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BRAIN TUMOR DETECTION BASED ON SEGMENTATION USING MATLAB

[1]K.AAISHA BEE, [2] I.RAJASEKHAR
[1]M.Tech Student, [2]Associate Professor,
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING,
SHRI SHIRDI SAI INSTITUTE OF SCIENCE AND ENGINEERING,
ANANTAPURAMU-515002,ANDHRA PRADESH

ABSTRACT

An unusual mass of tissue in which some cells multiplies and grows uncontrollably is called brain tumor. It starts growing inside the skull and interposes with the regular functioning of the brain. It needs to be detected at an early stage using MRI or CT scanned images when it is as small as possible because the tumor can possibly result to cancer. This paper, mainly focuses on detecting and localizing the tumor region existing in the brain by **proposed methodology** using patient's MRI images. The proposed methodology consists of three stages i.e. pre-processing, edge detection and segmentation. Pre-processing stage involves converting original image into a grayscale image and removes noise if present or crept in. This is followed by edge detection using Sobel, Prewitt and Canny algorithms with image enhancement techniques. Next, segmentation is applied to clearly display the tumor affected region in the MRI images. Finally, the image is clustered using the k-means algorithm. Here we have used MATLAB 9.4 for the development of the project.

The detection of tumor regions in Glioma brain image is a challenging task due to its low sensitive boundary pixels. In this paper, Non-Sub sampled Contourlet Transform (NSCT) is used to enhance the brain image and then texture features are extracted from the enhanced brain image. These extracted features are trained and classified using Adaptive Neuro Fuzzy Inference System (ANFIS) approach to classify the brain image into normal and Glioma brain image. Then, the tumor regions in Glioma brain image is segmented using morphological functions

I.INTRODUCTION

Brain is the kernel part of the body. Brain has a very complex structure. The brain is a soft, delicate, non-replaceable and spongy mass of tissue. It is a stable place for patterns to enter and stabilize among each other. Brain is hidden from direct view by the protective skull. This skull gives brain protection from injuries as well as it hinders the study of its function in both health and disease. But brain can be affected by a problem which cause change in its normal structure and its normal behaviour. A tumour is the name for a neoplasm or a solid lesion formed by an abnormal growth of cells which looks like a swelling. A tumour is a mass of tissue that grows out of control of the normal forces that regulates growth. Brain tumour is a group of abnormal cells that grows inside of the brain or around the brain. Tumours can directly destroy all healthy brain cells. It can also indirectly damage healthy cells by crowding other parts of the brain and causing inflammation, brain swelling and pressure within the skull. Tumour is not synonymous with cancer. A tumour can be benign, pre-malignant or malignant, whereas cancer is by definition malignant. Over the last 20 years, the overall incidence of cancer, including brain cancer, has increased by more than10%, as reported in the National Cancer Institute statistics (NCIS). The National Brain Tumour Foundation (NBTF) for research estimates that 29,000 people are diagnosed with primary brain tumours each year, and nearly 13,000 people die. In children, brain tumours are the cause of one quarter of all cancer deaths. The overall annual incidence of primary brain tumours is 11 to 12 per 100,000 people for primary malignant brain tumours, that rate is 6 to 7 per 1,00,000.

BRAIN TUMOR:

Brain tumour causes the abnormal growth of the cells in the brain. The cells which supplies the brain in the arteries are tightly bound together thereby routine laboratory test are inadequate to analyse the chemistry of brain. Computed tomography and magnetic resonance imaging are two imaging modalities that allow the doctors and researchers to study the brain by looking at the brain non-invasively

A **tumour**, also known as a **neoplasm**, is an abnormal mass of tissue which may be solid or fluid-filled. A tumour does not mean cancer- tumours can be benign (not cancerous), pre-malignant (pre-cancerous), or malignant (cancerous). There are many different types of tumours and a variety of names for them - their names usually reflect their shape and the kind of tissue they appear in. Put simply, a tumour is a kind of lump or swelling, it does not necessarily pose a health threat.

Figure 1: Brain Tumour Image

BENIGN TUMOUR

A **benign tumour** (benign neoplasm) cannot metastasize - it cannot spread. Examples include uterine fibroids and moles. "Benign" means it is non-progressive, it remains as it is.Most benign tumours are not harmful to human health. Even though they are not cancerous, some may press against nerves or blood vessels and cause pain or other negative effects. Benign tumours of endocrine tissues may result in the excessive production of some hormones.

1.1 AIM OF THE PROJECT

This main aim of this project is to obtain a segmented image which contains the region affected by tumour and to classify this tumour into its respective stages depending on its spread area. In previous days this process was done by human inspection which dealt with manual inspection of the MRI or CT scans by specialists who identified the criticality of the condition and then took appropriate decisions based on the spread areas. The main drawback of this method is that only clinicians, researchers or specialists can identify the exact problem in the concerned area regarding the tumor region.

In order to overcome this problem a fast and robust algorithm which deals with stage classification and segmentation was developed. In this algorithm the segmentation of the tumor region was done by seed selection followed by cellular automata. The stage classification was done by extracting a certain set of features from the input image. These extracted features are energy, entropy, homogeneity, contrast and correlation. These were given as inputs to the first layer of the probabilistic neural network. The same set of features are also extracted from the nine database images out of which the first 3 images belong to the first stage, the next 3 to the second stage and the last 3 to the final stage in an ascending order depending on tumor intensity and spread area. These are given as inputs to the pattern layer i.e the second layer of the probabilistic neural network. Thus, when the probabilistic neural network is executed and the output stage is computed by calculating how close the features of the input layer are to the pattern layer.

1.2 SCOPE OF THE PROJECT

Computational applications are gaining significant importance in the day-to-day life. Specifically, the usage of the computer-aided systems for computational biomedical applications has been explored to a higher extent. Detection of Brain tumour is the most common fatality in the current scenario of health care society. Automated brain disorder diagnosis with MR images is one of the specific medical image analysis methodologies.

This project mainly deals with the segmentation of the tumour region in the brain and identification of this tumour region. The tumour region obtained by this method is very accurate and the boundaries are well defined when compared to the existing methods. This advancement in technology helps the specialists in radio surgery. Hence, by using this method a doctor can differentiate the tumour region accurately, thereby preventing the unaffected tumour region from being exposed to the radiology. In this way it helps the doctors in automatic radio surgeries. This analysis can be extended to any part of the body containing a cancerous tumour thereby, providing a good future scope for this project.

1.3 LITERATURE SURVEY

The survey on Segmentation and classification of brain tumours is extensive. The entire literature survey is beyond the scope of this single project work. The main aim of this project is to provide a clear understanding of selecting certain type of image and the respective process required to perform on the image. Experimental observations of various other phenomena are reviewed and discussed in this section.

This section is divided into two parts. First deals with the selection of certain input image that provides all the required details.

Second deals with selection of a robust process that complements this image in achieving the required output.

Many theories have been proposed in the segmentation and classification process of brain tumour images and therefore this project work consists of various important elements of which the input image selected for this process to take place is the key. The input image selected needs to be clear and should comprise of even the minutest details. Hence the chosen image should help to simplify the process of segmentation and classification. In order to satisfy this purpose the image selected is a magnetic resonance image.

1.4 MAGNETIC RESONANSE IMAGING:

Magnetic Resonance Imaging (MRI), nuclear magnetic resonance imaging (NMRI), or magnetic resonance tomography (MRT) is a medical imaging technique used in radiology to visualize internal structures of the body in detail. MRI makes use of the property of nuclear magnetic resonance (NMR) to image nuclei of atoms inside the body.

An MRI scanner is a device in which the patient lies within a large, powerful magnet where the magnetic field is used to align the magnetization of some atomic nuclei in the body, and radio frequency magnetic fields are applied to systematically alter the alignment of this magnetization. This causes the nuclei to produce a rotating magnetic field detectable by the scanner—and this information is recorded to construct an image of the scanned area of the body. Magnetic field gradients cause nuclei at different locations to process at different speeds, which allows spatial information to be recovered using Fourier analysis of the measured signal. By using gradients in different directions, 2D images or 3D volumes can be obtained in any arbitrary orientation.

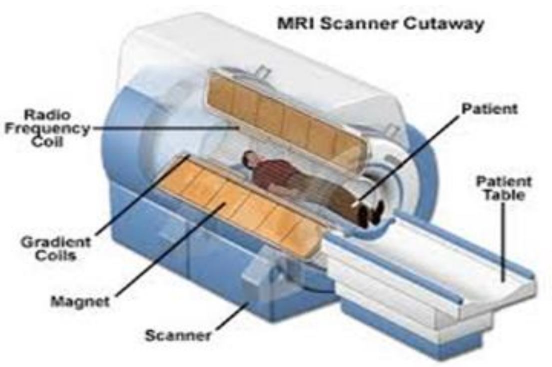


Figure 2: MRI Scanner

Working of MRI scanners:

MRI machines make use of the fact that body tissue contains lots of water, and hence protons (^{1}H nuclei), which get aligned in a large magnetic field. Each water molecule has two hydrogen nuclei or protons. When a person is inside the powerful magnetic field of the scanner, the average magnetic moment of many protons becomes aligned with the direction of the field. A radio frequency current is briefly turned on, producing a varying electromagnetic field. This electromagnetic field has just the right frequency, known as the resonance frequency, to be absorbed and flip the spin of the protons in the magnetic field. After the electromagnetic field is turned off, the spins of the protons return to thermodynamic equilibrium and the bulk magnetization becomes re-aligned with the static magnetic field. During this relaxation, a radio frequency signal (electromagnetic radiation in the RF range) is generated, which can be measured with receiver coils.

1.5 PRECEDENCE OF MR IMAGES

MRI provides good contrast between the different soft tissues of the body, which makes it especially useful in imaging the brain, muscles, the heart, and cancers compared with other medical imaging techniques such as computed tomography (CT) or X-rays. Protons in different tissues return to their equilibrium state at different relaxation rates. Different tissue variables, including spin density, T_1 and T_2 relaxation times, and flow and spectral shifts can be used to construct images. By changing the settings on the scanner, this effect is used to create contrast between different types of body tissue. MRI is used to image every part of the body, and is particularly useful for tissues with many hydrogen nuclei and little density contrast, such as the brain, muscle, connective tissue and most tumours.

In clinical practice, MRI is used to distinguish pathologic tissue (such as a brain tumour) from normal tissue. One main advantage of an MRI scan is that it is harmless to the patient. It uses strong magnetic fields and non-ionizing electromagnetic fields in the radio frequency range, unlike CT scans and traditional X-rays, which both use ionizing radiation.

While CT provides good spatial resolution (the ability to distinguish two separate structures an arbitrarily small distance from each other), MRI provides comparable resolution with far better contrast resolution (the ability to distinguish the differences between two arbitrarily similar but not identical tissues). The basis of this ability is the complex library of pulse sequences that the modern medical MRI scanner includes, each of which is optimized to provide image contrast based on the chemical sensitivity of MRI. However, MRI is generally more useful because it provides more detailed information about tumour type, position and size. For this reason, MRI is the imaging study of choice for the diagnostic work up and, thereafter, for surgery and monitoring treatment outcomes.

Primary malignant brain tumours, such as gliomas, appear as hypo intense, dark areas on gadolinium enhanced T1-weighted MRI images, and as hyper intense, bright areas on T2-weighted images. While interpretation of gadolinium-enhanced T1-weighted images and T2-weighted images remains the mainstay of brain tumour diagnosis, this approach has limitations. For example, it is sometimes difficult to differentiate new from old tumours, or tumours from nontumour lesions, like ischemia. Grading, monitoring of tumour progression, treatment response assessment, and detection of residual tumour after surgery may also be problematic. Techniques other than T1- and T2-weighted MRI can help overcome these limitations. The following sections describe the most established and widely available.

Hence, MR Images can be undoubtedly used for analysis of brain tumours.

The goal of segmentation is to simplify and change the representation of an image into something that is more meaningful and easier to analyze. Image segmentation is typically used to locate objects and boundaries (lines, curves, etc.) in images. Various methods are used for image segmentation. Generally segmentation of the brain tumour is carried out using the following methods

1.6 CLUSTERING METHODS

Figure 3: Source image. Figure1.5:Image after running k-means with k = 16.

Note that a common technique to improve performance for large images is to down sample the image, compute the clusters, and then reassign the values to the larger image if necessary.

II.BRAIN ANATOMY AND BRAIN TUMOR

In this, the structure and functions of the brain are examined in detail. In addition, types of the brain tumor and their structures analysis have also been examined. This information about brain tumors plays an important role in diagnosis and treatment.

2.1 Introduction to Brain Anatomy

The brain is an important structure that serves many important functions. This structure gives a meaning to the events of the world. The brain receives different messages from sensory organs at the same time. The human brain manages memory, thought, speech, and the functioning of numerous organs. In addition the brain regulates heart and breath rates and determines how people will react in stressful situations (i.e. preparing an exam, loss of job, childbirth, disease, etc.). The brain is an organized structure that fulfills important functions and consists of many structures.

2.2 Structure of the Brain

The brain structure is divided into five main parts. These are working in coordinated provide to a sense of reasoning, emotional life, and events that take place in the world. In addition, each one has its own specific functions (Apuzzo et al., 2009). The main parts of the brain are examined in detail below. Figure 2.1 shows the main parts of the brain and their locations.

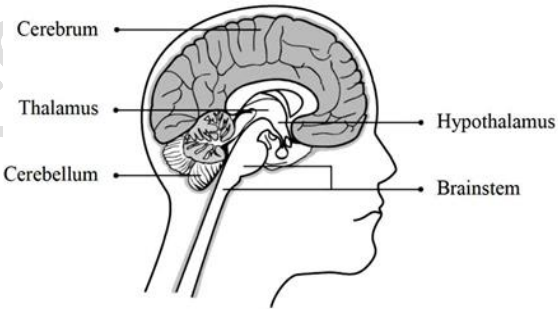


Figure 4: Main parts of the brain (Apuzzo et al., 2009)

2.2.1 Cerebrum

The Cerebrum forms the majority of the brain and is slipt up in two main compartments. These compartments are known as right and left cerebral. The Cerebrum is an expression to identifies the brain. The structure dividing the brain into two hemispheres is named great longitudinal fissure (Apuzzo et al., 2009). The two hemispheres of the brain are combined by the corpus callosum. The corpus connects the calyces of the calceum to provide communication between them. There are billions of neurons and glial cells on the surface of the cerebrum, and these cells form the cerebral cortex.

The cerebral cortex has a gray, brownish color and is known as the “gray matter”. At this point, brain’s face looks wrinkled. The cerebral cortex contains water (small grooves), cracks (large grooves) and grooves known as giyr. Scientists have special names for protrusions and grooves. Scientists have proven that the various parts of the brain have specific tasks as a result of years of experiments. Beneath the surface of the brain cortex and brain, fibers and neurons combine to form an area known as "white matter".

2.3 Brain Tumors

The brain tumor is a tissue mass in which some cells grow uncontrollably with the mechanism that manages healthy cells (Lois et al., 2007). When the tumor begins to grow, it takes up space in the skull and negatively affects the brain's functioning. Brain tumors can cause damages on brain tissues and the nerves by making pressure which pushes parts of the brain toward the skull. Brain tumors can build pressure on the nerves which cause disabilities for the humans.

Based on the statistics of the World Health Organization, brain tumors have more than 120 varieties. Brain tumors are categorized according to the region, tissue type, non-cancerous or cancerous (benign or malignant) cells, site of originate (primary or secondary) and other important factors (Lois et al., 2007). The World Health Organization categorizes tumors of the brain as cell progenitors and cells as least aggressive to the most aggressive.

III. BRAIN TUMOR DETECTION SYSTEM

In this chapter, the proposed system is described. This system can be summarised in three stages. First stage is the pre-processing which enhances the brain MRI image and make it more suitable to analyze. Enhenced images are obtained using morphological operations, pixel subtraction and image filtering. Second stage is the intensity adjustment based segmentation which segments the region of the tumor from the enhanced image. Third stage is pixel addition which shows the location of the tumor on the original image. Figure 4.1 shows the proposed system's flowchart.

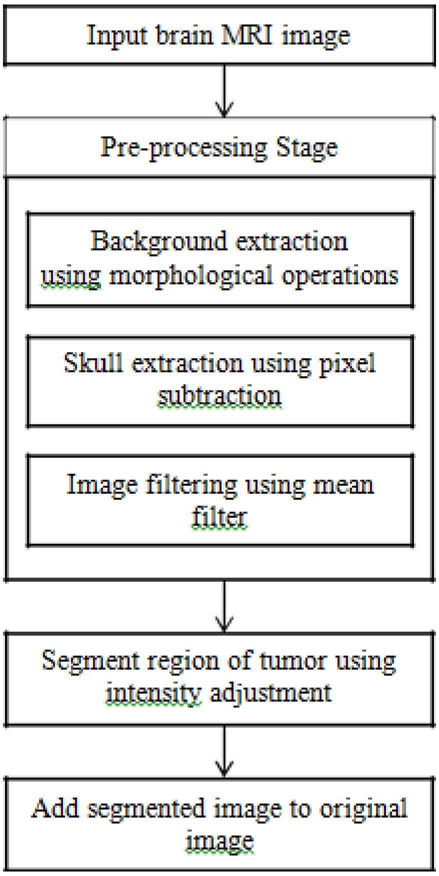
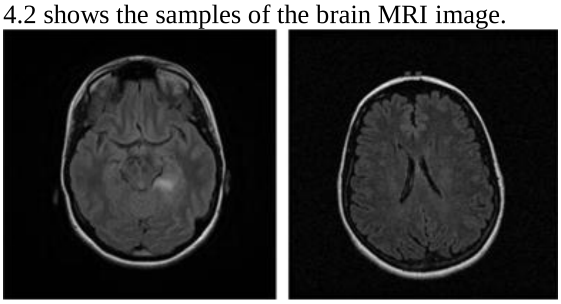


Figure 5: Flowchart of the proposed system

3.1 Database

In this thesis, the digital magnetic resonance images (MRI) are used. The database is obtained from The Cancer Imaging Archive website (The Cancer Imaging Archive, 2016). All images are 256 x 256 pixels and 8 – bit grayscale. There are 100 images in the database which contain 70 abnormal and 30 normal (with and without tumor) brain MRI images. The original data is in dicom format. The images are converted to raw format in order to be used in MATLAB environment. Figure 4.2 shows the samples of the brain MRI image.



(a) abnormal image (b) normal image

Figure 6: Brain MRI images

4.2 Morphological Operations

Mathematical morphology is known as a non-linear effective technique used to identify the boundaries and skeleton of objects in an image. Besides, this technique is used to extract

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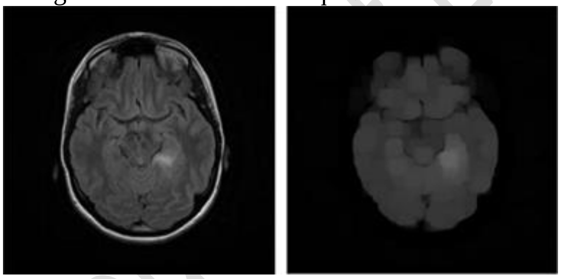
components of objects. Morphological operations create a small shape or template called a structural element on an image (Gonzalez & Woods, 2008).

This template is placed in all possible locations on the image and the corresponding pixel is compared with the neighborhood by querying. By selecting the size and shape of the neighborhood, builds a morphological operation which is sensitive to particular shapes within the input image. In this thesis, the background of the image is extracted using a morphological operation with the structure element "disk" and radius "7". The most commonly morphological operations are dilation and erosion.

Dilation is a morphological operation that can be applied to both binary and grayscale images. Dilation causes objects to grow by expanding the boundaries. With the effect of this operation, the small holes in the regions that begin to expand become even smaller. Erosion is a morphological operation that can be applied to both binary and grayscale images like dilation. Erosion causes object dimensions to be examined. Erosion basically erodes the boundaries of objects in the image (Radha & Lakshman, 2013). In the region where erosion is applied, the size of the pixels shrinks and the size of the holes starts to grow.

3.2.1 Background extraction

The background extraction occurs with the morphological operation named image opening (Chugh et al., 2015). The image opening is a morphological operation that occurs from erosion and then dilation using the same structure element. Figure 4.3 shows the implementation of the background extraction technique.



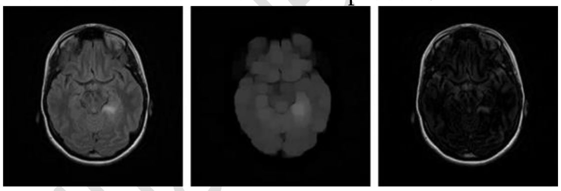
a) original (b) background extracted

Figure7: Images before and after background extraction

In this thesis, background extraction is used to remove skull on the image. When the skull is removed, some of the pixels are also removed from the tumor region unintentionall. Therefore, background extracted image cannot be used directly for segmentation of the tumor. The background extraction on its own is not enough to remove the skull properly. Pixel subtraction is used to extract the skull from the brain image in a more efficient manner.

3.3 Pixel Subtraction

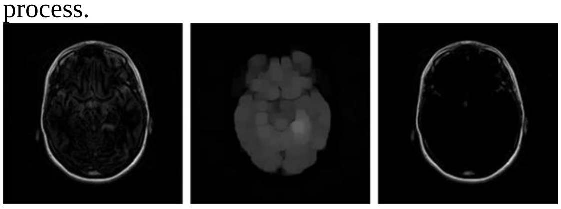
The pixel subtraction operator takes as input images of the same size. The pixel values of the second image are subtracted from the respective pixel values in the first image and a third image is obtained at the end of this process. Taking an image as input and subtracting a fixed value from all the pixels is also a common process (Qidwai & Chen, 2009).Some of the subtraction operators are output the absolute difference of two pixels, instead of the signed output. Using a single pass two images are subtracted giving a signed output. The pixel values of the output image are given as follows. In this thesis, the following pixel subtraction operations are conducted. First, the image obtained from background extraction is subtracted from the original image which seperates the skull from the original image. Figure 4.4 shows the result of the skull extraction process.



(a) original (b) background extracted (c) skull

Figure 8: Images of skull extraction process

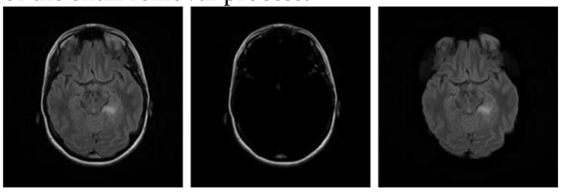
Then image obtained from background extraction is subtracted from the skull image which removes the undesierd gray pixels from the skull image. Figure 4.5 shows the result of the skull cleaning process.



(a) skull (b) background extracted (c) cleaned skull

Figure 9: Images of skull cleaning process

Lastly, the cleaned skull image is subtracted from the original image. This gives us an image of the brain without the skull. Figure 4.6 shows the result of the skull removal process.



(a) original (b) cleaned skull (c) skull removed

Figure 10: Images of skull removal process

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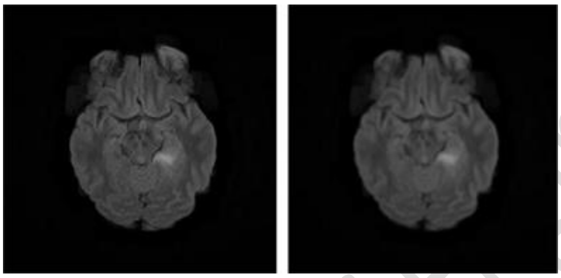
3.4 Image Filtering

The purpose of image filtering is to remove the noises on the digital images. Image filtering is one of the most common issues in digital image processing. Image filtering is the main tool in the majority of image processing software (Gonzalez & Woods, 2008). Image filtering is one of the most common methods used to improve image quality. Image quality is important for human vision. In image processing, the image often has noise that cannot easily be removed.

The noise affects the quality of the image badly. There are many ways to get rid of the noise in the image. In the noisy environment, many image processing algorithms do not work well (Tania & Rowaida, 2016). This is why the image filter is used as a pre-processing tool. However, conventional filtration based on numerical computation is quickly disintegrated in noisy environments. One of the most commonly used methods for image filtering is the mean (average) filter.
In this thesis, 5x5 square neighborhood (kernel) pixels around the evaluated pixel are used.



(a) skull (b) mean filtered

Figure 11: Images before and after noise removal

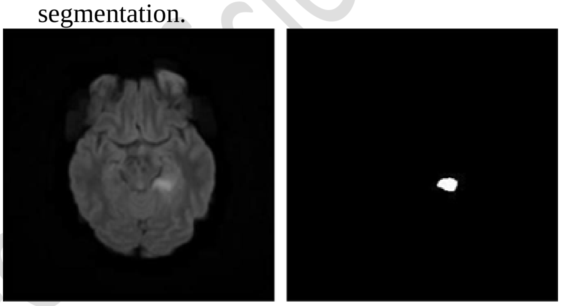
3.5 Intensity Adjustment

The intensity is a concept that interests the entire image. The intensity value should be at an appropriate level so that the image can be seen clearly. If the intensity of the image is not at the proper level, it needs to be adjusted. The method called intensity adjustment is used to find the appropriate intensity value of the image (Gonzalez et al., 2004). In addition, this technique expands the pixel intensity to improve the quality of the image.

The intensity adjustment technique is applied to grayscale images. In this technique, the pixel values below a certain value appear in black, whereas the pixel values above a certain value appear in white. Pixels between these two values appear in gray tones (Gonzalez et al., 2004). In short, this technique is to improve the image by changing the low and high intensity values.

In this thesis, the intensity adjustment is used on the mean filtered image. After skull removal, the highest intensity pixel takes place on the tumor region. To be able to segment the tumor, some adjustments had to be made on the image. The low and high intensity values are set to 0.41 and 0.42 respectively.

The pixel values below low intensity are set to 0 and the pixel values above high intensity are set to 1. By this operation, gray pixels are removed and the tumor is segmented from the image. High intensity value is determined by sampling the database. This value is calculated as the overall average of the mean value of the column containing the highest intensity pixel on the tumor of the sample images. Determination of the high intensity value is given in appendix b. Figure 4.9 shows the result of the tumor segmentation.



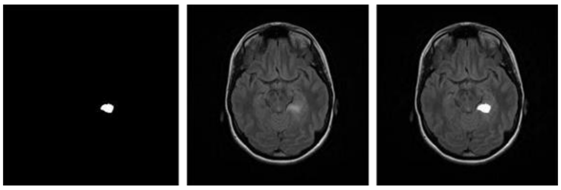
(a) mean filtered (b) segmented image

Figure 12: Images before and after tumor segmentation

3.6 Pixel Addition

The pixel addition operator takes as input two images of the same size. This operator obtains a third image by adding the pixel values of the first image to the respective pixels of the second image. Using the same procedure, it can be applied to more than one image in the continuation of the previous process. Taking an image as input and adding a fixed value to all the pixels is also a common process (Qidwai & Chen, 2009). The pixel values of the output image are given as follows.

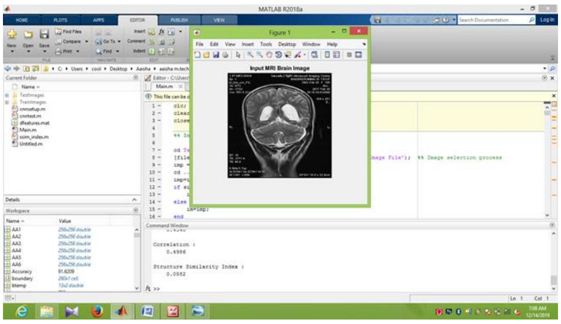
In this thesis, the segmented image is added to the original image anabling the medical people to analyze the image and make their decision. Figure 4.10 shows the clarification of the tumor.

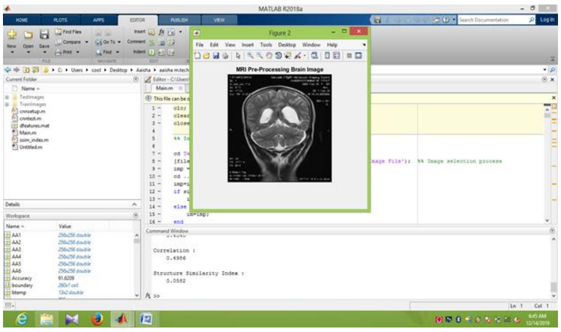


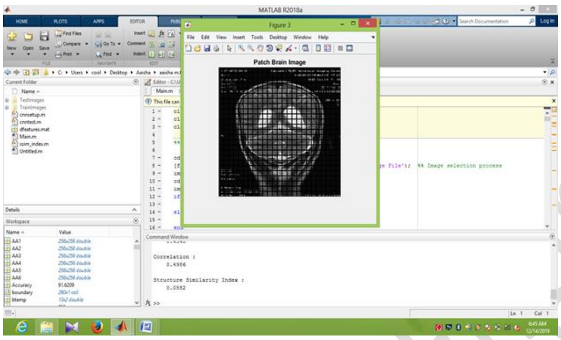
(a) segmented (b) original (c) result

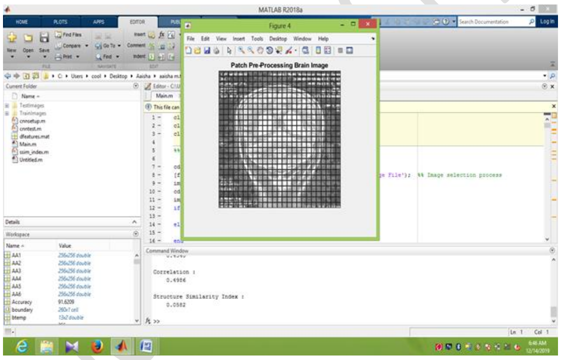
Figure 13: Images of clarification of the tumor

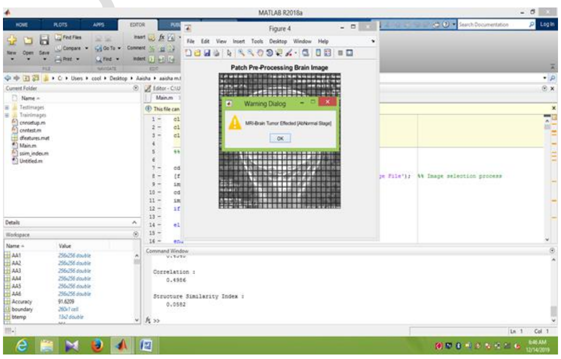
IV. RESULT ANALYSIS

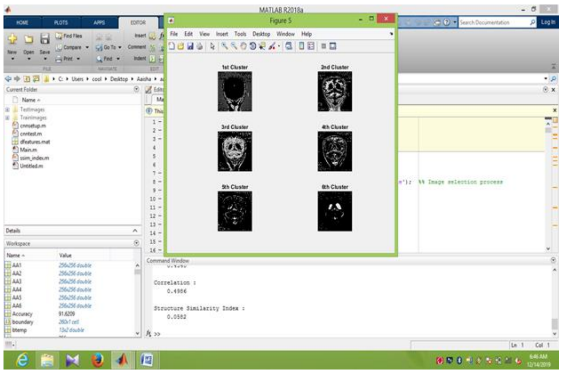


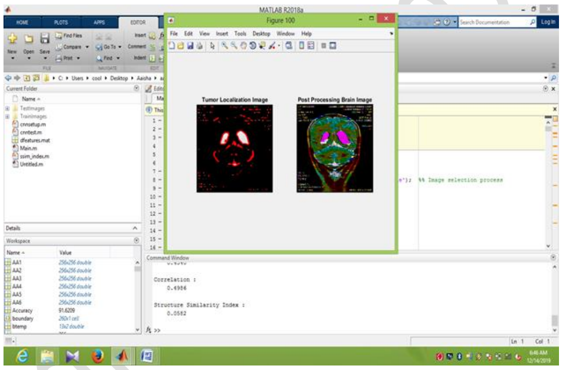


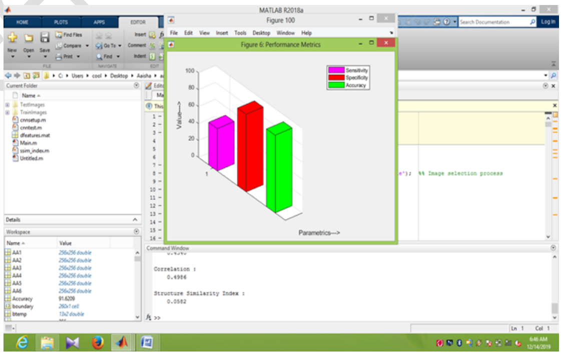












V.CONCLUSION

The system developed in this thesis is an aid to the medical people to diagnose the brain cancer using MRI images. The system uses morphological operations, pixel subtraction, mean filtering, intensity adjustment based segmentation and pixel addition to identify the images with and without tumor. The images obtained from The Cancer Imaging archive (TCIA) are used in this thesis. 70 images with tumor and 30 images without tumor are tested. The method is introduced has 100% recognition rate on the images without a tumor and 94.29% recognition rate on ones with the tumor. The overall success rate is 96% which is better a performance our the methods compared with. There are two issues that are to be improved in my system. One is the inaccurately classified images that have tumor. Here perhaps different methods of classification like Neuro Fuzzy or Support Vector Machine should be tried. Second is that the proposed method is not an automatic procedure.

The technologies used may be brought together for a single processing environment.

REFERENCES

Aggarwal, A., Chauhan, R. S., & Kaur, K. (2013). An Adaptive Image Enhancement Technique Preserving Brightness Level Using Gamma Correction. Advance in Electronic and Electric Engineering, 3(9), 2231-1297.

Aghababian, R. V., Bird, S. B., & Braen, R.G. (2010). Essentials of emergency medicine (2nd ed.). Sudbury, MA: Jones & Bartlett Publishers.

American Association of Neurological Surgeons. (2016). Anatomy of Brain. Retrieved June 19, 2016 from http://www.aans.org/Patient%20Information/Conditions%20and% 20Treatments/Anatomy%20of%20the%20Brain.aspx

puzzo, M. L., Liu, C. Y., Sullivan, D., & Faccio, R. A. (2009). Surgery of the human cerebrum a collective modernity. Neurosurgery, 61(1), SHC-5.

Biaggioni, I. (2011). Primer on the autonomic nervous system. Amsterdam: Elsevier Health Science.

Borden, N. M. (2007). 3D Angiographic Atlas of Neurovascular anatomy and pathology.New York, NY: Cambridge University Press.

Buckner, J. C., Brown, P. D., O'neill, B. P., Meyer, F. B., Wetmore, C. J., & Uhm, J. H. (2007). Central nervous system tumors. In Mayo Clinic Proceedings, (pp. 1271-1286). Elsevier.

Burger, W., & Burge, M. J. (2009). Principles of digital image processing: Fundamental techniques. London: Springer-Verlag.

Chugh, Y., Gupta, R., & Kaushik, R. (205). Image Enhancement Using Morphological Operators. International Journal of Engineering Technology, Management and Applied Sciences, 3(1), 2349-4476

Costa, A. L. (2008). 12 brain/mind learning principles in action: Developing executive functions of the human brain. Thousand Oaks, CA: Corwin Press.

Di Salle, F., Duvernoy, H., & Rabischong, P. (2006). Atlas of morphology and functional anatomy of the brain. Berlin: Springer Science

Doi, K. (2006). Diagnostic imaging over the last 50 years: Research and development in medical imaging science and technology, Physics in Medicine and Biology, doi: 10.1088/0031-9155/51/13/r02.