termed thoracic function, depends on a stable diaphragm and on active rib motion of respiration, which depends on the presence of separate ribs, intercostal muscles, and symmetry of the thorax. Congenital malformations affecting thoracic volume or function may result in thoracic insufficiency syndrome [1].

II. 4D OBJECT MODELING

A. Stage-0 Data-Sets

Thorax (Upper Body) DATA-SETS are the input. These are MR-images from a subject who is completely normal. We received 4 types of DATA-SETS; these are tabulated

in Appendix (Table-A.1).

B. Stage-1 3D-Volume

Obtaining 3D-Volume from 2D-MR Image [4] was done in this stage. The input files used for this stage is from DATA-SET-1.

Thorax Organs (Lungs and Diaphragm) were segmented manually. For segmentation we have used LWOF [5,6] and Paint. After segmentation we have separated the right and left lung segmentations using Algebra functions. Fig.4 shows the segmentation process.

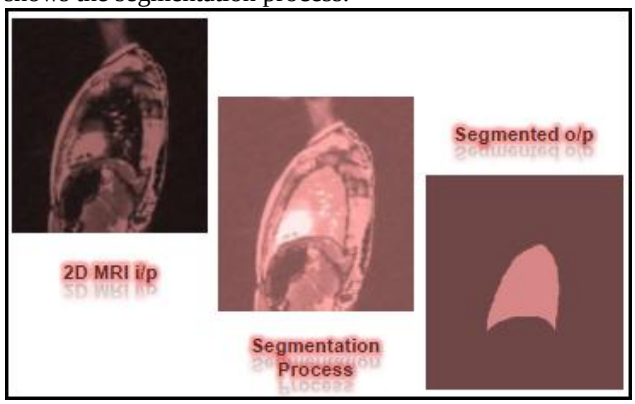


Fig. 4. Segmentation using LWOF and Paint was done on 2D MRI with the help of 3DVIEWNIX tool.

Shape Based interpolation [7,8] was then used to increase the number of slices after segmentation. This step was incorporated to create a smooth object for 3D modeling.

After Shape Based Interpolation, we filtered the 2D slices using a Gaussian 3D filter. This was done to generate a smooth object in 3D. Fig.5 shows the effect of 3D Gauss filter.

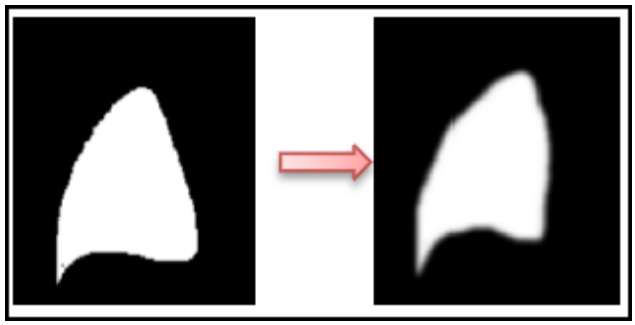
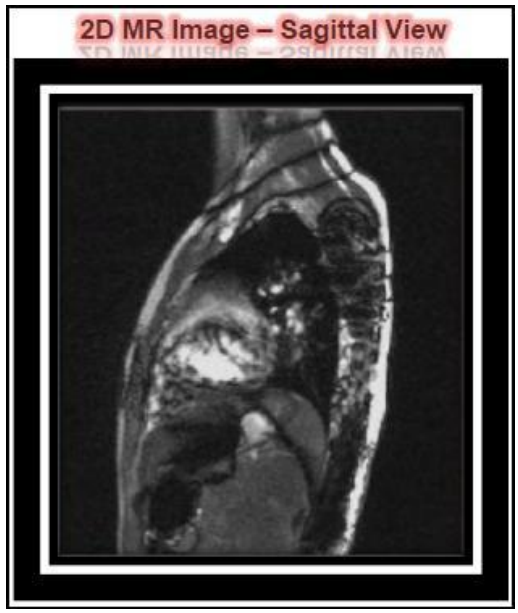


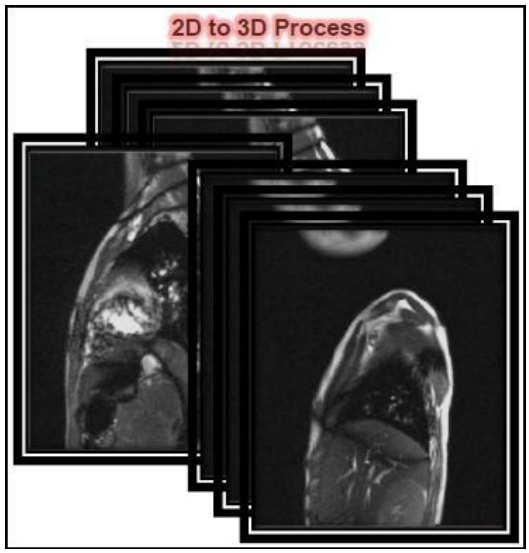
Fig. 5. 3D Gaussian Filter smoothens the segmented image in 3Dimensions.

The Filtered Object was then thresholded, by setting a threshold of 117 grey value, to obtain a sharper image.

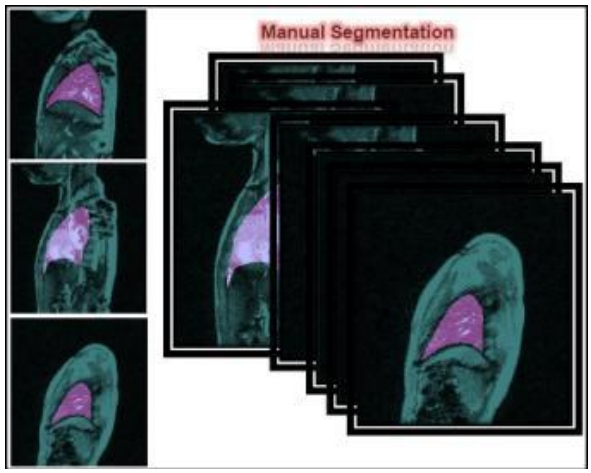
Once the preprocessing was completed, the 3D Volume was rendered. Complete 2D to 3D process is shown in Fig.6.



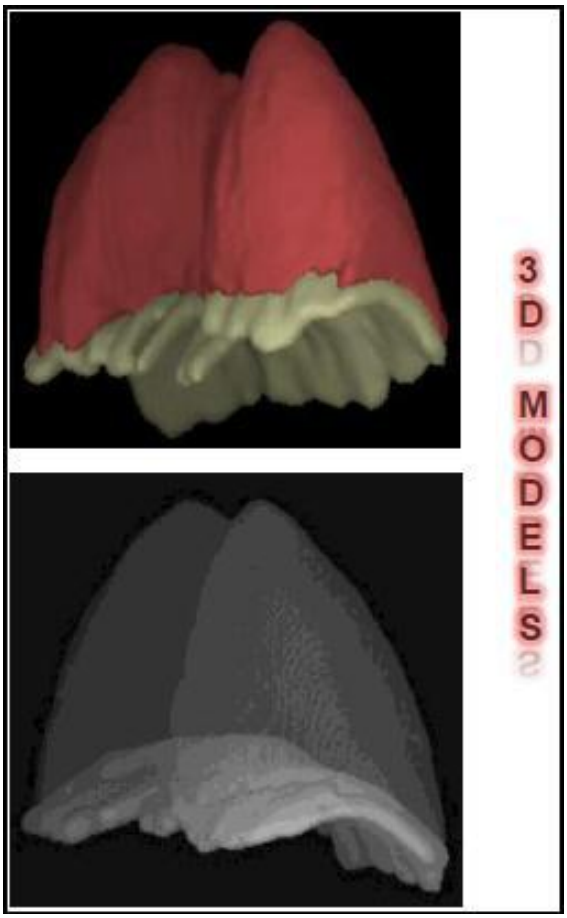
(a)



(b)



(c)



(d)

Fig. 6. The complete 2D to 3D process is shown from (a) to (d). (a) 2D MR Image in Sagittal View; (b) Stacking 2D MR Images to obtain 3D; (c) Manual Segmentation on Slices to extract Lungs and Diaphragm; (d) 3D Models.

The complete process involved in stage-1 has been shown as a flowchart in Appendix (Fig.A.1).

C. Stage-2 4D-Object

Obtaining 4D-Object from 3D-Volume was done in this stage. The input files used for this stage are the 3D-Volumes of Stage-1.

The 3D-Volumes were stacked together and combined using Easy-Header. The collection of various 3D-Volumes at different time intervals gave us our 4D-Object.

Once the 4D-Object was generated. We interpolated the 4-D Object using Time Based Interpolation to generate more 3-D Objects inside the 4D-Object. The number of 3D-Volumes to be generated has to be decided considering the 30 frames/sec criteria for animation in stage-3.

The 4D-Object was filtered using a Gaussian 3D filter. This was done to compensate the irregularities generated during the Time Based Interpolation.

The obtained 4D Object after filtering was thresholded at a grey level value of 117, this was done to sharpen the filtered output.

The complete process involved in stage-2 has been shown as a flowchart in Appendix (Fig.A.2).

D. Stage-3 Animation

Obtaining an animation from the 4D-Object was the task in this stage.

The screenshot of images in the 4D-Object was taken sequentially and was appended to obtain it as one SCRN format file.

This SCRN file was processed and converted to TIFF files. The TIFF files were sequentially arranged and timely spaced on the windows-movie-maker software. The intermediate images during the breathing process are shown in Fig.7.

We ensured 30frames/sec while setting the time-stamps in the software.

With this we obtained a WMV (& AVI) format movie files. This contains the complete lung motion animation during breathing.

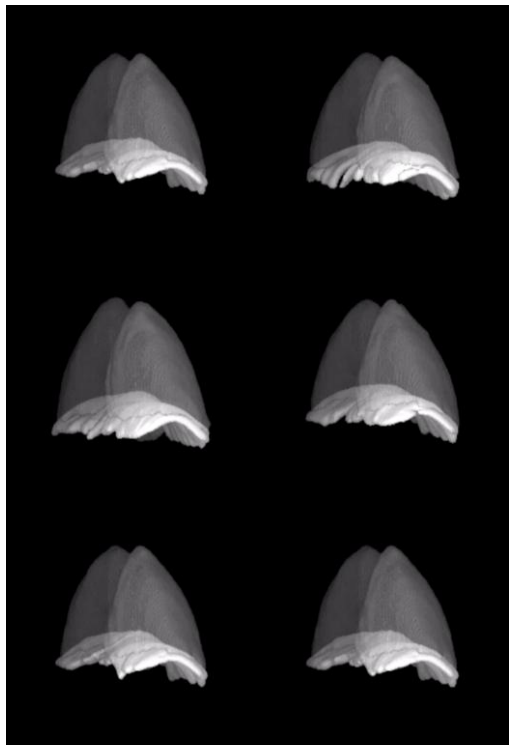


Fig. 7. The intermediate Lung and Diaphragm Images during the breathing process (View: L-R then bottom).

E. Stage-4 Analysis

Obtaining the Lung Volume, Change in Lung Volume and Diaphragm Excursion Volume 3D-Volume from the 3D-Object was done in this stage. Once these are obtained we perform a TIS analysis on the data we obtain.

The Lung Volume can be calculated easily by using the count of number of white voxels (obtained after segmentation). The exact Volume is known by multiplying the number of white voxels with the voxel volume.

The Change in Lung Volume is calculated by difference between successive time-point Volumes.

The Diaphragm Excursion Volume is calculated by registering the first time-point 3D-Volume on the second time-point 3D-Volume. Here we have used Mutual Information Image Registration. After registering the two successive objects, we have subtracted the second image from the registered object to highlight the Volume which the Diaphragm spans between the two time points. This portion is segmented again to obtain the Volume of this portion. This step has been iterated to calculate the Diaphragm Excursion Volume over the complete breathing period.

To identify the degree of TIS in the subjects, we have used linear correlation between Lung Volume and Diaphragm Excursion Volume.

The Lung Volume at Discrete time intervals and the Diaphragm Excursion Volume are very closely related. Because, the diaphragm is like a piston to pump air into/out-of the lungs. Hence Linear Correlation value can help us understand and analyze the level of TIS in the patient.

The push/pull work by the Diaphragm should have an effect in the Lungs; correlation value can be used to indicate the degree of TIS in the subject.

F. Stage-5 Automation

Obtaining Segmentations automatically using shape-based interpolation technique is the task. The segmented binary files at the extremes of the time interval are the input. The input files used for this stage is DATA-SET-2.

Using Shape Based Interpolation [7,8] we were able to generate the intermediate segmentations of the time-points from the Full Lung Residual Capacity (FRC) to Total Lung Volume (TV) and from TV back to FRC. This is a semi-automatic technique. Fig.8 shows the results of Shape Based Interpolation.

We also plan to completely automate the segmentation process using Fuzzy-Connectedness (FC) and Registration Techniques.

Fuzzy-Connectedness Idea [9] – We can refine the shape-based interpolation segmentations using FC technique. The only problem encountered in shape-based interpolation segmentation is that the segmentations near the diaphragm seem incomplete in many slices. To overcome this, we are trying to use fuzzy-connectedness to fill the small areas close to the diaphragm for a perfect segmentation. This method is in its trial stage.

Registration Idea [10,11] – We perform segmentation on a static image acquired in high quality. Once this segmentation is done, we try to propagate the segmentations over many time-points. To do this we register the images with the static, we obtain the registration parameters. We make use of these parameters and apply them to the manually segmented binary files to obtain another binary file to match up as the new segmentation. This method again is in its trial stage.

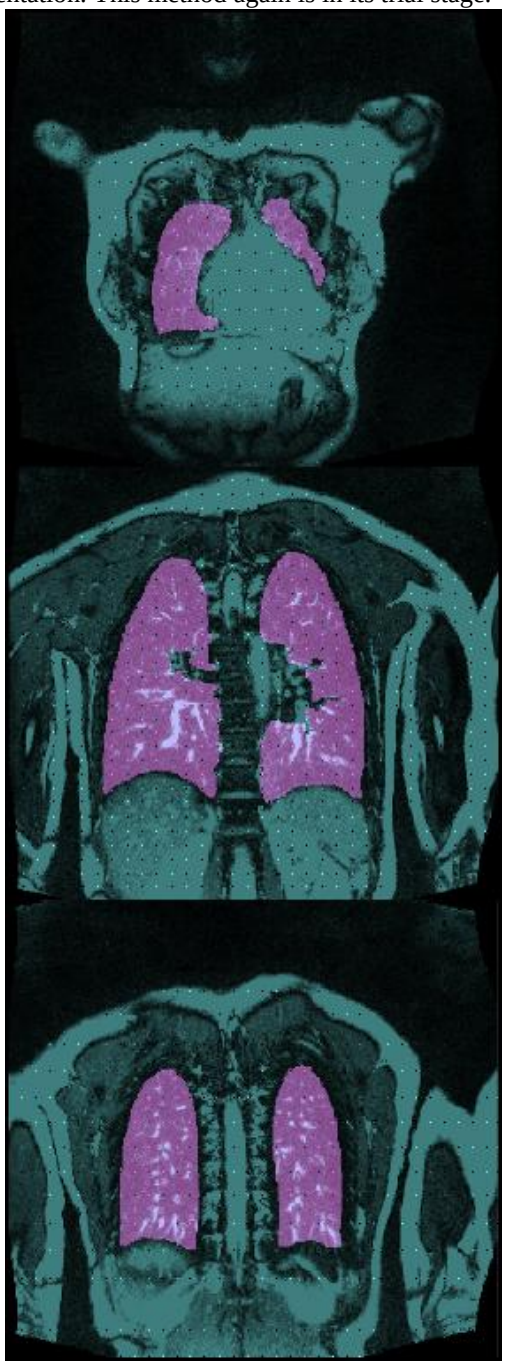


Fig. 8. This shows the results of semi-automatic segmentation using Shape Based Interpolation on the Data-Set.

III. RESULTS

We have calculated the Lung Volume to be 66000mm^3. This deviates from the expected value of 57900mm3. This has introduced an error of 12.27% in the Lung Volume calculated by our models. This is shown in the graph of Fig.9.

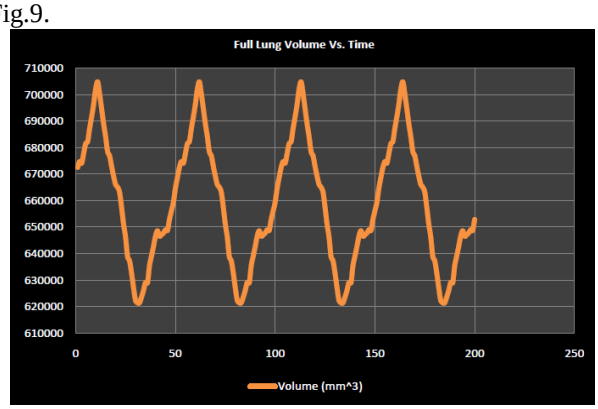


Fig. 9. This graph shows the Lung Volume calculate during breathing time.

We have also found out the Change in Lung Volume and the Diaphragm Excursion Volume. This has been shown in the graph below. Fig.10 shows the above data calculated over the breathing time. Fig.11 shows the cumulative graph containing all the data calculate.

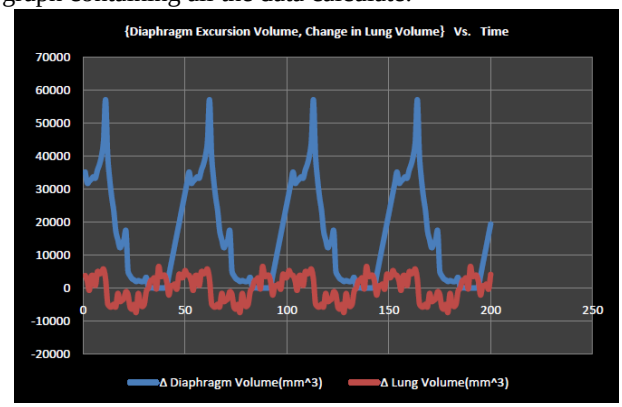


Fig. 10. This graph shows the Diaphragm Excursion Volume & Change in Lung Volume with time.

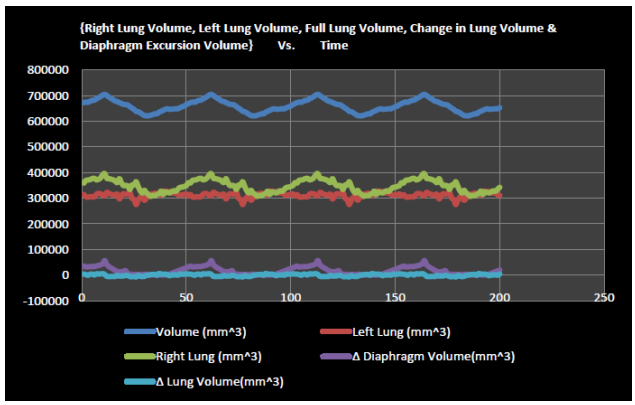


Fig. 11. This shows the cumulative results of all the results obtained.

TIS analysis was performed using the linear correlation between the Lung Volume and Diaphragm Excursion Volume. This value was calculated to 0.89224. This indicates a good correlation between the Lung Volume and Diaphragm Excursion Volume for a normal subject, and therefore the correlation value is very high. This value indicates how much of the Diaphragms activity is used during the breathing process by the lungs. In normal subjects this value is high, but in TIS patients the deformity of the thorax kicks in and this value may be very low.

Apart from this we have also made an animation of the Lung and Diaphragm motion for the complete breathing cycle.

IV. CONCLUSION

We have presented a method for modeling 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.

V. ACKNOWLEDGEMENT

We are indebted to Dr. Jayaram K Udupa. His guidance, support, motivation and encouragement were invaluable. Help from MIPG staff eased the process of identifying and rectifying the problems encountered during this study. The medical images used in this study were provided by the Children's Hospital of Philadelphia.

VI. REFERENCES

[1] 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*", JBJS, Vol.85-A No.3, March 2003

[2] Jayaram K Udupa, Odhner D & Samarasekera S, "*3DVIEWNIX: An open transportable, multidimensional, multimodality, multiparametric imaging software system*", SPIE proceedings, 1994

[3] George Grevera, Jayaram K Udupa, Dewey Odhner, Ying Zhuge, Andre Souza, Tad Iwanaga & Shipra Mishra, "*CAVASS: A Computer-Assisted Visualization and Analysis Software System*", Journal of Digital Imaging, Vol.20 Suppl.1, 2007

[4] Gabor T Herman & Jayaram K Udupa, "*Display of 3-D Digital Images: Computational Foundations and Medical Applications*", IEEE Transactions, 1983

[5] Alexandre X Falcão, Jayaram K Udupa & Flávio K Miyazawa, "*An Ultra-Fast User-Steered Image Segmentation Paradigm: Live Wire on the Fly*", IEEE Transactions on Medical Imaging, Vol.19 No.1, January 2000

[6] Jayaram K Udupa, Falcao A, Samarasekera S, Sharma S, Hirsch B E & Lotufo R, "*User-steered image segmentation paradigms: Live wire and live lane*", GMIP, Vol.60 No.4, 1998

[7] Jayaram K Udupa & Raya S P, "*Shape-based interpolation of multidimensional objects*", IEEE Transactions on Medical Imaging, Vol.9 No.1, March 1990

[8] Jayaram K Udupa & Grevera G J, "*Shape-based interpolation of multidimensional grey-level images*", IEEE Transactions on Medical Imaging, Vol.15 No.6, December 1996

[9] Jayaram K Udupa & Punam K Saha, "*Fuzzy Connectedness and Image Segmentation*", IEEE Transactions, Vol.91 No.10, October 2003

[10] László G Nyúl, Jayaram K Udupa & Punam K Saha, "*Incorporating a Measure of Local Scale in Voxel-Based 3-D Image Registration*", IEEE Transactions on Medical Imaging, Vol.22 No.2, February 2003

[11] László G Nyúl, Jayaram K Udupa & Punam K Saha, "*Task-specific comparison of 3-D image registration methods*", Proceedings of SPIE, Vol.4322, 2001

Sudhish Kasaba Ramesh received his B.Tech degree in Electronics & Tele-Communication Engineering from Vellore Institute of Technology, Vellore, India in 2011.

Presently he is working with Media-Room-Development Team, IPTV Division, Research & Development at Alcatel-Lucent, Chennai, India. During the past years, he has worked in the field of image processing as a student intern at MIPG-Lab, ABB-Robotics, ABB-SAS and AT&S. He has solely developed 'Block Hole Test' software for PCB testing at AT&S, which uses image processing to check the quality of the manufactured PCBs.

Manmeet Singh received his B.Tech degree in Electronics & Tele-Communication Engineering from Vellore Institute of Technology, Vellore, India in 2011.

Presently he is working with Network-System-Integration Team, IPTV Division, Research & Development at Alcatel-Lucent, Chennai, India. During the past years, he has worked in the field of image processing as a student intern at MIPG-Lab and done research projects with Texas instruments and NIT-Trichy.

VII. APPENDIX

A. TABLES

TABLE A.1
TYPES OF DATA-SETS USED

Type	No.Of Files	Fat	Quality	Voxel Size	Scene Size	Speed Of Acquisition	Plane	Orientation of Slices
DATA-SET-1	5	Not Suppressed	Very-Low	0.98mm x 0.98mm x 6.0mm	224 x 256 x 32	Fast	Sagittal	Left to Right
DATA-SET-2	14	Not Suppressed	Low	1.33mm x 1.33mm x 4.8mm	320 x 320 x 33	Fast	Coronal	Chest to Spine
DATA-SET-3	2	Not Suppressed	High	1.17mm x 1.17mm x 2.5mm	320 x 320 x 72	Slow	Coronal	Spine to Chest
DATA-SET-4	3	Suppressed	High	1.17mm x 1.17mm x 2.5mm	320 x 320 x 72	Slow	Coronal	Spine to Chest

B. FIGURES

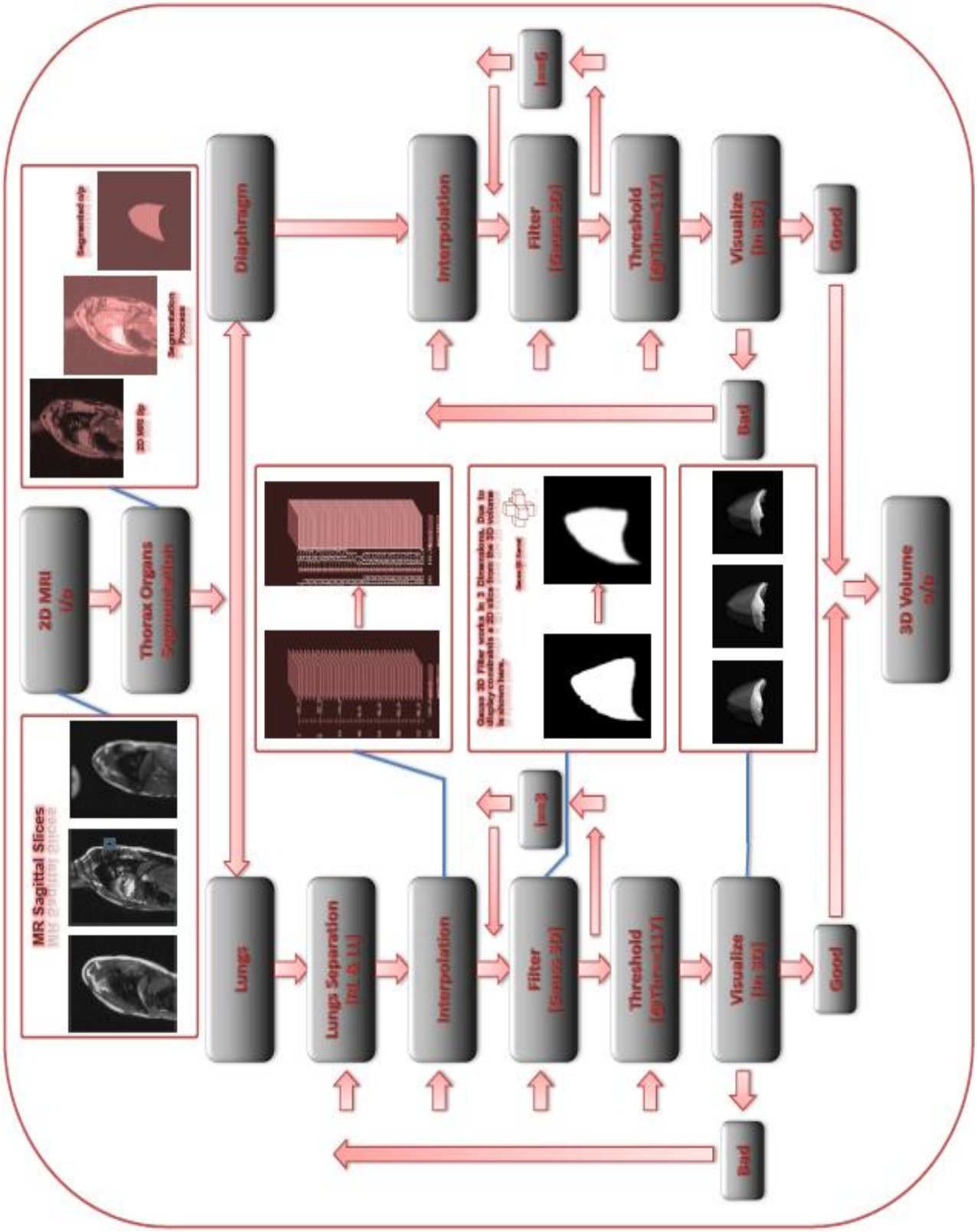


Fig. A.1 This shows the complete process of converting 2D MRI to 3D Volumes.

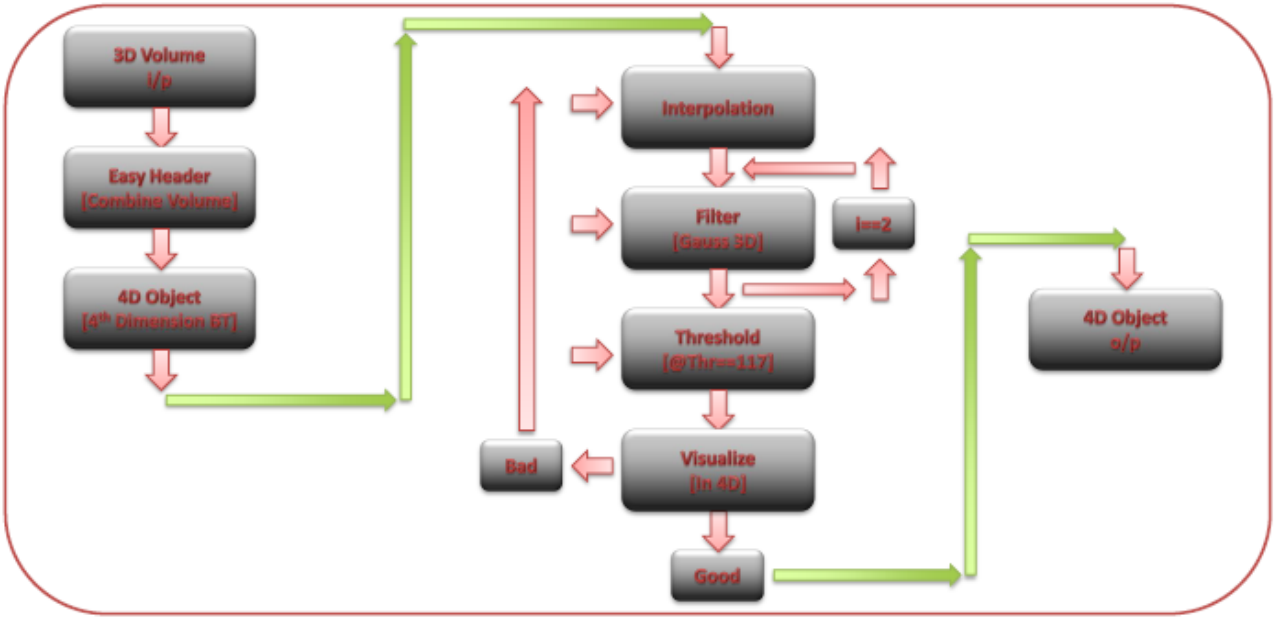


Fig. A.2 This shows the complete process of converting 3D Volumes to 4D Objects.