ORIGINAL ARTICLE

Detection of cancer in breast thermograms using mathematical threshold based segmentation and morphology technique

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Abstract The breast thermography measure is a physiological examination that gives information subject to the warmth varieties in the breast. Breast thermography is a physiological test that gives data dependent on the temperature changes in the breast. It accounts for the temperature spread of a human body in the exposure of the infrared radiation released through the outer side of that body. Precancerous tissue along with the surrounded zone around a risky tumor experiences higher temperature due to angiogenesis, and higher compound and vein activity than a standard breast thus breast thermography can identify early irregular variations in breast tissues. It may perceive the essential sign of building out sickness before mammography can distinguish. In this paper, the author derives the mathematical threshold-based methodology is reasonable, famously utilized in the segmentation strategy, and also Develop an algorithm that defines how well our technique is figuring out the hottest region and mark a ridgeline on hottest suspected regions.

1 Introduction

Thermal imaging is a strategy using infrared energy that doesn't seem to the independent eye, the energy transmitted by the article, is then changed over into a graphic Image (Mambou et al. 2019). Each article over a temperature of absolute zero produces warm energy in the infrared structure; accordingly, each article can be recognized using a warm imaging camera. Similar guidelines used to a specified subject endeavor a thermography determination, just as the whole locale where the formation, advancement, and end of cells carry on unusually. When the development of the cells is not, at this point controlled in an ideal extent of cell development to cell passing is watched, which is an essential method for malignancy (Mambou et al. 2018). Cancer indicates the uncontrolled expansion of cells. Change is the multistep cycle in which typical cells gain threatening attributes, for example, the capacity to attack tissues and to spread inaccessible destinations. Malignancy cells set up independent heredity by continuing proliferative signals and sidestepping development silencers. Neoplastic cells follow a metastatic course to attack and colonize far-off locales.

Screening alludes to the rule target of figured out screening programs is to assemble the amount of early recognized breast infections, which would give, for example, a decrease of ladies' mortality brought about by this ailment, inability rate decrease, high possibility of recuperating, quicker recuperation, improvement of the

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existing nature of sick ladies, a decrease of therapy cost. Thermography is a non-contact course of action of recording the inner thermal level by assessing infrared radiation from the body surface. Notwithstanding enlisting temperatures, thermography joins the use of refined gear and programming for diagnosing the state of patients reliant on their IR radiation. The outcome of thermal imaging is a thermogram, which shows a picture of temperature assignment outwardly of the watched object, in gray or some other concealing palette. Thermography can be requested by different models. One of the requirements is as per the system getting ready and investigation of the recorded thermograms, which divides thermography into quantitative and qualitative. Quantitative thermography proposes the examination of the quantitative data of thermograms. The quantitative data can be presented in tables in mathematical structure or as a histogram or chart. Subjective thermography is used uniquely for the view of the temperature scattering.

Thermal imaging can recognize tumorous development as it develops blood gracefully to proceed with its turn of events. Thermography can show physiological activity that happens 5–6 mm underneath the skin surface. In perspective on the standard of conductivity, the warmth that makes inside the tissue causes a change in the temperature advantages of enveloping tissues. All warmth moved from within the hotspot to the skin surface is released into the climate by radiation. Thermography is without possibility, torture-free and non-prominent, does exclude ionizing radiation, and less expensive than various strategies for bosom screening. Bosom thermography can be utilized for ladies of all ages group considered, with any bosom magnitude and thickness, for an energetic and pregnant lady. As a result of the affectability of thermography, the most dependable signs of bosom infection can be found in the temperature range (Milosevic et al. 2018).

Thermography is ending up being a choice as opposed to mammography with the merits of being non-meddlesome, safe versatility, and price ampleness. The temperature pattern of the bosom variations on account of high increased blood flow into affected cells. This provides the best way to deal with unevenness among common and harmful bosom which can be recognized using different strategies (Khan et al. 2018). Logical morphology is a notable sign of preparing development in picture-taking care. Disintegration and widening are amazingly renowned and supportive morphological operators. Procedures of these administrators are executed with a mathematical arrangement, for instance, line or plate which is called sorting out part. Exactly when the arrangement starts, it is put on a pixel in the deal with a grayscale picture and the design chooses a little area. The disintegration eventual outcome of the pixel is portrayed as the base of the dim

assessments of the extensive number of pixels in the region, while the widening result is the most outrageous. Thus, the morphological systems give all the bosom malignant growth recognition by the proposed methodology (Milosevic et al. 2014).

Getting customized, a speedy and careful division of the bosom ROI and bosom thickness from MR image is an essential and testing issue. The bosom picture can be originated in dissimilar shapes, sizes, and thickness designs. Also, the pectoral muscles are immovably related and share comparable power conveyance with bosom ROI. Subsequently, the underlying identification of spots, for example, heart, lung, and pectoral muscle is an essential advance to encourage the proficient bosom ROI and bosom thickness process (Pandey et al. 2018). The principal limitations of bosom MRI are; Specificity is unnecessarily low and interpretation is complex and not standardized which suggests the screening of high-risk ladies. The rule focal points are the high spatial goal, no radiation introduction, can all the more probable perceive the intraductal spread of threatening growth (Jaglan et al. 2019).

All parts of the body have expressed tone and each tone exhibits a particular temperature. GLCM feature extracted from every ROI. The ability of features set in differentiating abnormal from normal tissue is inspected using an assistance vector machine classifier, Naive Bayes classifier, and K-Nearest Neighbor classifier. After the assessment of classifiers, the best classifier is SVM (Milosevic et al. 2015). In this paper ultrasound, bosom tumors were divided thus by a benchmark system. The auto-covariance surface highlights and morphologic highlights were first isolated after the use of a genetic algorithm to recognize huge highlights and choose the nearby ideal boundaries for the assist vector with machining to perceive the tumor as good or hazardous. This CAD system can isolate well from compromising bosom tumors with high precision and short element extraction time (Wu et al. 2012). The division of ROI has routinely been a basic development in therapeutic assurance, where computerized systems lead to brisk and outstandingly reproducible assessment. Exactness depends on the segmentation algorithm; the reproducibility of this algorithm is higher than manual and semi-mechanized procedures. Time utilization not exactly the two methodologies and relies on the speed of the processor (Singh et al. 2019). Medical imaging frameworks have for the most part been being utilized in the assurance and identification of bosom threatening development. The inconvenience of smearing these strategies is the enormous period of use in the physical completion of each image pattern by an expert radiologist. Automated classifiers could significantly upgrade the diagnosis method, to the extent of both exactness and time requirement by isolating benign and malignant patterns automatically. Neural framework

expects a critical occupation in such a manner, especially in the utilization of bosom threat detection (Mehdy et al. 2017).

Numerous states exist in which a degenerate added substance component (commotion) must be separated from an anonymous advanced sign; A model can be a two-dimensional picture. Even though this multifaceted nature doesn't have an overall arrangement, genuine and engineered images have enough changed attributes from customary commotion to permit the ascent of numerous significant clamor pressure calculations. The accomplishment and highlights of these calculations unequivocally rely upon how individuals separate speak to the inconsistency at the point when they need to disconnect "uproar" from "signal." In this remarkable circumstance, the sign can be recognized as whatever contains an elevation or a generally un-over a given out spatial region. This depiction is from an overall perspective free, considering the information plan data. Along these lines, it is furthermore used to smooth and disjoint signs (Alpar et al. 2018).

Having a more intensive gander at the preprocessing of thermal image (Mambou et al. 2019), it shows up through writing the right utilization of Thermal image can prompt a great result, as appeared by (Li et al. 2019). As referenced in the creator's paper (Li et al. 2019), current strategies for seeing boats by warm infrared possibly face a huge lessening in execution, in case of an essential marine blockage. To adjust to this circumstance, (Li et al. 2019) introduced another technique for recognizing ships subject to morphological revamping and multifunctional study. Regardless, the warm infrared picture is set up by a morphological engendering of the dim levels subject to the opening or shutting to smooth the astounding prevailing piece of the foundation while holding the force, shape, and structure credits of the objective of the boat. Considering the highlights of intensity and contrast, the fusion saliency apprehension methodology including a forefront warmth saliency map and shine contrast saliency map is given to feature potential targets of boats and remove congestion from the Wed. Starting now and into the foreseeable future, an elective shape depiction, unequivocally the mean eigenvalue of the edifice tensor, is made to isolate the aims of up-and-comer ships, remembering data for the verifiable structure is familiar with perceiving the certified focal points of boats from waiting for targets not related to vessels. In conclusion, the double strategy is utilized to simultaneously recognize light and dull focuses of vessels in the Thermal infrared image.

Even though image pre-processing should be possible utilizing a few methods, one of the utmost widely recognized is morphology. Its utilization of the basic dataset can extend the usage period of an entire PC vision framework and adds to its introduction. Thinking about scarcely any differences of the image morphology, creators in (Zhang et al. 2020; Novel et al. 2020; Bouaynaya et al. 2008; Devarriya et al. 2020) show a calculation that refined binary morphology on pictures depicted by a quadtree. They also disclosed that their approach fundamentally reduces the performance period of various pictures. The final is a direct result of the truth, a noteworthy number of pictures and the number of hubs in their depiction in a quadtree, is immaterial appeared differently concerning the number of pixels. For example, the impact of the tumor, the article plots the association between the centrality of the tumor and the temperature at the surface. A degree of 1:3 (distance across to significance) sets the cut-off for the imaginable combinations of the temperature at the surface. As the temperature is recognized apparently of the chest, it was basic to build up a model that can assist with grasping the baffling solicitation of the significance and width of the tumor, likewise as its region. Henceforth, a striking model was introduced, known as Everse illustrating (Mambou et al. 2018). The outline of the thermal diffusion in customary breast portrayal has been shown in Fig. 1

The rectangular space gave the basic look at judicious models that narrate superficial temperature to tumor territory and size in Fig. 2 (Czech et al. 2018).

Diameter and depth of the tumor: The paper by Czech et al. 2018 shows the depth and diameter of the tumor as an issue to be fathomed utilizing thermal strategies, utilizing the width at half height (FWHM) to assess the depth of a little heat wellspring of the isothermal circulation problem areas zone. Moreover, due to the unpredictable structure of bosom heat transfer, the use of a vascular model requires itemized information on the microvascular network. Accordingly, the Penne bioheat condition (1) was utilized to display the heat transfer in the bosom:

$$pc\frac{\delta T}{\delta t} = \nabla . k \nabla T - w_b p_b C_b (T - T_b) + O_m \tag{1}$$

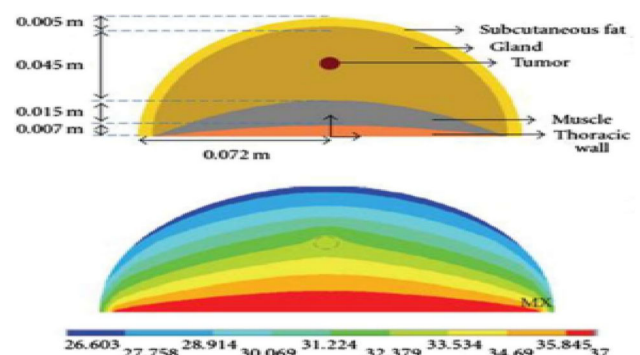where c, p, and k mean the specific heat, density, and thermal conductivity of the tissue. Cb and Pb are the

Fig. 1 Outline of the thermal diffusion in customary breast portrayal (Kandlikar et al. 2017)
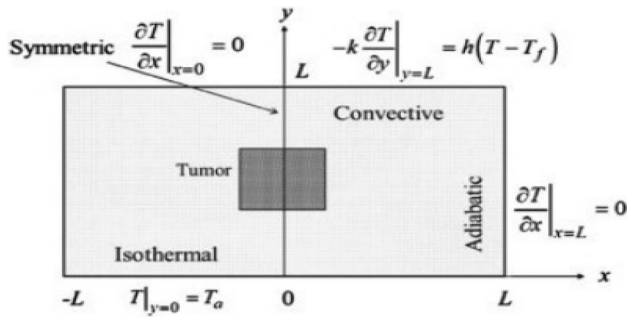
Fig. 2 The tumor size and area

specific heat and density of the blood; wb (mL/s/mL) is the blood perfusion rate; Ob is the metabolic heat generation, Ta is the steady blood vessel blood provider temperature, and T is the bosom temperature.

One of the fundamental systems that we discovered to be significant was to keep up the room temperature somewhere in the range of 18 and 22 °C, so the absolute heat misfortune can be viewed as proportional to (Ts − Tf), gave that (Ts − Tf) is little. In this manner, the limit condition at the bosom surface has been diminished as appeared in Eq. (2), with a surface conductance considered in Eq. (3).

$$-k\frac{\delta T}{\delta t}|skin = h_o\big(T_s - T_f\big) \qquad (2)$$

where h_0 is known as a consistent surface conductance that is made out of convective and radiative parts.

$$h_0 = h_{conv} + h_{rad} \qquad (3)$$

Hemispherical space with non-concentric layers in Fig. 3, which is a typical model as of its capability to copy the superficial temperature (Unar-Mungu et al. 2017). In the setting of the bosom tumor area, the breast superficial temperature is the game plan of the heat transfer condition, therefore it is satisfactory to choose the boundary assessment of this condition. The use of the backward demonstrating technique, in any case, requires a model for the bosom. Also, in our specific situation, the heat transfer condition is illuminated for a bunch of introductory estimations of the bodily, warm conditions of bosom tissues.
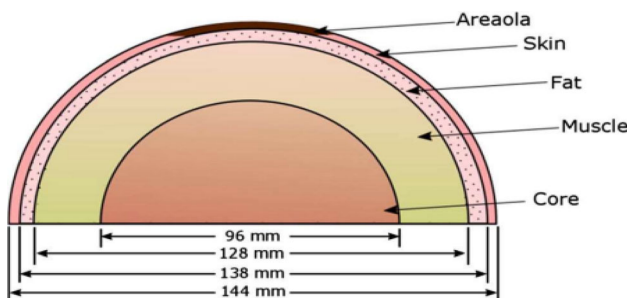

Fig. 3 Different layers of the breast

From the above literature, it is ascertained that most of the work is on the mammography technique and very limited work is reported on thermography. This paper aims to detect cancer using the mathematical threshold-based methodology. It is reasonably utilized in the segmentation strategy and also we have developed an algorithm that defines how well our technique is figuring out the hottest region and marking a ridgeline on the hottest suspected regions.

The association of the paper is as per the following: Methodology is given in segment 2. The result and discussion are depicted in segment 3. section. The end is given in segment 4.

2 Methodology

The proposed work has shown in the block diagram Fig. 4.

2.1 Acquisition of breast thermography images

The images are caught utilizing FLIR. In the information base, at least 8 pictures for every client per bosom were caught and the point of the pivot of the bosom was changed for each catch. This paper dealt with all-out 36 pictures.

Figure 5 Reflects breast thermography image of healthy patients. Figure 6 Reflects breast thermography image of sick patients.

2.2 Threshold method for segmentation strategy

The threshold methodology is reasonable and famously utilized in the segmentation strategy. It brings into explanation the variety in gray incentive between the
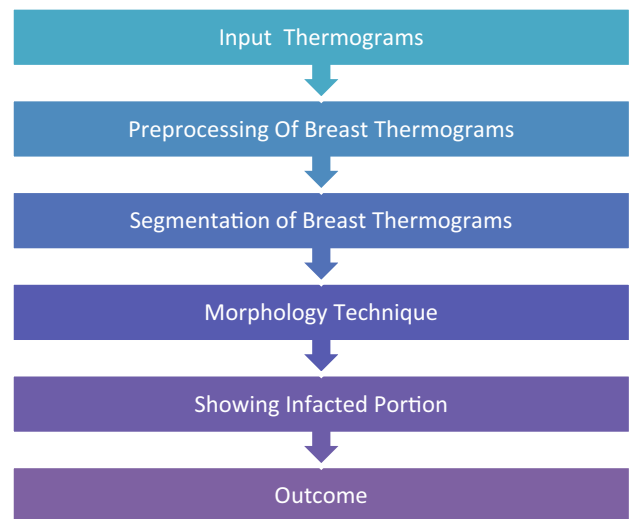

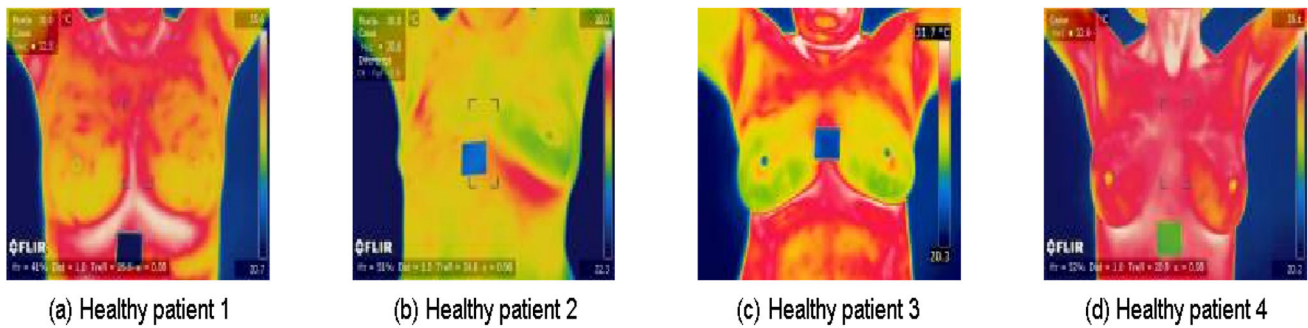**Fig. 4** flow chart of procedure work

(a) Healthy patient 1   (b) Healthy patient 2   (c) Healthy patient 3   (d) Healthy patient 4

Fig. 5 Healthy patient breast thermography

(a) Sick patient 1   (b) Sick patient 2   (c) Sick patient 3   (d) Sick patient 4
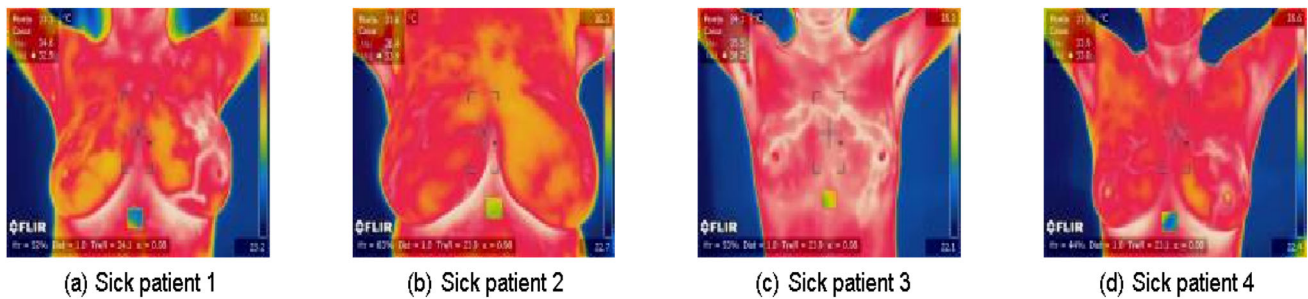
Fig. 6 Sick Patient Breast thermography

background and aim objects, at that point decides at least one image thresholds utilizing certain principle gatherings to isolate the picture into at least one section. The dim pixel esteem over the limit is coordinated in a district class, while the gray pixel regard underneath the threshold is systematized in another zone class, whereas the gray pixel regard underneath the threshold is requested in an alternative region class. It can pack a lot of information as well as impressively make simpler the examination and picture processing stages Subsequently, in different conditions, the segmentation of the threshold is very critical before feature extraction, pattern recognition, and system investigation. It is particularly applicable to the conditions where the background and the target have unmistakable gray levels. The advantages are productivity and straightforward tasks. There are numerous methods of threshold segmentation. Contingent upon the field of use of the data, it tends to be partitioned into two classes, one is the worldwide limit, and another is the strategy-dependent anxious location. As far as possible picks up the advantage of information from the whole image. It at that point decides the ideal threshold for the entire picture, which can be an extraordinary worth or numerous threshold. The "Ostu" measure takings the gray worth, which can make the variance inside the classes arrive at the most noteworthy quantity as the ideal threshold.

where p stands as a pixel value. T is the no. of pixels. g is the grayscale value of an image.

$$T = \sum_{i=1}^{g} x_i \tag{4}$$

Additionally, a probability coming about of every pixel is figured as

$$P_p = \frac{x_p}{T} \tag{5}$$

Also, a separation into two sets of S of the gray qualities is essential

$$S_o = \{1, 2, 3, 4. \ldots \ldots .v\} \tag{6}$$

$$S_1 = \{v+1, v+2, v+3, \ldots g\} \tag{7}$$

Here v ε N.

Besides, a probability Z of each group can be registered as

$$Z_0 = \sum_{j=1}^{v} \left(\frac{x_i}{T}\right)_j = > Z_0 = \sum_{j=1}^{v} (P_p)_j = Z(v) \tag{8}$$

$$Z_1 = \sum_{j=v+1}^{g} \left(\frac{x_i}{T}\right)_j = > Z_1 = \sum_{j=v+1}^{g} (P_p)_j = 1 - Z(v) \tag{9}$$

Also, calculating the average value A of each set

$$A_0 = \sum_{i=1}^{v} p\left(\frac{P_p}{Z_0}\right) = > A_0 = \frac{A(v)}{Z(v)} \tag{10}$$

$$A_1 = \sum_{j=v+1}^{g} p\left(\frac{P_p}{Z_1}\right) = > A_1 = \frac{A - A(v)}{1 - Z(v)} \tag{11}$$

Returning to the entire image, the average value is A

$$A = \sum_{p=1}^{g} p(P_p) \tag{12}$$

Thinking about Eqs. (1–9), the best threshold value can be calculated by changing the value v in the given eq. underneath:

$$Var(v) = Z_0(A_0 - A)^2 + Z_1(A_1 - A)^2 \tag{13}$$

2.3 Algorithm Include in the proposed Model

Accepting the particular capacities threshold as the mains entertainers depicted in the above work process, some random a grayscale picture of a bosom cancer dataset, the algorithm underneath characterize how sound our procedure will sort out the hottest region and mark a ridgeline on hottest suspected regions.

1: Input: Image_Dataset

2: Input: Number_Image

3: Output: Ridge Line

4: Batch [10]←0, counterBatch ←0, counter10←0, counterImg←0, Total_Image_dataset[Number_image] ←Image_Dataset//Initialization

5: **while** counter10< Number_Image **do** // beginning counterBatch←0

6: **while** counterBatch, 10 **do**

7: Batch[counterBatch] ←total_Image_Dataset[counterImg]

8: counterBatch←counterBatch+1

9: **end while**

10: counterBatch←0

11: **while** counterBatch,10 **do**

12: image_Threshold = Threshold (Batch[counterBatch])

13: L = watershed (image_Threshold)

14: Wi = label2rgb (L, 'hot', 'w')

15: im = I

% Mark on ridge line

16: im (L==0) = 0

17: counterBatch←counterBatch+1

18: **end while**

19: counterImage←counter10 // next time count after value content in counter10

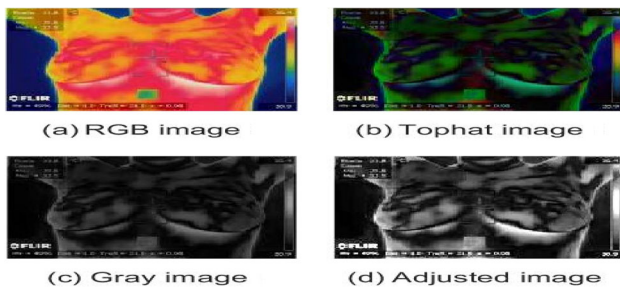20: counter10 ← counter10+10

21: **End while** //end

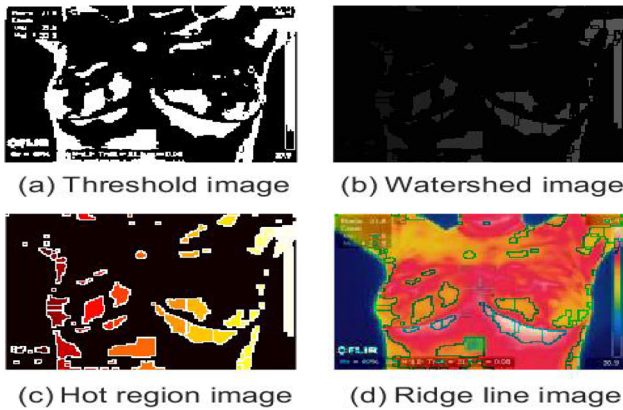**Fig. 7** Sick Patient Breast thermography

Fig. 8 Sick Patient Breast thermography

3 Result and discussion

3.1 Image processing

Recalling our objective, which is to expose the locale of interest as the whitest are of the grayscale image. The Morphology image preparation has appeared in Fig. 8. Firstly, capture the thermography image Fig. 7a, in the second step thermography image is converted into a Tophat image Fig. 7b i.e., a very useful morphological

transformation to subtract the background from an image is the so-called Tophat. Tophat is the subtraction of an opened image from the original. a gray image can be obtained here Fig. 7c, removing all features smaller than the structuring element including noise, and then the adjustment is done just for histogram stretching Fig. 7d.

3.2 Threshold image and the proposed model using watershed technique

Morphological watersheds provide a complementary approach to the segmentation of objects. It is especially useful for segmenting objects that are touching one another. Considering the work process underneath and the given issue of bosom Cancer image. Any pre-processing of grayscale pictures dataset can be enclosed by ridge one picture for each emphasis to ensure an ideal outcome (see Fig. 8). Using the ortho segmentation finding of the correct threshold level where the image is divided into two modes is done. So, this level of threshold is selected Fig. 8a. In Fig. 8b watershed is used and give zeros for all the watershed ridge line and catchment basins are non-zero. Figure 8c shows all the levels and converts them into an RGB according to the color data map specified so a hot operator is used here and a hot color map will be used to display this. The hot color map is showing the breast cancer region. In Fig. 8d original image is taken and just to superimpose ridgeline these values are taken such that L would have zero whenever the ridgelines a present, it will show black outlines for these ridges. This can be seen in Fig. 8d.

Figure 9a is showing the original cropped breast thermography image. Figure 9b is showing the image after processing. Figure 9c is showing the extracted hottest region. In Fig. 9d, the exact hottest region after processing again is presented. Figure 9e also the hottest region is marked on the original thermogram.
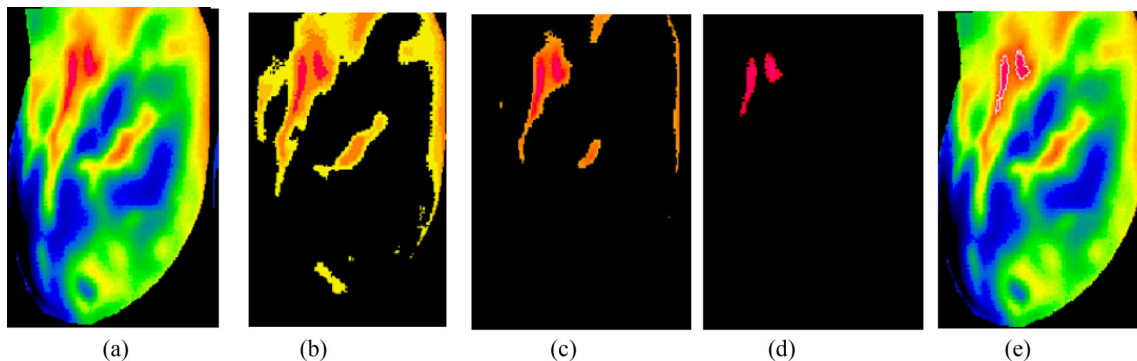

Fig. 9 Thermogram of a breast cancer patient **a** cropped breast, **b** result after processing, **c** hottest region extracted, **d** again process and get exact hottest region, **e** hottest region outlined on the original image

4 Conclusion

Image processing is a technique for changing an image over to digital form by execution procedure on it to get a better-quality image or to extricate valuable data from it. In this paper, the author derives the mathematical threshold-based methodology is reasonable, famously utilized in the segmentation strategy, and also Develop an algorithm that defines how well our technique is figuring out the hottest region and mark a ridgeline on hottest suspected regions. The hottest region is showing breast cancer area. So, using the watershed algorithm Author has detected the cancer region on the breast. In the treatment of grayscale breast disease image, so this procedure reveals the region of interest as the whitest area.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Alpar O, Krejcar O (2018) Detection of irregular thermoregulation in hand thermography by fuzzy C-means. In: International conference on bioinformatics and biomedical engineering. Springer, Cham, 10814, pp 255–265

Bouaynaya N, Schonfeld D (2008) Theoretical foundations of spatially-variant mathematical morphology part II: gray-level images. IEEE Trans Pattern Anal Mach Intell 30(5):837–850

Czech Society for Oncology. National Oncology Program. Available online: https://www.linkos.cz/narodnionkologicky-program/ Accessed 24 Aug 2018

Devarriya D, Gulati C, Mansharamani V, Sakalle A, Bhardwaj A (2020) Unbalanced breast cancer data classification using novel fitness functions in genetic programming. Expert Syst Appl 140:112866

Jaglan P, Dass R, Duhan M (2019) Breast cancer detection techniques: issues and challenges. J Institut Eng (India) Series B 100:379–386

Kandlikar SG, Perez-Raya I, Raghupathi PA, Gonzalez-Hernandez JL, Dabydeen D, Medeiros L, Phatak P (2017) Infrared imaging technology for breast cancer detection–current status protocols and new directions. Int J Heat Mass Transf 108:2303–2320

Khan AA, Arora AS (2018) Breast cancer detection through gabor filter based texture features using thermograms images. In: 2018 First international conference on secure cyber computing and communication (ICSCCC) IEEE, 412–417

Köşüş N, Köşüş A, Duran M, Simavlı S, Turhan N (2010) Comparison of standard mammography with digital mammography and digital infrared thermal imaging for breast cancer screening. J Turk German Gynecol Assoc 11(3):152

Li Y, Li Z, Zhu Y, Li B, Xiong W, Huang Y (2019) Thermal infrared small ship detection in sea clutter based on morphological reconstruction and multi-feature analysis. Appl Sci 9(18):3786

Mambou SJ, Maresova P, Krejcar O, Selamat A, Kuca K (2018a) Breast cancer detection using infrared thermal imaging and a deep learning model. Sensors 18(9):2799

Mambou S, Krejcar O, Maresova P, Selamat A, Kuca K (2019b) Novel hand gesture alert system. Appl Sci 9(16):3419

Mambou S, Maresova P, Krejcar O, Selamat A, Kuca K (2018) Breast cancer detection using modern visual IT techniques. In: Modern approaches for intelligent information and database systems. Springer, Cham, 769, 397–407

Mambou S, Krejcar O, Maresova P, Selamat A, Kuca K (2019) Novel four stages classification of breast cancer using infrared thermal imaging and a deep learning model. In: International work-conference on bioinformatics and biomedical engineering. Springer, Cham, 11466, 63–74

Mehdy MM, Ng PY, Shair EF, Saleh NI, Gomes C (2017) Artificial neural networks in image processing for early detection of breast cancer. Comput Math Methods Med 2017:1–15

Milosevic M, Jankovic D, Peulic A (2014) Thermography based breast cancer detection using texture features and minimum variance quantization. EXCLI J 13:1204

Milosevic M, Jankovic D, Peulic A (2015) Comparative analysis of breast cancer detection in mammograms and thermograms. Biomed Eng\Biomedizinische Technik 60:49–56

Milosevic M, Jankovic D, Milenkovic A, Stojanov D (2018) Early diagnosis and detection of breast cancer. Technol Health Care 26(4):729–759

Nobel TB, Dave N, Eljalby M, Xing X, Barbetta A, Hsu M, Jones DR (2020) Incidence and risk factors for isolated esophageal cancer recurrence to the brain. Ann Thorac Surg 109(2):329–336

Pandey D, Yin X, Wang H, Su MY, Chen JH, Wu J, Zhang Y (2018) Automatic and fast segmentation of breast region-of-interest (ROI) and density in MRIs. Heliyon 4(12):01042

Peter SC, Wenkel E, Weiland E, Dietzel M, Janka R, Hartmann A, Ellmann S (2020) Combination of an ultrafast TWIST-VIBE Dixon sequence protocol and diffusion-weighted imaging into an accurate easily applicable classification tool for masses in breast MRI. Euro Radiol 30:2761–2771

Singh J, Arora AS (2019) Automated approaches for ROIs extraction in medical thermography a review and future directions. Multimedia Tools Appl, 1–24

Unar-Munguía M, Meza R, Colchero MA, Torres-Mejía G, de Cosío TG (2017) Economic and disease burden of breast cancer associated with suboptimal breastfeeding practices in Mexico. Cancer Causes Control 28(12):1381–1391

Wu WJ, Lin SW, Moon WK (2012) Combining support vector machine with genetic algorithm to classify ultrasound breast tumor images. Comput Med Imaging Graph 36(8):627–633

Zhang X, He S, Ding B, Qu C, Zhang Q, Chen H, Lan X (2020) Cancer cell membrane-coated rare earth doped nanoparticles for tumor surgery navigation in NIR-II imaging window. Chem Eng J 385:123959

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