Assessment and Detection of Brain Structural Abnormalities in MRI Images

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Introduction

Substantial changes in cognitive abilities and/or functional limitations often lead to diagnostic attempts to evaluate possible factors related to brain structural alterations.

Research conducted in developed countries shows that people affected by brain tumor often die due to its inaccurate detection.

Therefore, accurate diagnosis of brain tumor is crucial for its successful treatment.

Magnetic resonance imaging (MRI) is the most commonly used modality for brain tumor growth imaging and its location detection.

The conventional method for CT and MRI brain images classification and tumor detection is human inspection.

Typically, radiologists perform visual evaluation of MRI images which is time consuming and prone to human errors affecting accurate determination of stage and size of tumor.

Operator assisted classification methods are impractical because of large amounts of data and are also non reproducible.

Introduction

Segmentation of brain tumors in MRI data sets is of great importance for improved diagnosis, growth rate prediction, and treatment planning. However, quantification of any part of this process is challenging due to the presence of severe partial volume effect and considerable variability in tumor structures, as well as imaging conditions.

The most practical way to evaluate brain tumors in detail requires an MRI and/or CT images and also to follow patients after surgery or other treatment procedures.

Many times, there is a difficulty in distinguishing brain tumor tissue from normal tissue because of the similar color density.

In particular, brain tumor segmentation is done to separate brain tumor tissue from other tissues such as fat, normal brain tissue, edema and cerebrospinal fluid to overcome this difficulty.

The proposed methodology aims to differentiate between normal brain tissue and brain tumor (benign or malignant).

Introduction

MRI brain images analysis, classification and tumor detection are mostly based on a direct radiologists' inspection and conventional assessment.

Specifically, a developed novel method and applicable algorithm for brain tumor detection is presented, to assist doctors with accelerated diagnosis and quantification of the degree of abnormality.

Developed image processing approach and results generation can be applied to quantitative evaluation of other image documented structural changes.

Description of the Developed Algorithm

Image processing plays an important role in medical diagnosis and it is particularly essential tool for radiologists, neurologists, neurosurgeons in brain tumor diagnosis utilizing CT and MRI.

Brain tumor detection and segmentation is a challenging task due to large variations of its appearance and shape.

Novel computer aided method is proposed that is focusing on algorithmic image processing assisting radiologists in brain tumor diagnosis in multi-parametric MR images.

Description of the Developed Algorithm

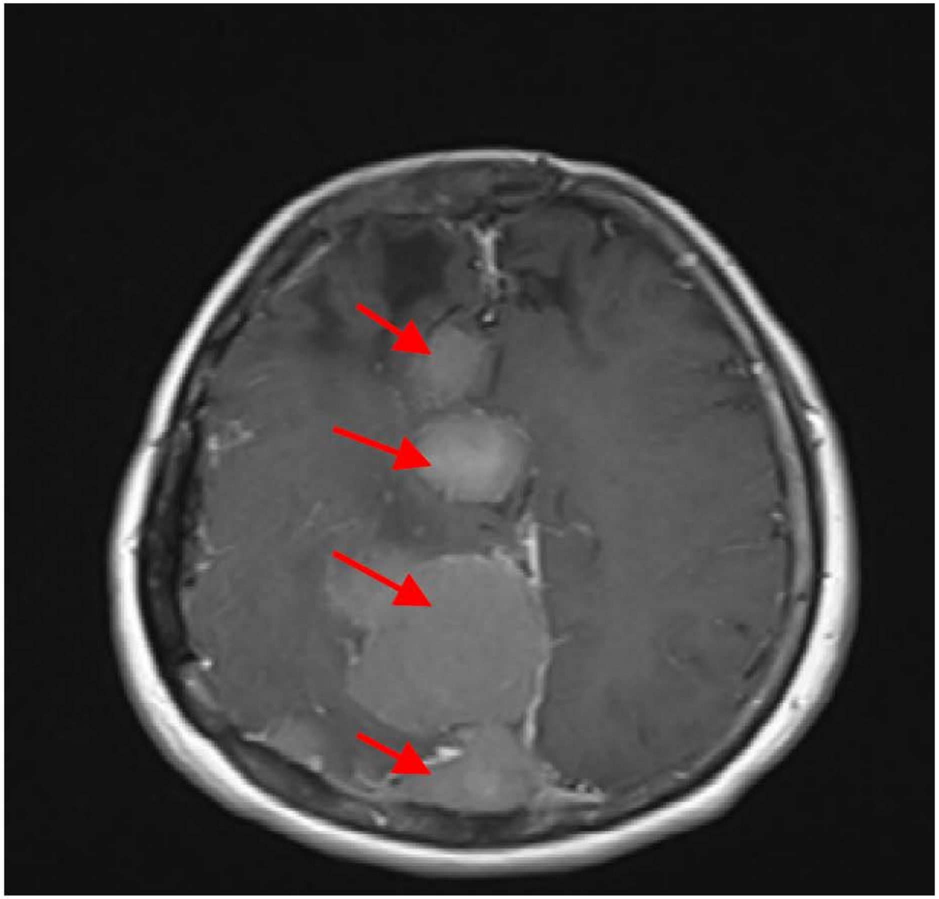
The presented method was tested on 30 brain MRI images showing a tumor.

This method allows the segmentation of tumor tissue with accuracy and reproducibility comparable to manual segmentation.

Further, this method for tumor detection in MRI images also provides information about its exact position and determines its shape.

Description of the Developed Algorithm

Original Brain Images with the conditions as characterized.



a) MRI T1 sequence showing Meningiomatoses where multiple meningiomas (usually noncancerous tumor) are present in the right hemisphere along along parasagital (arrows) line taken in 53 yrs old patient as a part of the initial diagnosis.

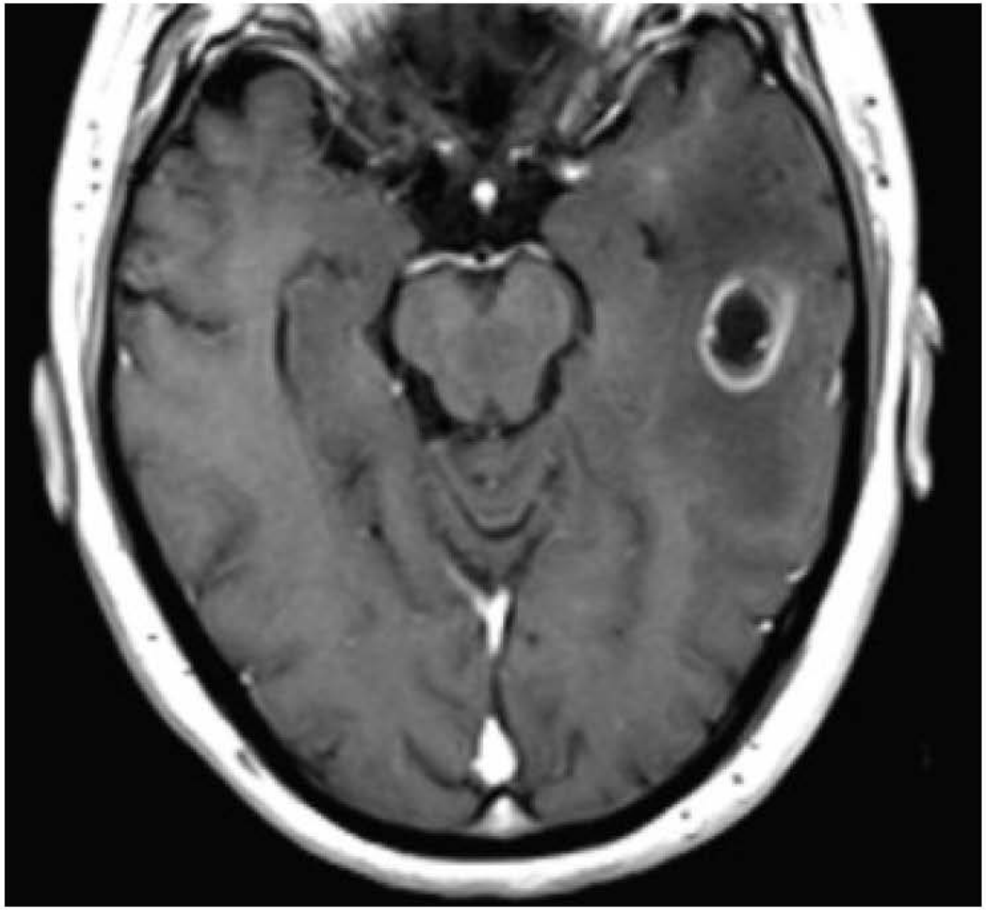
Description of the Developed Algorithm

Original Brain Images with the conditions as characterized.

b) MRI T1 sequence showing a 49 years old woman with Meningioma diagnosis, one tumor, localized in the midline of the brain in, in pre surgery stage. Her MRI in sequence T1 with gadolinium (a substance used to enhance the image of the tumor commonly called contrast), her symptoms were chronic headache, dizziness, and decreased visual acuity.

Description of the Developed Algorithm

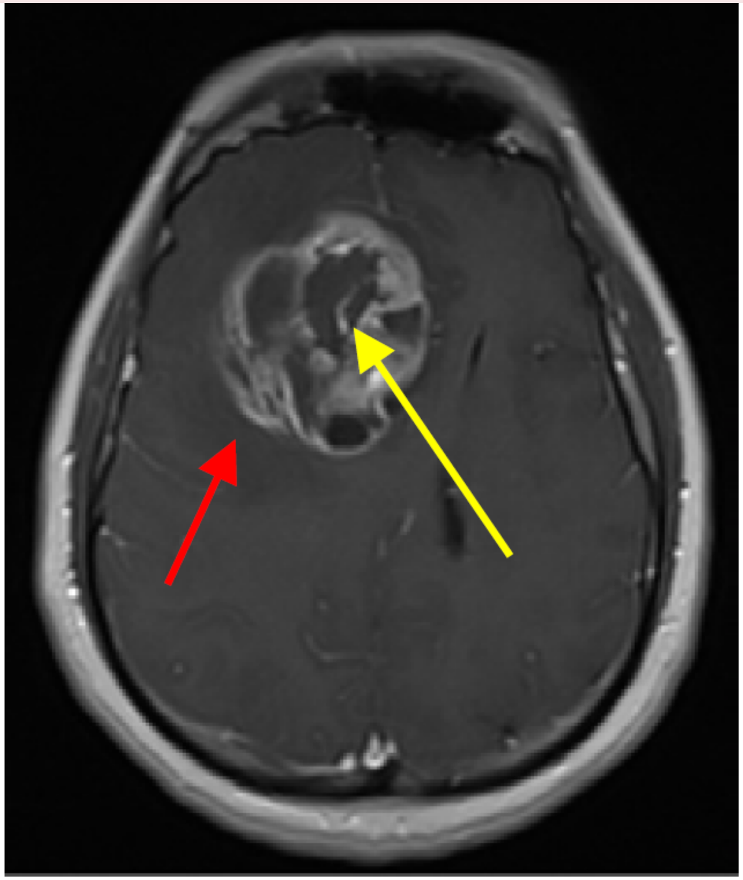
Original Brain Images with the conditions as characterized.



c) A case of a 65 years old man, whose MRI in T1 sequence shows a left temporal tumor, a Glioma, 4x3x3 cm, moderately vascularized, his symptoms included headache and seizures.

Description of the Developed Algorithm

Original Brain Images with the conditions as characterized.



d) MRI T1 sequence with gadolinium showing malignant tumor (Glioblastoma) of the right frontal lobe showing irregular borders and hyperintense signal (red arrow) and necrosis areas inside (yellow arrow) taken in a 42 years old male patient.

Description of the Developed Algorithm

There are various serious challenges in reference to the analysis of these images.

These adverse factors are due to the fact that these images were taken under different clinical conditions and with diverse MRI scanners.

The complexity of analyzed images implies challenges related to:
1) Different image resolutions;
2) Various contrast conditions and uneven contrast under which images are displayed;
3) Often poor contrast.

Description of the Developed Algorithm

Taking all of these adverse factors and challenges into account, a dedicated algorithm for brain tumor detection and segmentation was developed which consists of several stages:

1) brain images acquisition, sharpening, their contrast enhancement and denoising by applying wavelet filters;
2) sinus function and natural logarithm function filtering for the purpose of background of the scull region removal;
3) skull and meninges removal;
4) and 5) application of natural logarithm function, the sinus hyperbolicus function and tangent function with the goal to take pixels' grey level intensity values to different scale which enables better distinction of targeted tumor areas;
6) spatial median filtering in order to emphasize the targeted tumor areas;
7) thresholding of the obtained images and
8) displaying the region of detected tumor tissue as well as providing corresponding numerical values.

I Phase of the Developed Algorithm

(I) In the first phase of the developed algorithm brain images are acquired and preprocessed by transferring it from RGB into a gray-scale space and by sharpening the image through enhancing its contrast.

Also, they are denoised by applying wavelet filters of type Symlet four and of order two.

I Phase of the Developed Algorithm

(I) Fig. shows the results obtained after application of wavelet denoising filter.

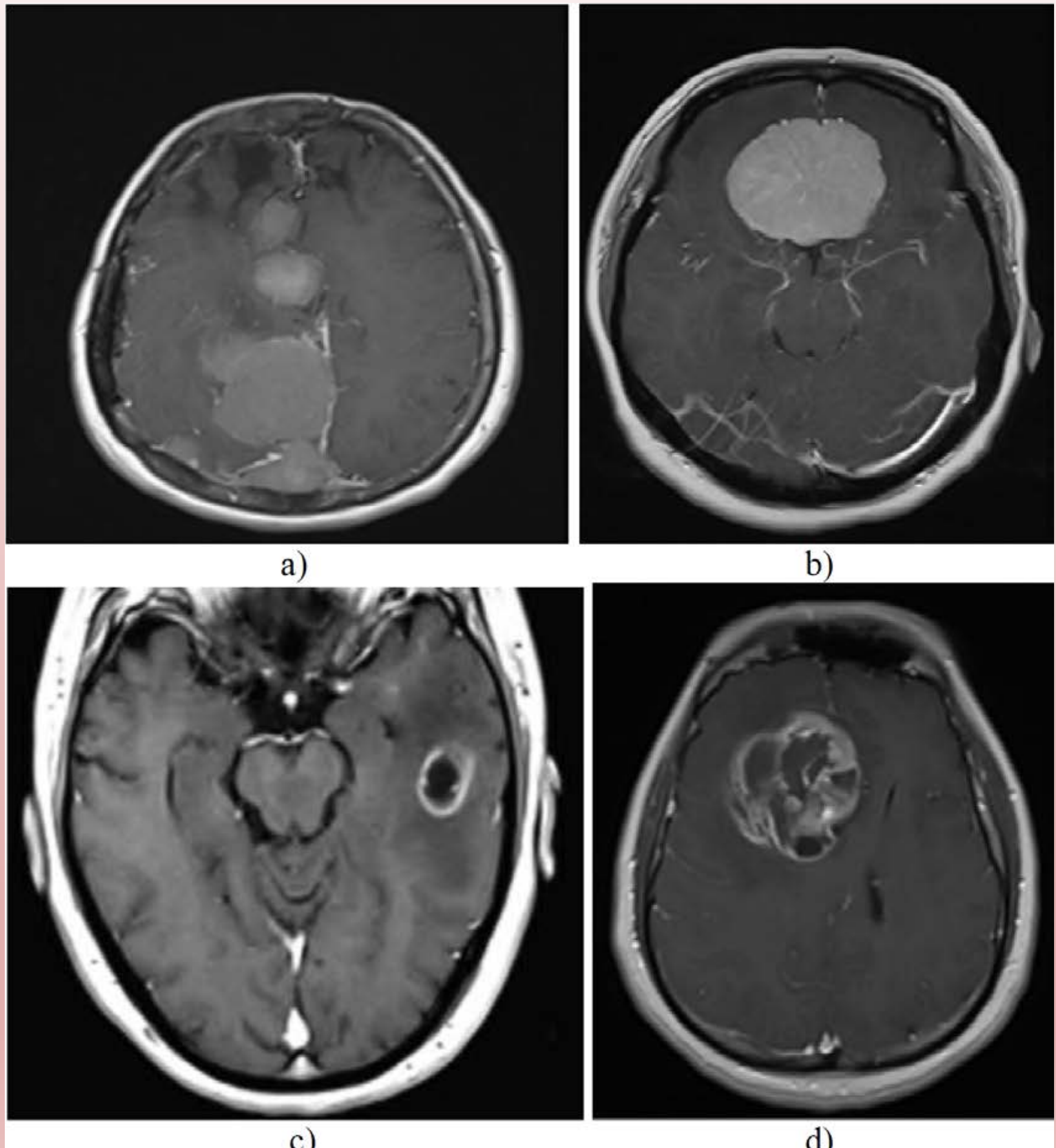


Fig. 2. Selected Brain Images denoised by wavelet filters of type Symlet four and of order two, Phase I.

II Phase of the Developed Algorithm

(II) The fact that the background of the scull and brain region of the processed MRI images, which is not of our interest, is having various grey level intensity levels and can be misleading in the next phases of the algorithm, takes us to the next algorithm stage that sets all background pixels to the same intensity level zero.

The second phase of the proposed algorithm represents taking sinus function of natural logarithm of denoised picture from step one and getting rid of all the pixels in the original image that are lower or equal to zero in image obtained in step two.

II Phase of the Developed Algorithm

(II) Fig. illustrates obtained results after application of sinus function on the natural logarithm of the original images and excludes all background pixels from our further analysis.

In this way, all the pixels that do not belong to the scull or brain in the original image are disregarded i.e. all background pixels' intensity values are set to zero.

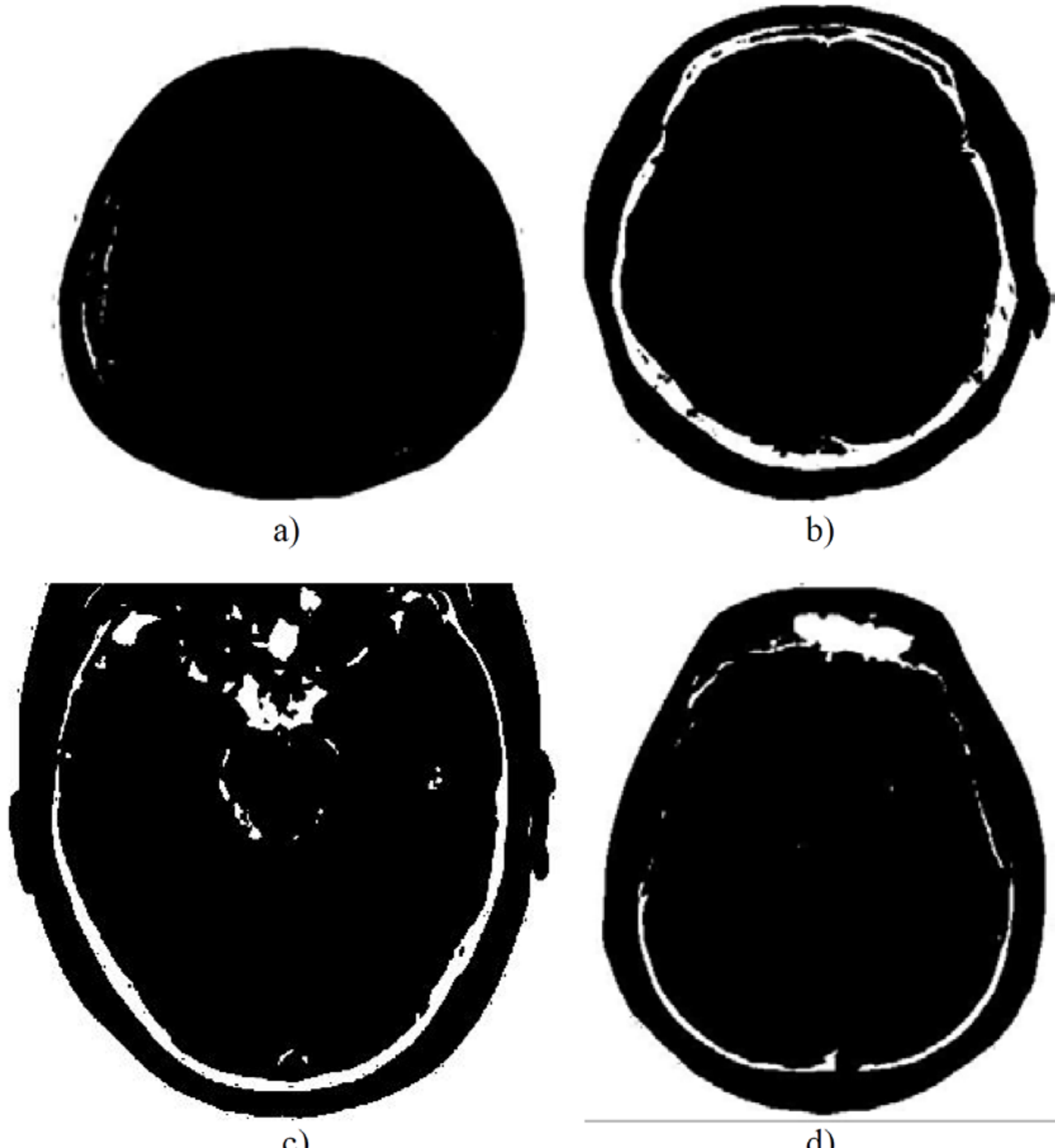


Fig. 3. Images obtained by application of sinus function on the natural logarithm of the original images shown in Fig. 1, Phase II.

II Phase of the Developed Algorithm

(II) The scull or brain area are extracted from the background and set background pixels to zero intensity value by applying the equation (1)

$$Phase\_2(i,j) = \begin{cases} I(i,j).\,sinus\ (logarithm\ (I(i,j)) > 0 \\ 0, & otherwise \end{cases} \quad (1)$$

II Phase of the Developed Algorithm

(II) Fig. shows the results obtained after application of the first and the second phase of the algorithm.

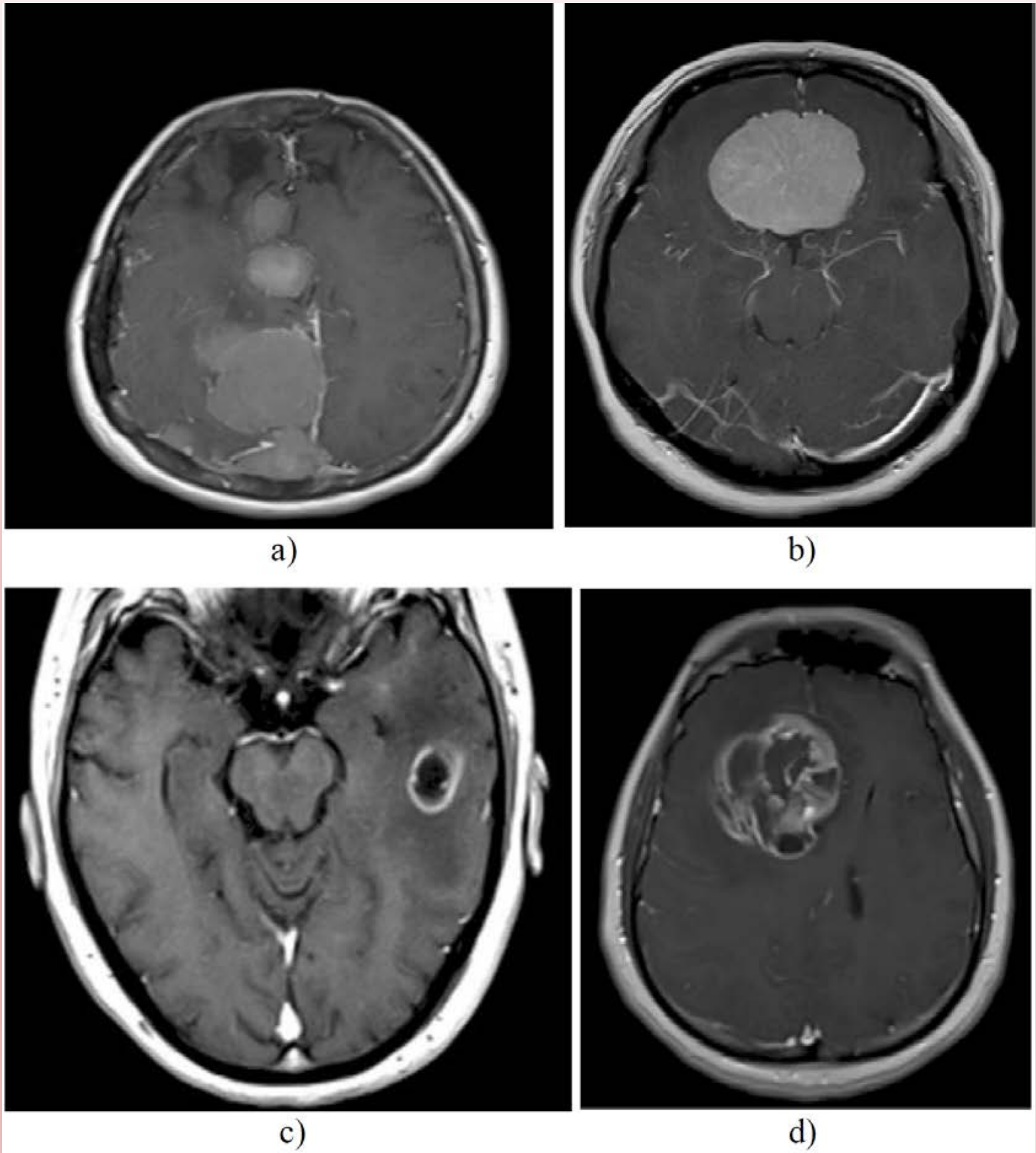
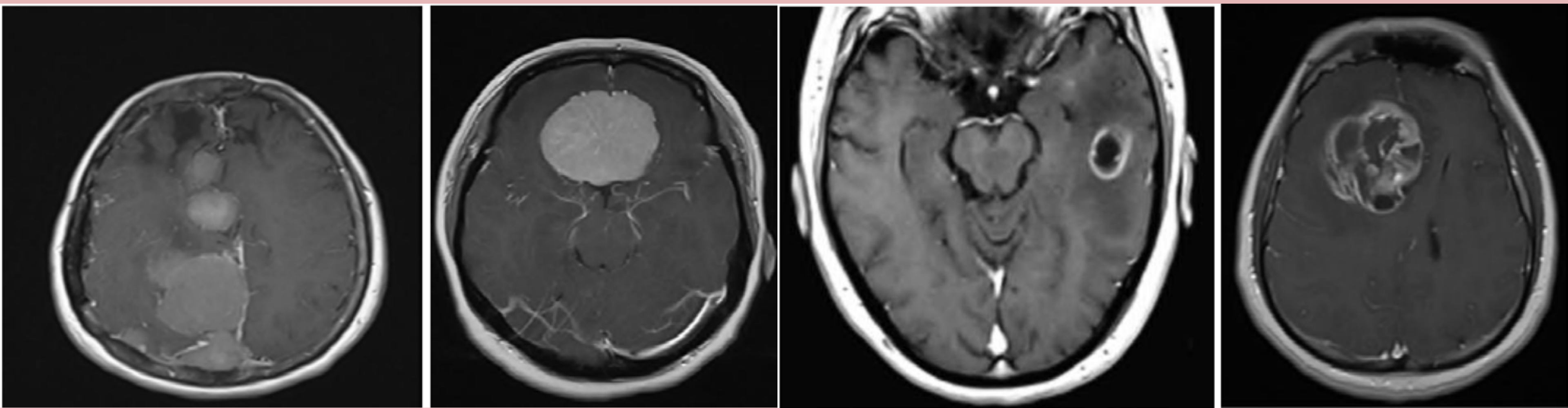


Fig. 4. Selected brain images with disregarded background pixels after application of equation (1), Phase II.

III Phase of the Developed Algorithm

(III) Observing the original brain images, it can be noted that the skull and meninges are almost of pure white gray scale tone. Also, it is obvious that the tumor, as well as the skull and meninges grey level tones, has much higher gray level than other tissues and stands out in much brighter gray level.

This is why similar scull and meninges removal technique is applied that is designed and presented in the previous paper.

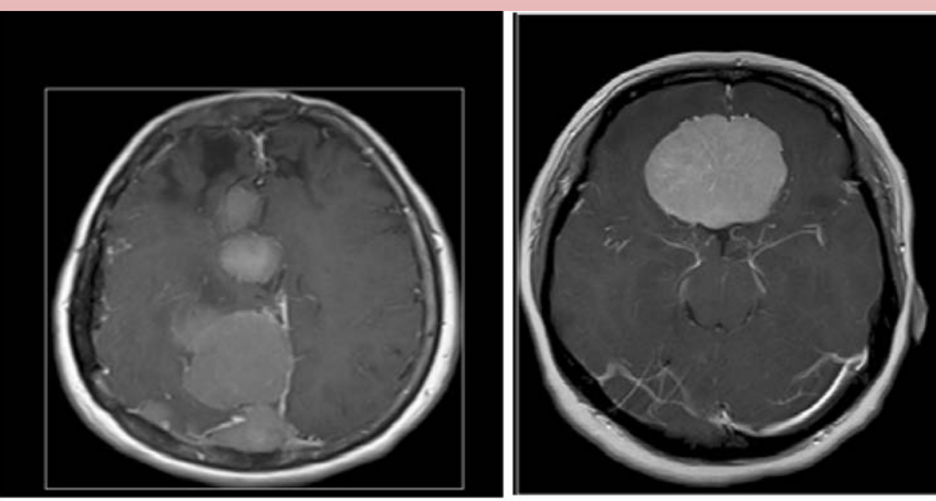


III Phase of the Developed Algorithm

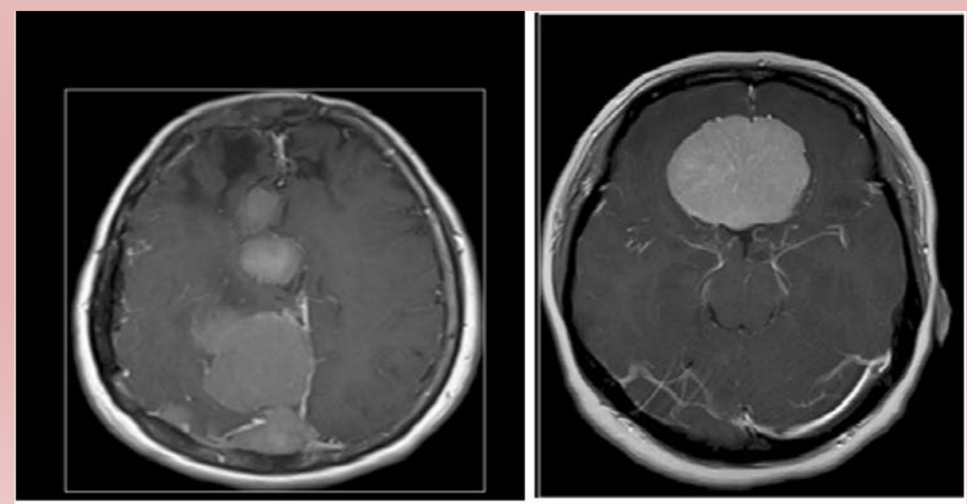
(III) Considering that all the background pixels in the previous phase of the proposed algorithm are successfully neutralized and noting that the skull appears to be in the shape of a symmetric oval, the most upper, bottom, left and right white area of the picture (boundaries of the scull) are detected and removed the skull and meninges region by symmetrically erasing it in four directions: from the left to the right, from the right to the left, from the top to the bottom and from the bottom to the top.

III Phase of the Developed Algorithm

(III) Fig. shows rectangle drawn around boundaries of the scull based on detected the most upper, bottom, left and right white area of the scull. The range of the erasure is controlled by two criteria: grey level and geometrical features. The average gray level of the continuous six pixels is computed and compared with the value of thirty percent of the average gray level of the entire image (if it is lower than as it is considered that these six pixels lie out of the skull and meninges region or belong to the healthy tissue, otherwise, the erasure starts) and geometrical limits are based on the empirical conclusion that the width of the skull is roughly 12% of the current vertical or horizontal dimension of the image.



a) b)



a) b)

III Phase of the Developed Algorithm

(III) Fig. shows brain images from Fig. 4 with removed skull and meninges areas.

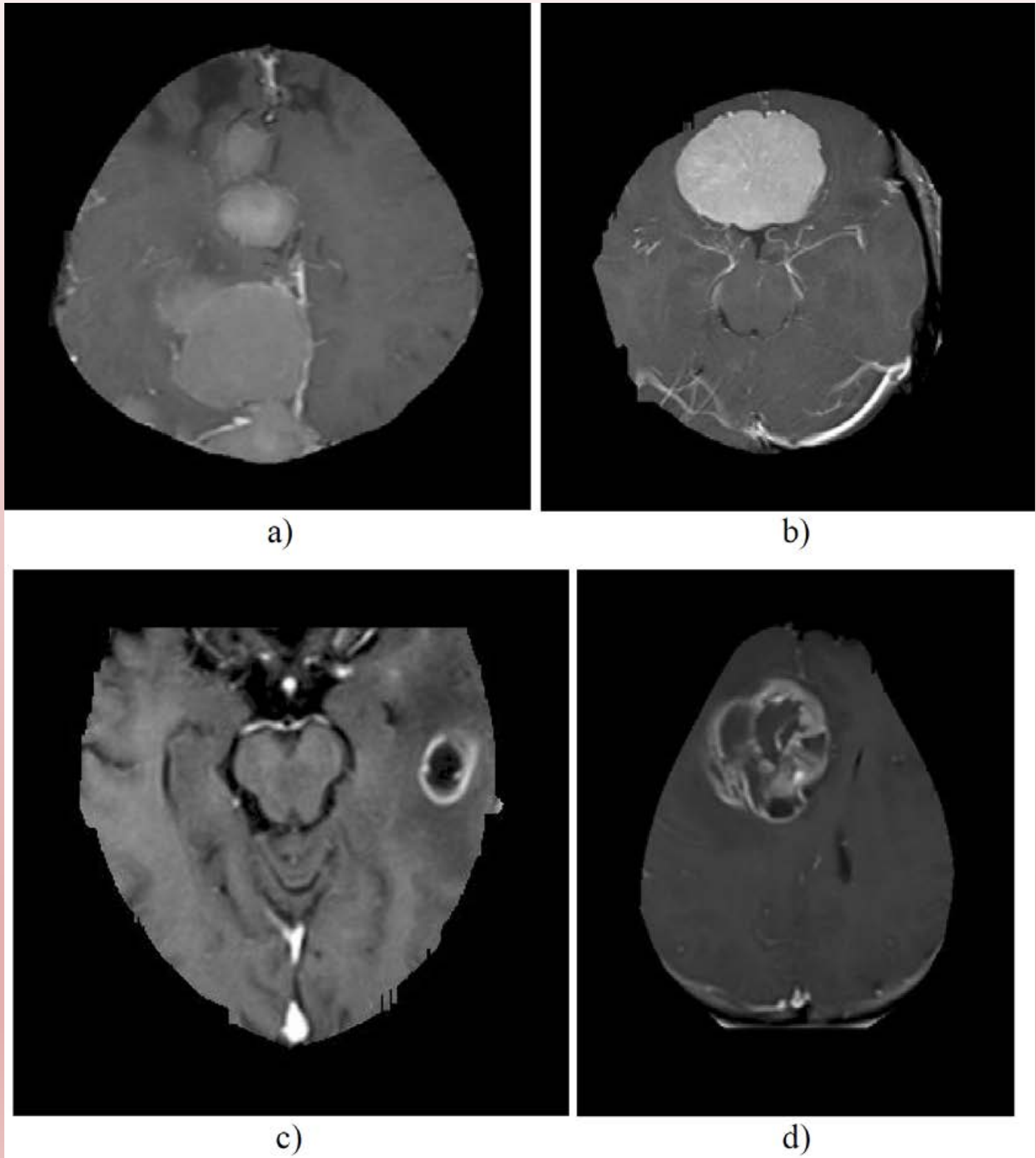


Fig. 6. Selected brain images from Fig. 4 with removed skull and meninges areas, phase III.

III Phase of the Developed Algorithm

(III) Fig. illustrates the removed scull and meninges regions from the brain images.

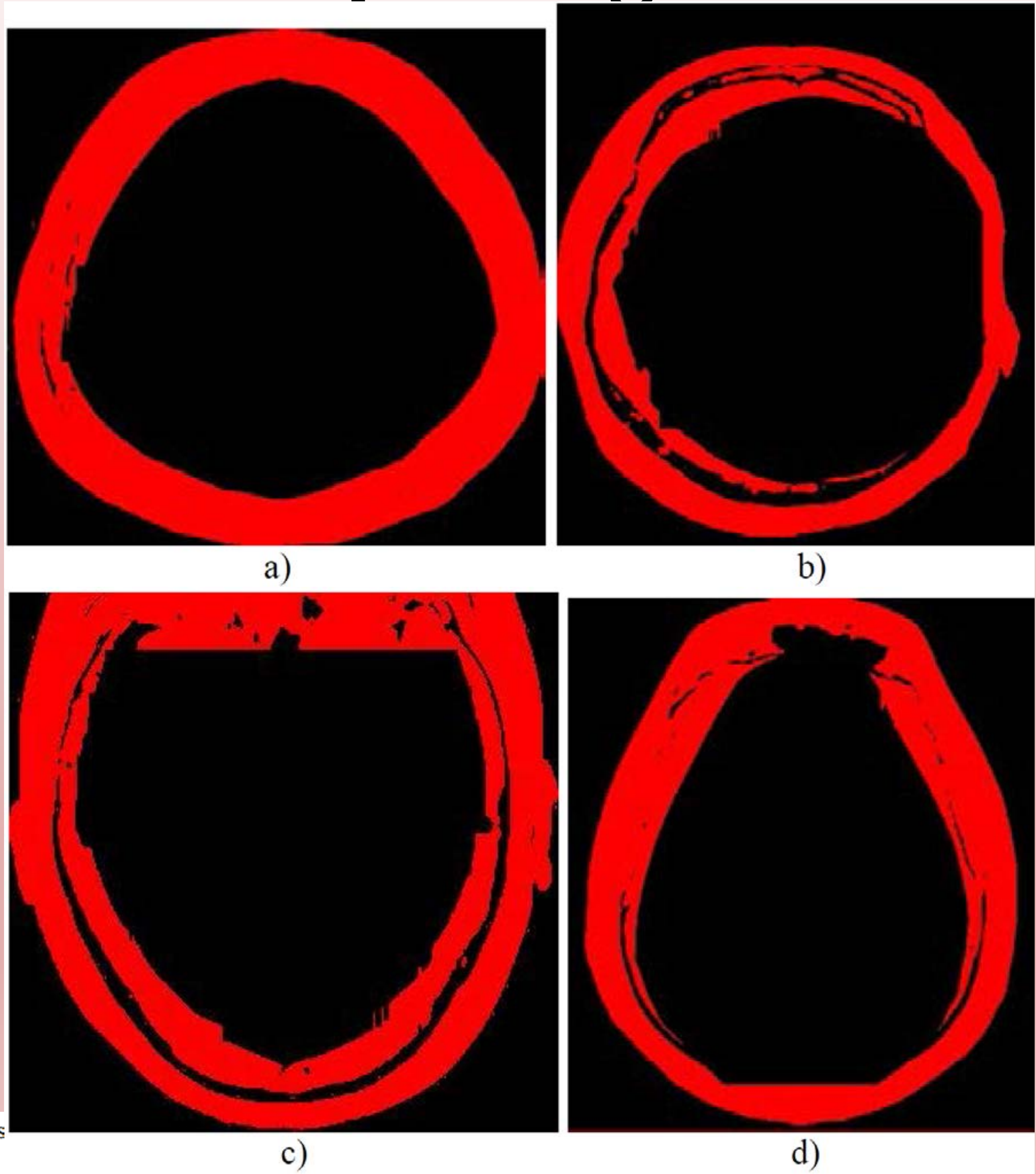


Fig. 7. Binary images showing the removed scull and meninges regions from the brain images marked in red, phase III.

IV Phase of the Developed Algorithm

(IV) In the fourth phase of the proposed algorithm the sinus hyperbolicus function on the natural logarithm of the brain images is taken.

$$Phase\_4(i,j) = sinus\ hyperbolicus\ (logarithm\ \left(Phase\_3(i,j)\right)) \quad (2)$$

IV Phase of the Developed Algorithm

(IV) Fig. illustrates the results obtained by application of equation (2).

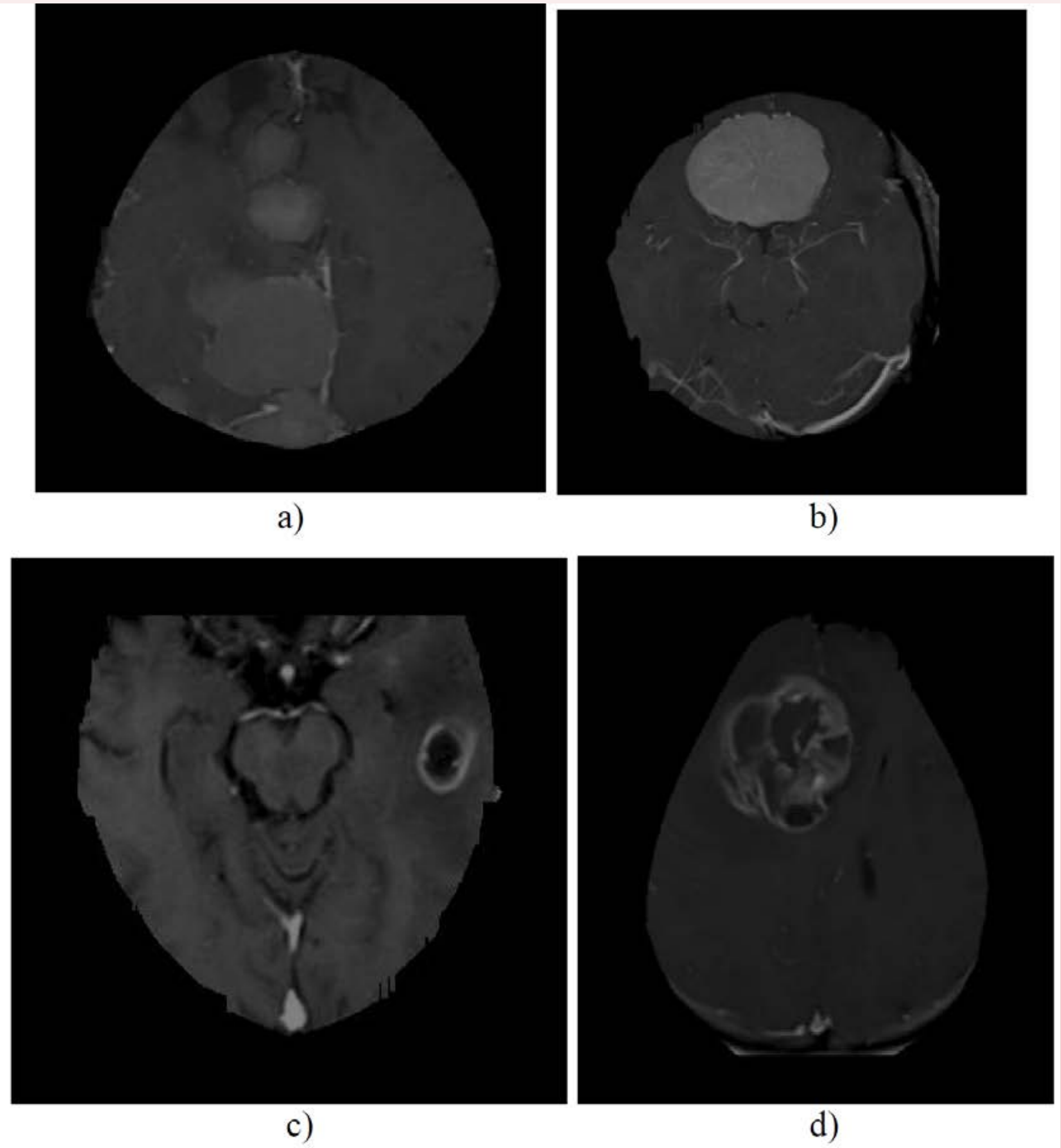


Fig. 8. Selected brain images obtained by application of the sinus hyperbolicus function on the natural logarithm of the brain images shown in Fig. 6, expressed with equation (2), phase IV.

V Phase of the Developed Algorithm

(V) Tangent function of the results obtained in the previous phase is taken in the fourth phase of the algorithm.

These two stages, the fourth and the fifth phase, take pixels' grey level intensity values to different scale which enables better distinction of targeted tumor areas.

V Phase of the Developed Algorithm

(V) Fig. illustrates the results obtained by application of equation (3).

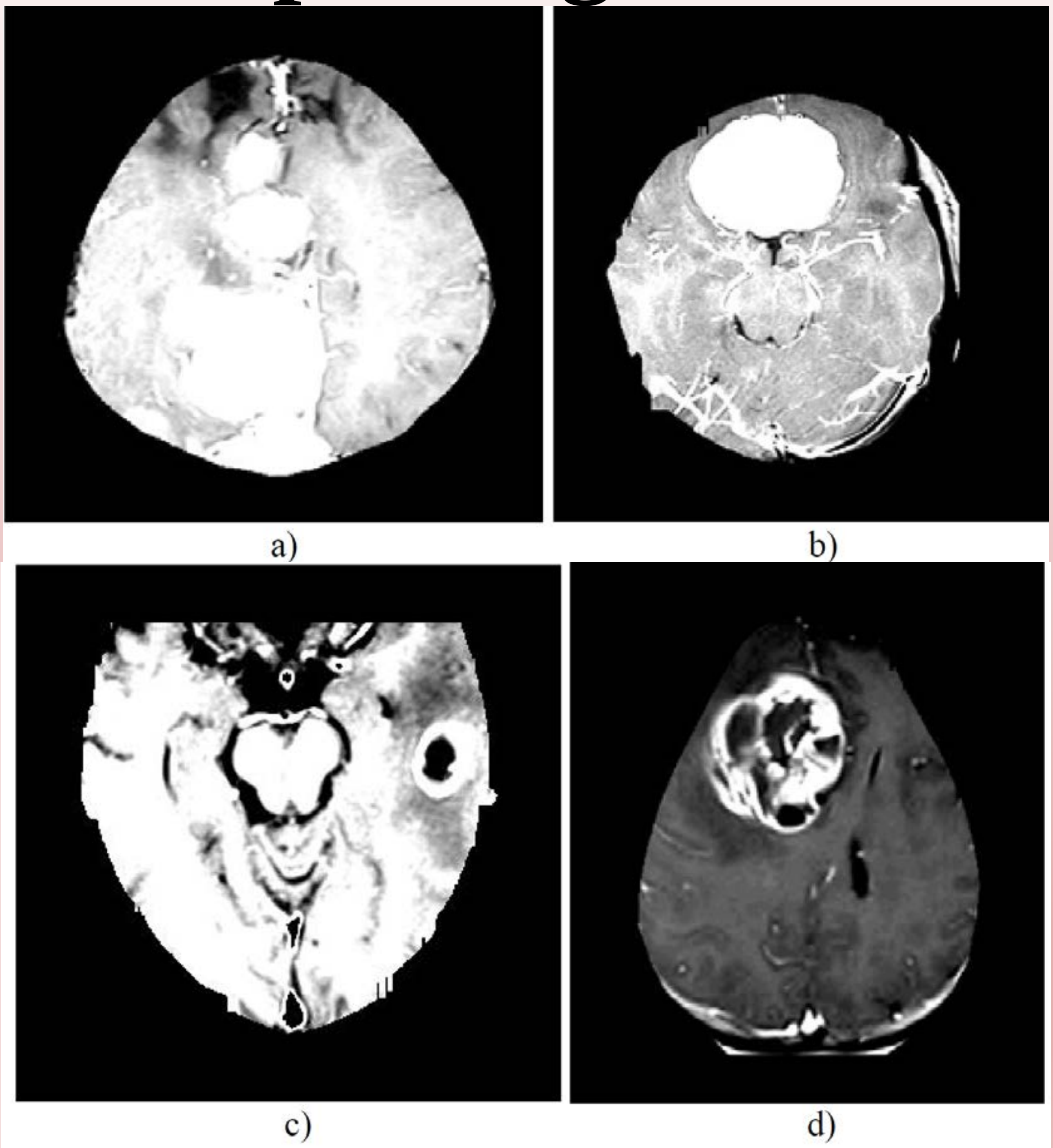


Fig. 9. Selected brain images obtained by application of the tangent function on the brain images shown in Fig. 8, expressed with equation (3) phase V.

VI Phase of the Developed Algorithm

(VI) In the following phase, spatial median filtering is applied on the images obtained in previous stage, in order to emphasize the targeted areas.

Fig. illustrates median filtered images with emphasized tumor areas on the selected original images.

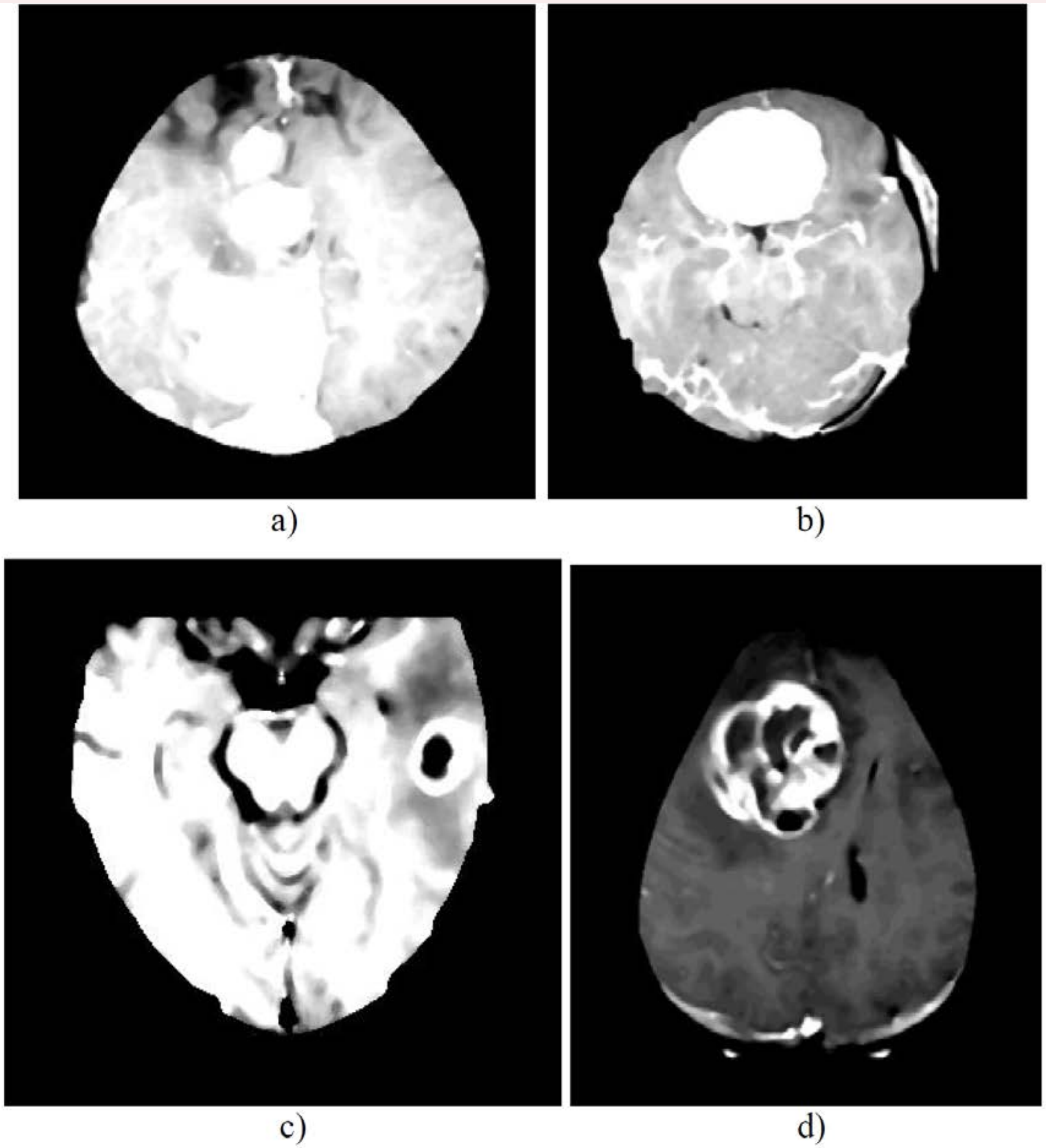


Fig. 10. Selected Brain images obtained after applying spatial median filter on images in Fig. 9, phase VI.

VII Phase of the Developed Algorithm

(VII) The seventh phase of the proposed method locates the targeted tumor regions by thresholding the images obtained in the previous stage.

$$BIN(i,j) = \begin{cases} 255, & Phase\_5(i,j) > T \\ 0, & otherwise \end{cases} \quad (4)$$

The obtained images are binarized by applying global threshold segmentation in order to extract the brain tumor.

Healthy tissues are marked in black and the tumor appears in white.

Threshold is obtained as three times the mean value of the processed image.

VII Phase of the Developed Algorithm

(VII) Fig. represents the result obtained by the sixth phase of the algorithm and illustrates the extracted region of interest which contains tumor tissue.

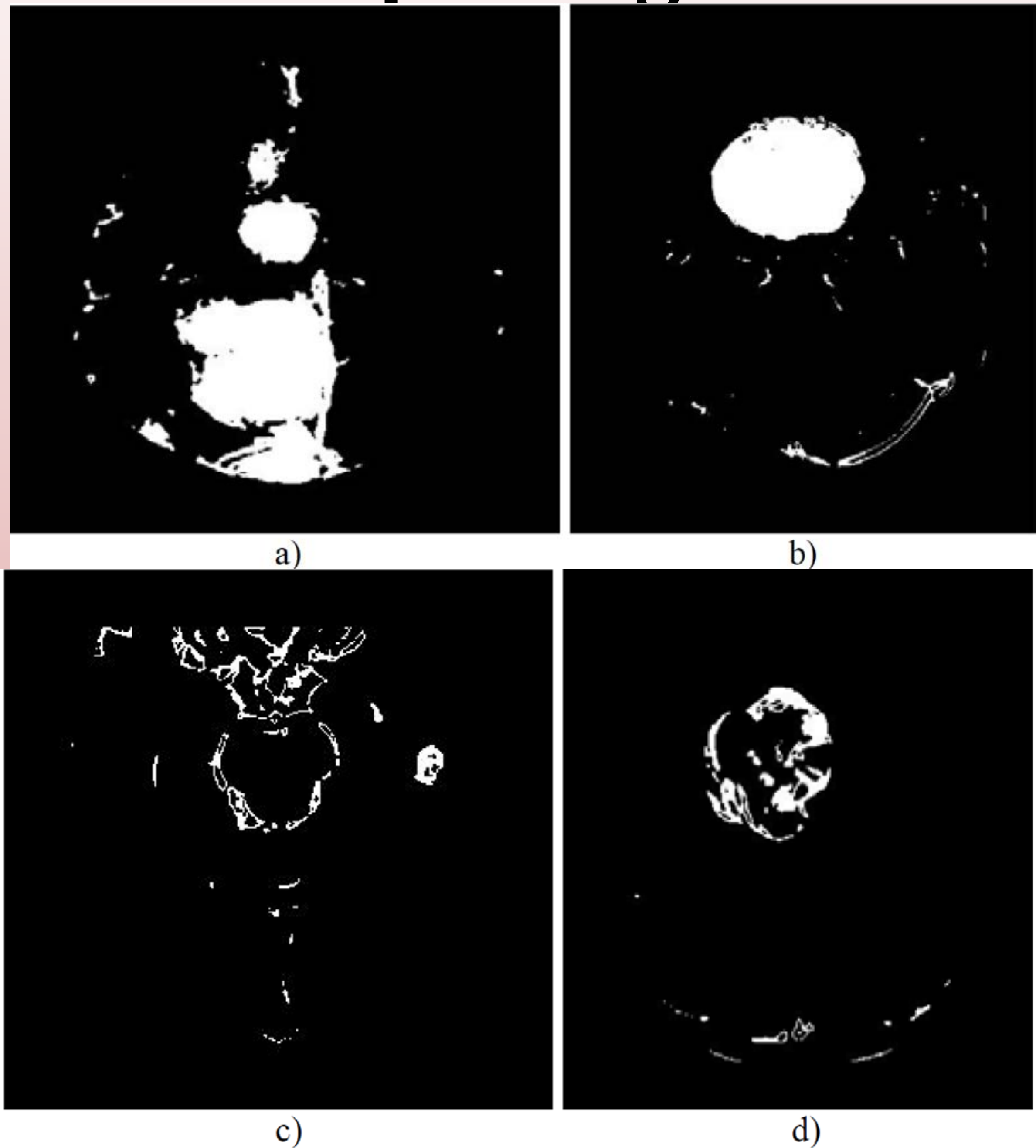


Fig. 11. Binary images obtained by binarization, applying global threshold segmentation in order to extract the brain tumor, phase VII.

VIII Phase of the Developed Algorithm

(VIII) The final eighth phase of the proposed method is realized through superimposing binary images with the extracted tumor, obtained in the previous phase, on the original brain image and dyed in red which makes tumor conspicuous and easy to diagnose.

VIII Phase of the Developed Algorithm

(VIII) Fig. contains the resulting binary images, generated in the eighth, final phase of the developed and tested algorithm, imposed over original, brain images with the tumor regions highlighted in red.

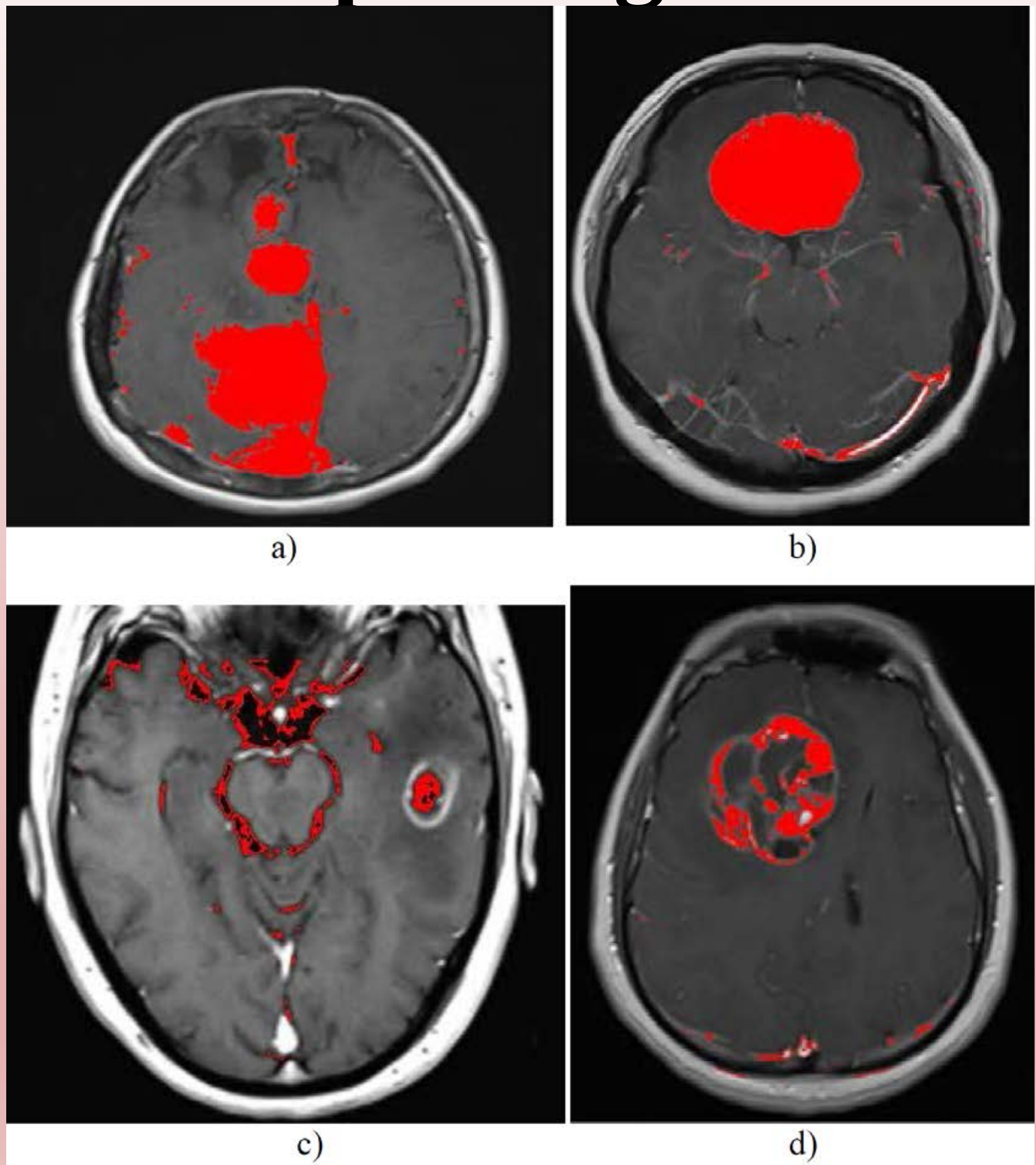
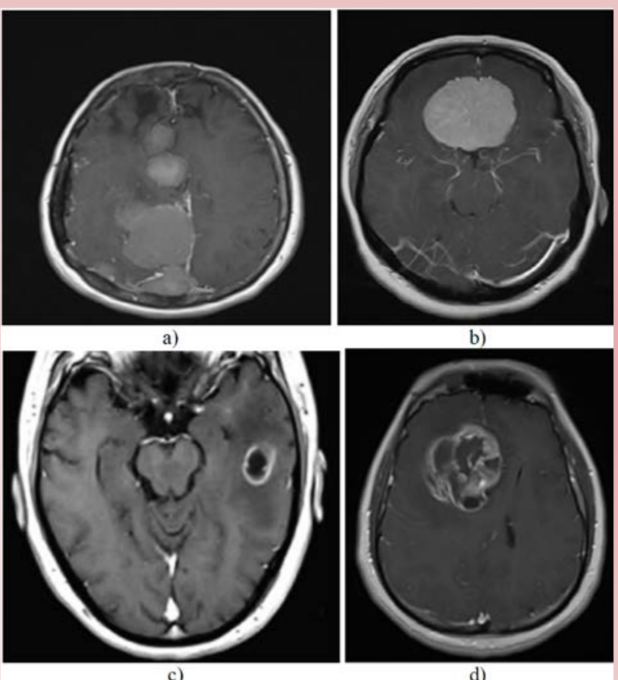


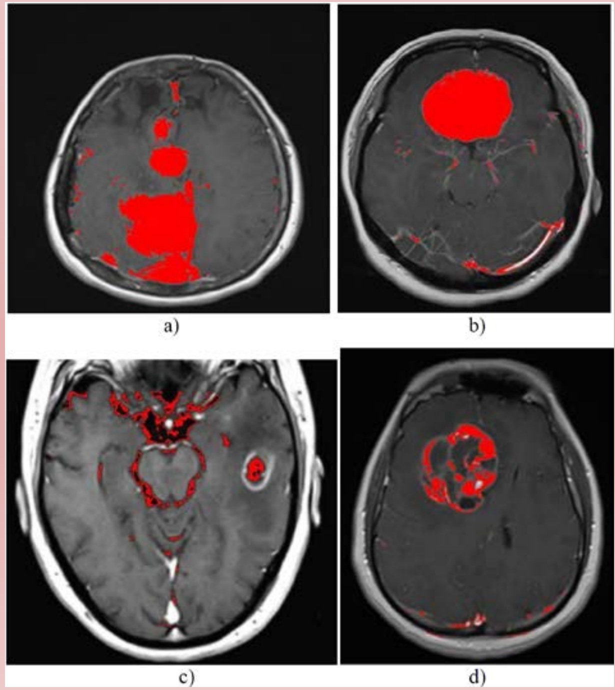
Fig. 12. Binary images from Fig. 11 imposed over original, brain images shown in Fig. 1 with the tumor regions highlighted in red, phase VII.

Description of the Developed Algorithm

As mentioned earlier, the adverse factors that made this task challenging are related to the fact that these brain images were taken under different clinical conditions, or when using different MRI scanners, under various contrast conditions and uneven contrast under which images are displayed as well as poor contrast in general.

Despite these disadvantages, the obtained results are very satisfactory, as it can be observed by visual comparison of specific features embedded in images and corresponding numerical values.

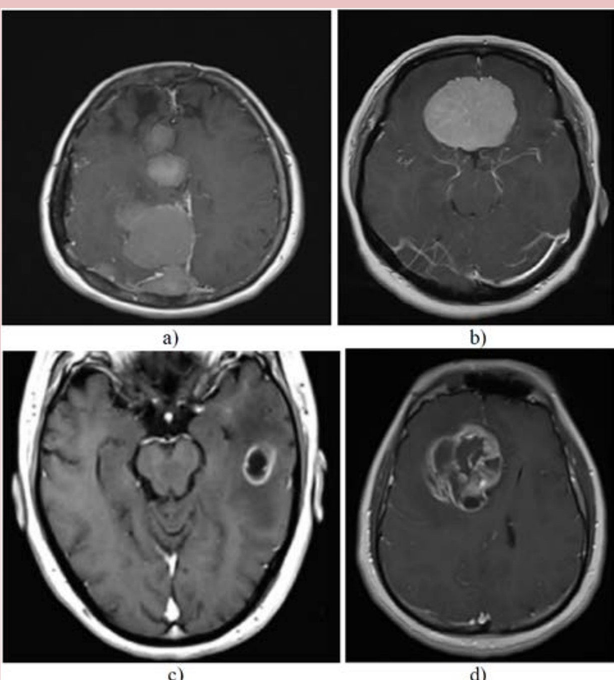


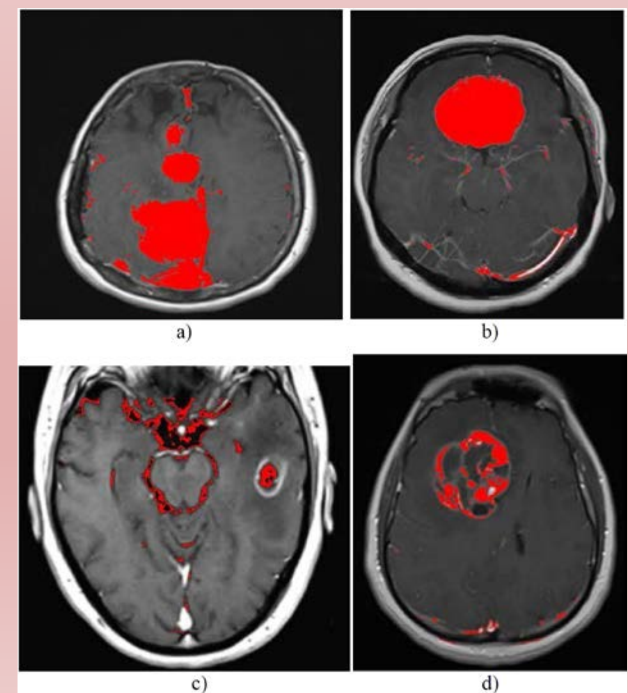


Results

The adverse factors that made this task challenging are related to the fact that these brain images were taken under different clinical conditions, or when using different MRI scanners, under various contrast conditions and uneven contrast under which images are displayed as well as poor contrast in general and exhibit various head positions of subjects.

Despite these disadvantages, the obtained results are very satisfactory, as it can be observed by visual comparison of specific features embedded in images and corresponding numerical values.





Results

The above outlined developed algorithm for classification of tumor brain images was tested on 30 images, some of them being taken before and after brain surgery, where samples of these images are presented.

Final results generated by the application of the developed technique, should be very useful to surgeons and their potential patients.

It could also assist medical doctors in sharing their previous experiences with other team members, or patients as well as planning for their potential surgery.

Results

The presented algorithm offers visual representation of the detected tumor brain area and also accompanying related numerical representation which is numerical equivalent to the visually marked tumor tissue in the images.

Table 1 shows the quantification results of the proposed method and the percentage of the detected tumor areas in MRI images.

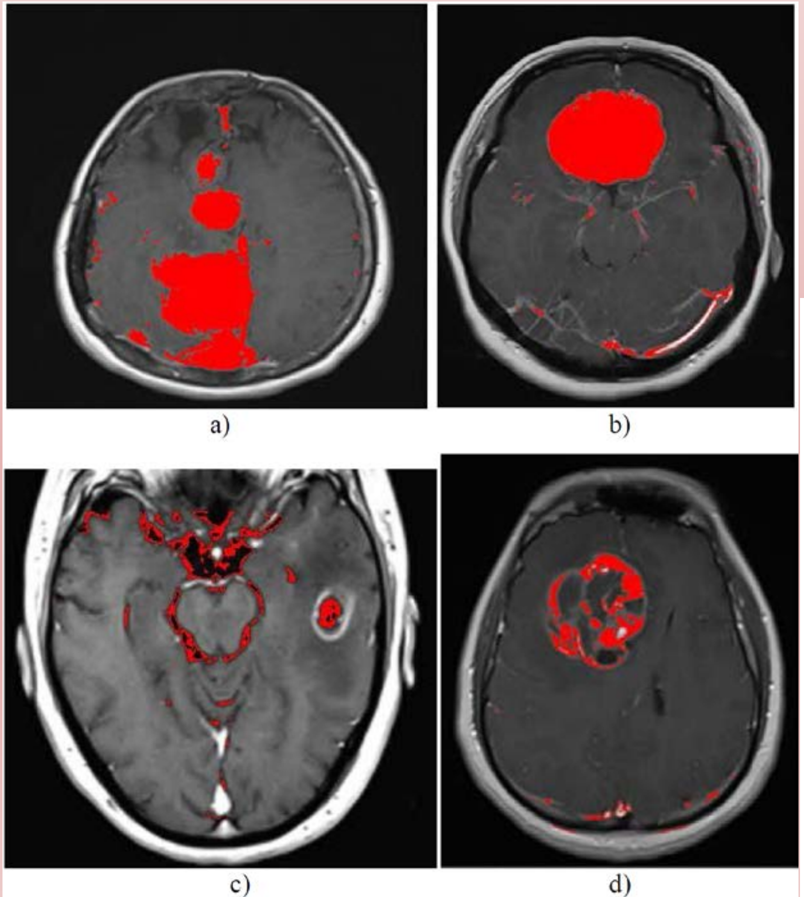
TABLE I
SUMMARY OF THE OBTAINED RESULTS OF THE QUANTIFICATION

Image	Area [%]
Fig. 12 a)	6.7214
Fig. 12 b)	6.3497
Fig. 12 c)	1.7976
Fig. 12 d)	7.2296

Results

The area values presented in this table consider the pixels contained within the region detected as tumor area.

They represent the numerical equivalent of the visual detection and impression.



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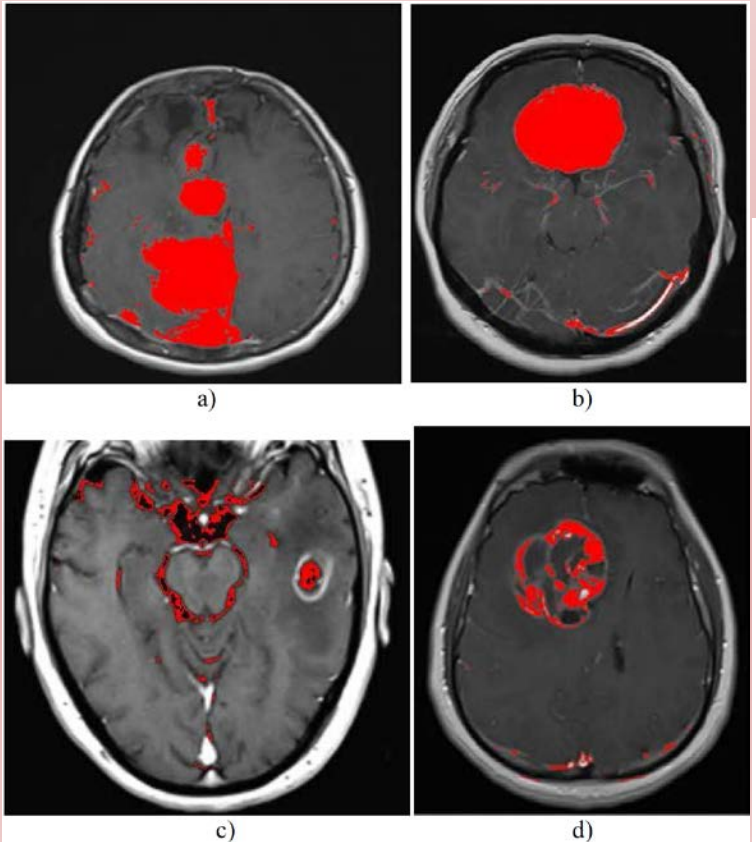
Results

The ratio between the detected pixels that belong to the tumor tissue and the total of all the pixels within the brain area in the analyzed image represents percentage of the quantification shown in Table I.

The extent of surgical procedure necessary is expressed through the percentage number presented in Table I, i.e. higher percentage number reflects larger tumor present.



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Conclusion

A specific tumor represents uncontrolled growth of tissue in the body and as there are varieties of tumors that possess different characteristics, this requires highly specialized treatment.

The developed method represents an attempt to assist medical doctors and surgeons in particular to create measurable feedback and outcome as well as applicable tool to share this more precise assessment with the patients or their caregivers.

Furthermore, developed quantitative assessment algorithm applied on MRI brain tumor images, represents attempt to create a programmed mathematical and simulation technique capable of routinely detecting targeted tumor tissue areas with a specific goal to assist medical doctors to plan surgical strategies, radiotherapy and/or radiosurgery.

The proposed method was applied on thirty patients’ images taken under various clinical conditions.

The algorithm shows to be robust to various appearance changes of processed images in clinical settings.

Conclusion

As a part of this project, the simulation model was developed, software generated and more than satisfactory results were obtained.

The developed image analysis tool shows to be successful in differentiating and detecting tumor areas in the images taken under various clinical conditions.

Further this technique might be also useful in assessment of any similar complications as well as planning and assessment of any related medical procedures.

Supplementary, this numerically focused technique can be used to provide a feedback to the medical practitioner and patient in terms of possible prognosis and treatment approaches.