Fully Automatic Segmentation and Volumetry on Brain MRI of Coronal Section

*Yun-Chang Sung, **Chang-Jun Song, ***Seung-Moo Noh, *Jong-Won Park
*Dept. of Information Communications Engineering, Chungnam National University
**Dept. of Diagnostic Radiology, Chungnam National University
***Dept. of General Surgery, Chungnam National University
Gungdong 220, Yoosung Gu, Taejon 305-764, Korea
Tel: +82-42-821-7793, Fax: +82-42-823-5586
E-mail: ycsung@crow.chungnam.ac.kr

Abstract: This study is to segment white matter, gray matter, and cerebrospinal fluid(CSF) on a brain MR image of coronal section and to calculate the volume of each. First, we segmented the whole region of a brain from a black colored background, a skull and a fat layer. Then, we calculated the partial volume of each component, which was present in scanning finite thickness, with the arithmetical analysis of gray value from the internal region of a brain showing the blurring effects on the basis of the MR image forming principle. Calculated partial volumes of white matter, gray matter and CSF were used to determine the threshold for the segmentation of each component on a brain MR image showing the blurring effects. Finally, the volumes of segmented white matter, gray matter, and CSF were calculated. The result of this study can be used as the objective diagnostic method to determine the degree of brain atrophy of patients who have neurodegenertive diseases such as Alzheimer's disease and cerebral palsy.

1. Introduction

The medical research about the structure and role of human brain controlling an organic function of a body has been improved considerably and the progress of medical technique to cure various kinds of cerebral diseases also has been improved. Image diagnosis using a CT and a MR image plays an important role in this development of medical technique[1], and we expect that diagnosis technique using a medical image will continue to develop.

In the case of neurodegenerative diseases, we depend on the naked eye of a subjective diagnostic radiologist alone when we judge if a disease breaks out or not on a MR image. And the method for early diagnosis, through quantitative calculating atrophy of white and gray matter and the increasing degree of CSF by an objective standard, has not been developed clearly until now.

The increasing of CSF following atrophy of white and gray matter is a general tendency in patients who have symptoms such as Alzheimer's disease and cerebral palsy[2][3]. Quantitatively calculating the atrophy degree of those tissues and tracing the variation of their volume, and discovering the atrophy degree through comparing it with normal person's volume can be used as a basic and objective method to diagnose the outbreak of disease[2][3][4][5]. But the brain is a complex structure and has a physical property on its MR image.

As result, the quantitative method to calculate white matter, gray matter, and CSF has not been developed because there is no way to segment them from the MR image with blurring effects of gray value according to partial volume artifact induced by the size of a voxel[1][2][3].

But there were early attempts for some research teams to segment the whole region of a brain, making a brain MR image an object, and to segment the region of white matter and gray matter with semi-automatic method by a user's manual interface, making a T1 weighted image an object[4][5][6][7][8][9]. But their methods also have some problems. First, they could not segment each tissue exactly since the object of the methods was T1 weighted image, on which white and gray matter did not make a sharp contrast. Second, They could not process CSF alone. And finally there is an inefficiency of processing time caused by the user's manual interface.

In brain MR image, white matter and gray matter are mixed in a very complicated way. MR image is represented as a gray value at each location of 2 dimensional slice after scanning with a finite thickness [1]. At this time, MR image has blurring effects of gray value by partial volume artifact according to the size of voxel existed in the scanning thickness[10][11].
Therefore, it is difficult to calculate partial volume of white matter or gray matter within the original voxel from blurring gray value[1][2][3]. In this study, on the basis of the MR image forming principle, we interpreted gray value of blurring effects according to the ratio of each component. And then, we calculated partial volume of white matter, gray matter, and CSF, and suggested a method to determine the threshold to separate each tissue, and finally we calculated the volume of each segmented part.

2. Property of brain MR image

We can usually get various kinds of MR images, more than 100 slices, generated by scanning horizontally and vertically[1][10][11]. In this study, we have used the proton density and T2 weighted image for the same axial or coronal section of cerebral out of all the images.

The MR image is generated by the intensity of the signal, which examine the energy emission by interaction of high frequency radio waves and hydrogen atomic nucleus in the body. That is, after magnetizing atomic nucleus through injecting magnets to the examinee, and resonating atomic nucleus in the examinee's body through giving high frequency radio waves, the MR image is generated by emitting signal from the examinee's body when the resonated atomic nucleus are relaxed by cutting high frequency radio waves[1][10][11]. The generated gray value of MR image is depends on the density of hydrogen atomic nucleus, T1 relaxation time, T2 relaxation time and blood stream. Here the amount of water included in the human body is changed by the properties of a tissue. The abnormal tissue usually contains more water than the normal one. Therefore, a difference of density of hydrogen atom included in water is a primary element to distinguish each tissue in the MR image and we can get the contrast of desirable image by changing the parameter such as T1 or T2 relaxation time[1][2][3][4]. As a result, it can be said that lightness and darkness of the MR image is merely gray value generated by physical and chemical properties of each tissue instead of actual gray value of each tissue.

A proton density image out of various kinds of MR images is useful for the naked eye to perceive white and gray matter since it shows more sharp contrast of gray value than the T2 weighted image. But most of the brain region is represented as blurring gray value with white and gray matter and a small quantity of CSF[1][10][11]. Therefore, on the proton density image we determine the threshold to segment white and gray matter and segment two regions through analyzing blurred gray value. On the other hand, the T2 weighted image is darker than the proton density image, yet it is useful for extracting CSF because a small quantity of CSF region on the T2 weighted image is represented relatively brighter than on the proton density image[2][3][4]. In figure 1, MR image slices of (a) are proton density image samples used in this study, which are the 2^{nd}, 8^{th} and 12^{th} of 13 slices; (b) is an example of T2 weighted images which are scanned for the same section of proton density image.

(a) Initial proton density image samples

(b) Initial T2 weighted image samples

Fig. 1 Proton density and T2 weighted image for coronal section

3. Extraction of brain region

The segmentation of each tissue consisting brain is can be done after the inner part of brain is extracted from the whole brain image. Therefore, we could segment the inside of brain apart from the black colored background, skull and fat layer on given proton density image.

Figure 2 is a histogram for a proton density image. The pixels which make a high peak from 0 to 10 of gray value are the ones that make up the black background of the brain and the fat layer surrounding the inside of the brain. The pixels with more than a 90 gray value are the ones that consist of skull and the inside of the brain. Therefore, we can remove the background by using the difference between gray value distribution[12].

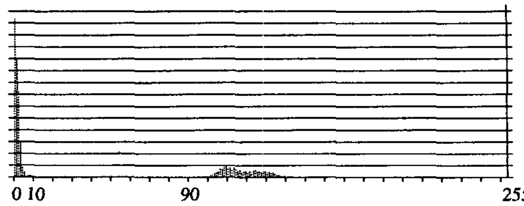

Fig. 2 A histogram for initial proton density image

In MR image of coronal section, the brain region is uniformly located in the size of 256*256 image slice. And the inside of the brain with adjusted gray value has more than a 90 gray value on the whole, and it is surrounded by the fat layer, which has less than a 90 gray value. Therefore, if starting at some pixels in the inside of the brain, and tracing the pixels with more than 90 of gray value by 4 connectivity, and then removing the traced pixels, we find only the black colored background, fat layer and the skull of the brain remaining. But if starting at a pixel consisting the background of brain image, tracing the adjacent pixels by 4 connectivity, and subtracting the traced region from the original proton density image, we can segment the inner part of the brain[10][11][12][13].

Figure 3 shows that the inside of brain with more than a 90 gray value are traced and removed, and figure 4 shows the inside of the brain segmented from the whole image of brain by the reverse use of figure 3. We can segment the inside of the brain on the corresponding T2 weighted image by using the image of figure 4, and figure 5 shows this T2 weighted image.

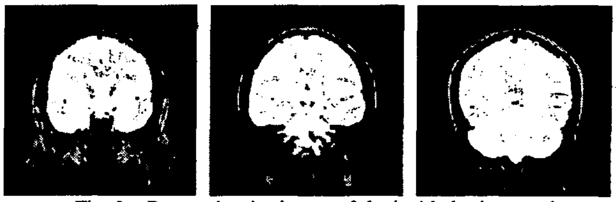

Fig. 3 Proton density image of the inside brain traced

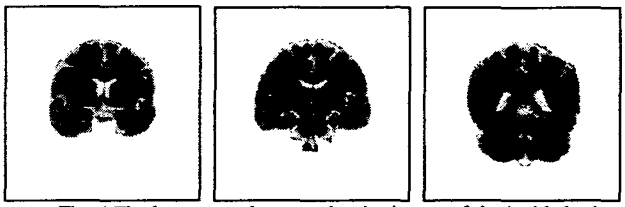

Fig. 4 Final segmented proton density image of the inside brain

Fig. 5 T2 weighted image of the inside brain segmented

4. Partial Volume Calculation

4.1 Analysis of blurred gray value

The problem of blurring effects usually was caused by the voxel size of the image. The MR scanner generates the image slices through scanning the brain by a finite thickness (3mm-10mm). If scanning thickness is thin, the size of voxel becomes smaller, and if it is thick, the size of voxel becomes lager accordingly. If a small voxel contains only fat or water, then a large voxel may be contains both of them. As result, the large voxel has the signal intensity equal to the average weight of the amount of water and fat contained in the voxel. Therefore, the gray value of one pixel in a two-dimensional slice is determined by the weighted average of the signal intensity emitted from each voxel consisting regular thickness.

Most of the blurring effects of gray value on the MR image scanned for coronal section of the cerebral occur because white matter, gray matter and CSF have the different amount of hydrogen atom within a finite thickness through which a magnetic field passes. That is, each tissue within a finite thickness emits a different amount of energy during the relaxation time of an atomic nucleus, and has different gray value according to the amount of the emitted energy. The MR scanner determines the weighted average of gray values by the signal intensity emitted from each voxel as one gray value. As a result, two-dimensional image slice shows blurring effects[1][10][11].

The (a) of figure 6 is the MR image of an axial section of the cerebral scanned by the 3mm and (b) is the MR image of it scanned by the 10mm. As stated above, compared with (a), (b) shows lower resolution of the image as the size of voxel becomes larger and accordingly the blurring effect appears stronger.

(a) 3mm thickness (b) 10 mm thickness

Fig 6. Proton density image scanned by different thickness

As a result, if two components of the MR image are segmented target, they are segmented by determining the appropriate gray value as a threshold from the gray values of the blurred region. And the blurred region is treated as a specific component according to each gray value after the segmentation[10][11][12][13].

Therefore, the represented gray value can be estimated when two components having a different gray value each other are mixed. And then, the partial volume of each components can be calculated from estimated gray value[10][11].

That is, when z% of one component with gray value y1 are mixed with (100-z)% of the other component with gray value y2 in a finite thickness, the blurred gray value G is calculated by the following expression because it is generated by the weighted average of the ratio of two components.

$$G = y_1 \cdot \frac{z}{100} + y2 \cdot (1 - \frac{z}{100})$$

4.2 partial volume calculation

The T2 weighted image is darker than the proton density image, but the CSF region is emphasized brightly on T2 weighted image. Therefore, we extracted the CSF from T2 weighted image first, and then extracted the pixel as CSF of the proton density image in the same location with CSF on T2 weighted image from the corresponding the proton density image[1][10][11].

On the T2 weighted image, the gray value distribution of pixels representing CSF can be different in every slice. Therefore, if we simply extract the pixels with more than a specific gray value as CSF by general observation value, we cannot extract it exactly because gray value for CSF has a different distribution in every slice.

Accordingly, we used the Gaussian distribution curve to determine minimum gray value of the pixels of CSF regardless of the gray value distribution of each slice. This is, after creating a histogram for inside brain of the T2 weighted image, we determined the highest gray value as a minimum gray value out of gray values folded with Gaussian distribution curve[11][12][13][14].

Figure 7 shows that the histogram of the T2 weighted image of the inside brain and the Gaussian distribution curve are overlapped. In this case, the minimum gray value of CSF was determined as 112.

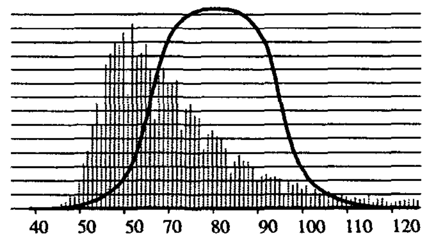

Fig. 7 Decision of a minimum gray value of CSF

Figure 8 shows the T2 weighted image after removed extracting CSF, and figure 9 shows the proton density image after removed CSF using figure 8. While figure 10 shows the CSF extracted from the proton density image.

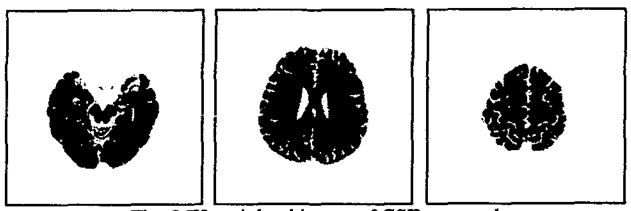

Fig. 8 T2 weighted image of CSF removed

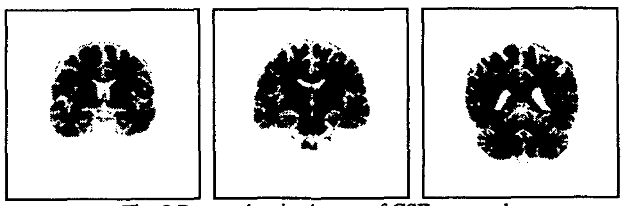

Fig. 9 Proton density image of CSF removed

Fig. 10 Extracted CSF from Proton density image

CSF extracted from the proton density image has a different distribution of gray value from that of the T2 weighted image. CSF is brightly represented in that case there is a pure CSF within a finite thickness. And CSF is darkly represented in proportion to the amount of white matter and gray matter if it is mixed with white matter and gray matter. A histogram of figure 11 shows the relation between CSF extracted from the T2 weighted image and CSF extracted from the proton density image.

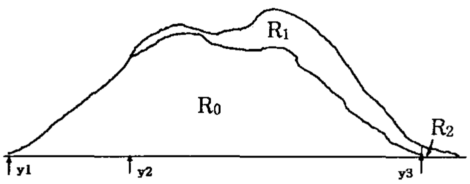

Fig. 11 A histogram for proton density image

In figure 11, region R_0 is a histogram for the proton density image of CSF removed, And region R_1 and R_2 are histograms of CSF extracted from the proton density image—R_2 is pure CSF and R_1 is CSF mixed with gray matter and white matter. Here y1 is minimum gray value of white matter, and y3 is considered a maximum gray value of gray matter and minimum gray value of pure CSF at the same time.

Given that the distributed function of a histogram to the region R_0 is H, H(y) is the number of pixels with gray value y. When z% of white matter with gray value y1 in a regular thickness and (100-z)% of gray matter with gray value y3 are included, gray value y is represented by blurring effects as follows

$$y = y_1 \cdot \frac{z}{100} + y_3 \cdot (1 - \frac{z}{100})$$

If gray value y represents the intermediate value of y1 and y3, 50% out of the pixels with these gray values can be considered white matter components, and the other gray matter components. Therefore, the number of pixels with partial volume of white matter in region R_0 is calculated as follows.

$$PV\,1 = \int_{y1}^{y3} H(y) \cdot \frac{y - y1}{y3 - y1} dy$$

Partial volume of white matter also should be calculated from region R_1. But we should extract the pixels with partial volume of CSF because white matter is mixed with it. Given that W is a distributed function of the regions R_1 and R_2, W(y) is the number of pixels with gray value y. Here the pixels with more than y3 gray value are extracted as pure CSF first. The number of the pixels representing extracted CSF is as follows.

$$PCSF = \int_{y2}^{y3} W(y) \cdot \frac{y3 - y}{y3 - y1} dy + \int_{y3}^{254} W(y) dy$$

Given that W` is the distributed function of a histogram for remaining parts after extraction of the pixels for partial volume of CSF. In region R_1, the number of pixels representing partial volume of white matter is as follows.

$$PV\,2 = \int_{y1}^{y3} W'(y) \cdot \frac{y - y1}{y3 - y1} dy$$

The sum PV of PV1 and PV2 is the number of the pixels representing white matter on the given proton density image, and then the number of the pixels representing gray matter is calculated as follows

$$PG = \left[\int_{y1}^{y3} H(y) dy + \int_{y2}^{y3} W'(y) dy \right] - PV$$

Figure 12 is a histogram which shows the explained procedure to calculate the partial volume of white matter.

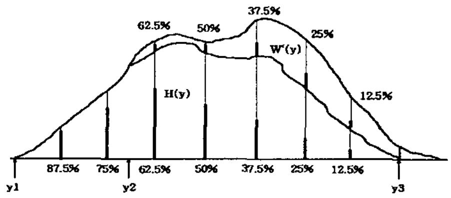

Fig. 12 A histogram to calculate partial volume of white matter

Given that T is the distributed function for histogram of the proton density image on which influence of CSF is removed, we determined the gray value t, which is the number of accumulated pixels including the sum of PV1 and PV2 for the first time, starting at minimum gray value of white matter, y1 and accumulating the number of pixels at each gray value, as a threshold. Figure 13 shows a histogram to determine the threshold.

$$PV\,1 + PV\,2 \leq \int_{y1}^{t} T(y) dy$$

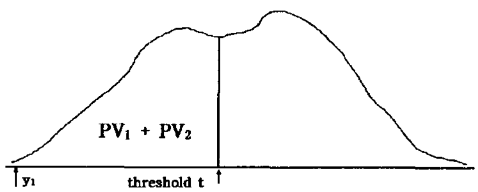

Fig. 13 A histogram of determining threshold

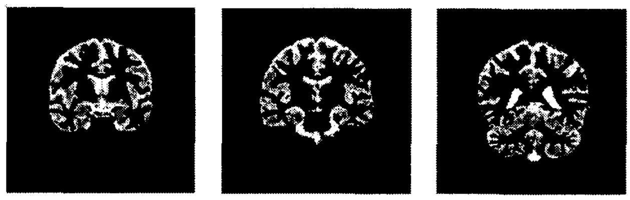

Fig. 14 Segmented image as white matter, gray matter and CSF

And figure 14 is the final proton density image segmented for each component by using the determined threshold. The bright part inside of a brain is CSF, the darkest part is white matter, and the rest is gray matter.

5. Volume Calculation

After segmenting white matter, gray matter, and CSF in each slice, we can calculate the volume of them by using the number of the pixels for each segmented component. We used information about both each pixel size and space between slices out of saved information in the header of the MR image. The volume is calculated by the following expression[10][11].

$$V = \sum_{i=1}^{N-1}(((W_p \cdot X \cdot Y)\ of\ S_i + (W_p \cdot X \cdot Y)\ of\ S_{i+1})/2) \cdot D$$

N : the number of slices,
S_i : slice cumber
W_p : number of pixels consisting segmented tissue
$X,\ Y$: vertical and horizontal length for one pixel

Table 1 shows the calculated volume with the explained method. By the observation of the calculated volume, although there is some exception, we can discover that the amount of CSF is increasing on the whole and that the amounts of white matter and gray matter are decreasing, as we grow older. This fact agrees with the common medical knowledge of diagnostic radiologists, who diagnose diseases in practice with the MR image of the brain. And from the analysis of the final segmented image of white matter and gray matter with the naked eye, they are decided that the exact segmentation is doing.

Table 1. Volume table of each component extracted

Age	Total Volume	Volume of white matter		Volume of gray matter		Volume of CSF	
18	0,975	0,395	40,55%	0,481	49,30%	0,099	10,15%
20	0,855	0,349	40,78%	0,415	48,56%	0,091	10,65%
23	0,713	0,311	43,62%	0,328	46,01%	0,074	10,37%
29	0,739	0,299	40,38%	0,359	48,49%	0,082	11,13%
29	0,787	0,308	39,19%	0,393	49,96%	0,086	10,87%
34	0,868	0,332	38,26%	0,443	51,06%	0,093	10,68%
37	0,835	0,320	38,32%	0,422	50,50%	0,093	11,17%
38	0,810	0,333	41,11%	0,390	48,20%	0,087	10,69%
38	0,873	0,347	39,70%	0,433	49,56%	0,094	10,73%
39	0,822	0,328	39,86%	0,388	47,26%	0,106	12,88%
43	0,755	0,273	36,17%	0,399	52,85%	0,083	10,98%
48	0,878	0,322	36,64%	0,456	51,92%	0,101	11,45%
49	0,918	0,336	36,65%	0,436	47,54%	0,145	15,80%
50	0,761	0,296	38,86%	0,357	46,96%	0,105	13,82%
52	0,770	0,259	33,61%	0,365	47,41%	0,146	18,98%
55	0,829	0,326	39,31%	0,366	44,15%	0,137	16,54%
56	0,850	0,297	34,93%	0,429	50,46%	0,124	14,59%
60	0,794	0,320	40,29%	0,353	44,44%	0,121	15,27%
60	0,835	0,405	48,53%	0,302	36,19%	0,128	15,28%
61	0,773	0,252	32,54%	0,393	50,84%	0,129	16,62%
61	0,817	0,307	37,54%	0,389	47,57%	0,122	14,89%
64	0,901	0,351	38,92%	0,401	44,53%	0,149	16,55%
66	0,873	0,338	38,70%	0,373	42,76%	0,162	18,54%
69	0,716	0,257	35,89%	0,323	45,06%	0,136	19,04%
70	0,762	0,291	38,25%	0,321	42,18%	0,149	19,56%
71	0,762	0,281	36,86%	0,315	41,32%	0,171	22,47%
80	0,767	0,280	36,44%	0,319	41,54%	0,169	22,00%
Average	0,816	0,315	38,59%	0,383	46,91%	0,118	14,51%

6. Conclusion

Considering partial volume of each component on the MR image of the brain blurred by partial volume artifact, we explained how to determine a threshold to segment white matter, gray matter, and CSF and how to calculate the volume of them.

In this study, we interpreted the specific gray value on a histogram to calculate the ratios of white matter, gray matter and CSF included within a finite thickness, calculated the number of the pixels of white matter and gray matter according to the interpreted ratio, and determined the threshold to segment each components on the basis of this. The MR image of the brain, especially, has the different gray value distribution in every person, and even one person has the different distribution in every slice. Considering this, through calculating independent threshold without regard to the different gray value distribution of slices, we made it possible to extract white matter, gray matter, and CSF without regard to the gray value distribution.

The accuracy of the segmented image and validity of the result from the volume of white matter, gray matter and CSF gained with a series of methods proposed in this study can be verified by a diagnostic radiologist. The result of this study can be used for the object diagnosis of the brain atrophy degree of the patients who have neurodegenertive diseases accompanying the brain atrophy. In a further study, to verify the suggested algorithm exactly, we will perform an experiment by using a phantom, which has the actual structure of a brain. We will also try to get statistic data about the volume of white matter and gray matter in the brain by applying the algorithm to more cases.

References

[1] A . Carrington and A. D. McLachlan," Introduction to Magntic Resonance", Chapman and Hall, London 1967.

[2] A. Brun and L. Gustafson, "Distribution of cerebral degenerationin Alzheimer's disease, "Arch. Psychiatry 223, pp.15-33, 1976.

[3] B. E. Tomlinson, G. Blessed, and M. Roth, "Observations on the brains of demented old people," J. Neurol. Sci. 11, pp.205 - 242, 1970.

[4] J. Szumowski and D. B. Plewes,"Separation of Lipid and Water MR Imaging Signals by Chopper Averageing in the Time Domain" Radiology 165, pp.247-250, 1988.

[5] M. I. John, N. K. Tanna, and G. T. Herman, "Analysis of brain and cerebrospinal volumes with MR imaging," Radiology 178, pp.115 - 122, 1991.

[6] H. Suzuki and J. Toriwaki, "Automatic Segmentation of Head MRI Images by Knowledge Guided Thresholding", Computerized Medical image Graphics, Vol.15, No4, pp.223-240, 1991.

[7] C. Li, D. B. Godlgof and L.O. Hall, "Knowledge based Classification and Tissue Labeling of MR Images of Human Brain, " IEEE Transaction Medical image,Vol.12, pp.740-750, 1993.

[8] M. S. Atkins and B.T. Mackiewich, "Fully Automatic Segmentation of the Brain in MRI," IEEE Transaction on Medical Image," Vol.17, No1, pp.98-107, 1998.

[9] N. Shareef and D. L. Wang, "Segmentation of Medical Images Using LEGION", IEEE Transaction on Medical Imaging, Vol. 18, No 1, pp.74-91, 1999.

[10] Y. C. Sung, et al, "Partial Volume Effects on Segmentation of White Matter from the Brain," Proceedings of the 4th Asia-Pacific Conference on Medial and Biological Engineering, pp.210-212, 1999.

[11] Yun-Chang Sung, et al, "Segmentation and Volume Calculation of White Matter, Gray Matter and CSF Through the Analysis of Blurred Gray Value from Brain MRI", Proceedings of IPIU2000 workshop, pp.558-564, 2000.

[12] M. J. Carlotto, "Histogram Analysis Using a Scale-Space Approach" IEEE Trans on PAMI, pp.121-129, Jan 1987.

[13] S. E. Umbaugh "Computer Vision and Image Procesisng :A Practical Approach Using CVIPtools" Prentice Hall PTR, pp.12-36, 1998.

[14] H. E. Burdock, "Digital Imaging Theory and Applications", McGrow-Hill, NewYork, pp.153-194, 1997.