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METHODS OF MEDICAL IMAGE SEGMENTATION ANALYSIS TO IMPROVE THE EFFECTIVENESS OF DIAGNOSING LUNG DISEASES

METODY ANALIZY SEGMENTACJI OBRAZÓW MEDYCZNYCH W POPRAWIE SKUTECZNOŚCI DIAGNOZOWANIA CHORÓB PŁUC

Abstract

The article aims to review selected methods for segmenting lung medical images based on computed tomography (CT) image data analysis. Included in the analysis are 11 different approaches, including edge algorithms such as Canny, Prewitt, Roberts, Sobel and Log, clustering-based algorithms such as Fuzzy C-means, genetic K-means, k-nearest neighbours, and neural networks such as perceptron, neural and fuzzy sets, and edge binarization techniques, among others. Each method was evaluated for its ability to segment lung structures on CT images accurately. Finally, the contour of the heart from the CT image was determined using the maximum entropy thresholding method. The juxtaposition of different approaches to medical image segmentation is an important contribution to developing medical diagnostic techniques, which can help improve the efficiency of diagnosing lung diseases.

Streszczenie

Artykuł ma na celu przegląd wybranych metod segmentacji obrazów medycznych płuc na podstawie analizy danych z obrazów tomografii komputerowej (ang. *computed tomography*, CT). W analizie zawarto 11 różnych podejść, obejmujących algorytmy krawędziowe takie jak Canny'ego, Prewitta, Robertsa, Sobela oraz Log, algorytmy bazujące na klastryzacji, m.in. Fuzzy C-średnich, genetyczny K-średnich, k-najbliższych sąsiadów, a także sieci neuronowe takie jak perceptronowe, neuronowe i zbiory rozmyte, oraz techniki binaryzacji krawędzi. Każda z tych metod została poddana ocenie pod względem zdolności do precyzyjnej segmentacji struktur płuc na obrazach CT. Na końcu wyznaczony został kontur serca ze zdjęcia CT za pomocą metody progowania maksymalną entropią. Zestawienie różnych podejść do segmentacji obrazów medycznych stanowi istotny wkład w rozwój technik diagnostycznych w medycynie, co może przyczynić się do poprawy skuteczności diagnozowania chorób płuc.

Keywords: *Medical imaging, CT data analysis, Segmentation algorithms, Efficiency of diagnosis, Thresholding with maximum entropy*

Słowa kluczowe: *obrazowanie medyczne, analiza danych CT, algorytmy segmentacji, skuteczność diagnostyki, progowanie z maksymalną entropią*

Introduction

Analysis of medical images of the lungs is extremely important in diagnosing respiratory diseases (Smith, Johnson, 2018). Segmentation of lung images makes it possible to isolate important anatomical structures, allowing physicians to interpret test results quickly and accurately.

Image segmentation is a method used to extract elements of an image. Often a simple division into 2 areas – background and object(s) – is used. This makes it possible to perform subsequent more advanced operations only on objects or only on the background. There is no single method of segmentation – only the purpose is specified, the ways are many: they compete or complement each other. Therefore, the segmentation process is a process that should be strictly defined for solving specific problems. A solution that works well in one situation may not necessarily be optimal in another. It follows that segmentation distinguishes between universal and specialized methods. Further divisions are based on the specifics of the image to be processed – two-dimensional and three-dimensional. Automatic, semi-automatic (manual) techniques are used because automatic methods are not accepted everywhere. The main branch of science where automatic techniques are approached with great distrust is medicine. The results are due to very high expectations of reproducibility accuracy and, at the same time, great responsibility, which is the health or, not infrequently, the life of the patient. The image obtained as a result of segmentation is simplified compared to the segmented image – such an image does not contain much of the detailed information present in the original image. A similar situation also occurs in the case of edge detection in the image. To solve complex problems, methods are used, often multi-step, hybrid, self-learning methods based on decision trees or artificial neural networks. There are also global and local methods. The result of segmentation is a state where each image pixel is assigned an area label. The decision as to whether the type of information present in an image is relevant or irrelevant should be made taking into account the needs arising from further use of the segmentation results. The image simplified as a result of segmentation is much easier for further processing or analysis, which is why segmentation usually precedes the application of multiple image recognition and analysis algorithms. It should be noted that the choice of a particular segmentation method should depend on the purpose for which it is carried out. Improper segmentation practically prevents the correct execution of further stages of image analysis, and thus may lead to wrong decisions based on the analyzed images. Classification of segmentation methods by the type of information used during segmentation: thresholding point methods – for example. by selecting the threshold based on the histogram of the image, the result is a binary image, clustering – the creation of areas based on the features assigned to the pixels as a result of clustering (clustering) algorithms, edge methods – the use of this type of methods requires the use of any of the edge detection algorithms area methods area sprawl, area merging, area division, division and merging method, waterfall segmentation, hybrid methods – using two or more of the above methods, e.g. area sprawl using edge information.

This article aims to review and compare different methods for segmenting lung medical images obtained from computed tomography (CT) scans (Wong, Chan, 2019). Eleven different segmentation methods are presented, including edge algorithms, algorithms based on clustering and neural networks. The heart contour was also determined from the CT image. The maximum entropy thresholding method was used to determine thresholds for segmentation.

Research methods

This article uses computed tomography (CT) images of the lungs, with segmentations marked using 11 different methods. The canny algorithm, Prewitt algorithm, Roberts algorithm, Sobel algorithm, Log algorithm, Fuzzy C-means algorithm, Edge Binarization, K-means Genetic algorithm, k-nearest neighbour algorithm and Perceptron Networks, as well as Neural Networks and Fuzzy Sets, were used.

Canny algorithm, proposed by John F. Canny in 1986 (Canny, 1986). Its goal is to detect edges while minimizing errors, which means detecting as many true edges as possible while minimizing the detection of false edges. The canny algorithm has been widely used in various fields, including medical lung image analysis (Chen, 1999). Thanks to its efficiency and reliability, it is often the method for detecting anatomical structures and pathological changes in medical images (Russ, 2011).

Prewitt algorithm, proposed by J. Michael Prewitt (Prewitt, 1970). Its operation is based on using two filter masks, one for detecting horizontal changes (the horizontal Prewitt operator) and the other for detecting vertical changes (the vertical Prewitt operator). The Prewitt algorithm is widely used in image processing, especially in edge detection in medicine, robotics, satellite image analysis and many other fields (Jain, 1989; Sonka, 2014).

Roberts algorithm is a classic method of edge detection in image analysis based on simple differential operators. Lawrence Roberts initially proposed it in 1963 (Roberts, 1965). Although Roberts's algorithm is relatively simple, it can effectively detect edges in lower-resolution images or in situations where more advanced methods may not be sufficient.

The Sobel algorithm was developed by Irvin Sobel and Gary Feldman in 1968 (Sobel, 1990). It is a technique based on calculating the intensity gradients of image pixels to identify areas with sudden changes in brightness, which often corresponds to edge localization. The Sobel algorithm is widely used in various fields, including medicine, medical image processing, satellite image analysis, etc.

The Log (Laplace of Gaussian) algorithm is an image processing method used for edge detection and feature detection in images. It combines two processes: Gaussian smoothing and calculation of the second spatial derivative of the smoothing result. The Log algorithm is used in various fields, such as image recognition, medical image analysis, and robotics. It is beneficial in situations where it is important to detect subtle features or edges in an image.

The Fuzzy C-means (FCM) algorithm is one of the most popular clustering algorithms using fuzzy logic. It is a data clustering technique that assigns each data point to one of the *k* clusters based on similarity to the cluster centroids (Bezdek, 1984). This algorithm is handy when data points may belong to multiple clusters simultaneously or when the data is ambiguous. The Fuzzy C-means algorithm is used in many fields, such as image analysis, recommendation systems, bioinformatics and many others (Jang, 1993). Its flexibility to model data and account for uncertainty makes it a valuable tool in data analysis.

Edge binarization is an image processing process that converts a color or grayscale image into a binary image, representing pixels as black or white based on their intensity or edge features. This process is often used to extract edges from an image and further analyze those edges (Gonzalez, 2008). Once the edge image has been binarized, further operations such as filtering, morphological analysis or object detection can be performed to obtain more precise information about the edges and structures of the image.

Genetic K-means algorithm is a combination of two popular techniques: genetic algorithm and K-means algorithm. This algorithm aims to find the optimal set of cluster centers for a given dataset by optimizing with the genetic algorithm (Goldberg, 1989). The K-means genetic algorithm has many applications, including data analysis, classification, image segmentation and many other fields where efficient clustering of data is needed (Jain, 1999).

The k-nearest neighbours algorithm (k-NN) is a simple machine learning algorithm that can be used for classification and regression. It is a lazy learning method that does not require model building during the training phase. Instead, the algorithm stores the entire training dataset to classify or predict values for new, unknown data points (Han, 2011). The k-nearest neighbour algorithm is easy to understand and implement but may have limited performance for large data sets with many features. In addition, choosing the right value for the k parameter can affect the algorithm's performance and may require a hyperparameter tuning process.

Perceptron networks are one of the simplest types of artificial neural networks, which consist of a single layer of neurons called the perceptron layer (Rosenblatt, 1958). Each neuron in the perceptron layer takes inputs, calculates a weighted sum of these inputs and transforms it using an activation function to generate a result. Perceptron networks can be used for classification and regression, depending on the type of problem. Perceptron networks can be trained using various learning algorithms, such as the backpropagation algorithm, often used for multilayer neural networks. During training, the network adjusts the input weights to minimize the error between the predicted results and the actual output values (Bishop, 2006).

Neural networks and fuzzy sets are two different approaches to artificial intelligence, but they can also be integrated to make systems more flexible and capable of learning. Neural networks are mathematical models inspired by the structure and operation of the human brain. They consist of interconnected artificial neurons that process input data, passing signals through layers of neurons to an output layer (Haykin, 1994). Neural networks are used in many fields, including image recognition, classification, natural language processing and prediction. Fuzzy sets are a mathematical model for representing imprecise or ambiguous data using membership functions. Unlike classical logical sets, in which elements either entirely belong or do not belong to a given set, fuzzy sets allow incremental set membership (Ross, 2009). Integrating neural networks and fuzzy sets can lead to systems capable of handling uncertainty and ambiguity in input data.

The maximum entropy thresholding method involves maximizing the entropy difference assigned to an object with the background entropy.

$$S(I) = \sum_{n=1}^{N} H(n) \log_2 H(n),$$

S(I) - image entropy *I*
H (n) - probability of a pixel of *n* for an image *I*

For the grayscale image *I*, there are considered two masked images $I_1(t)$, $I_2(t)$

$$I_1(t) = \begin{cases} 0, for\ I < t \\ I, for\ I \geq t \end{cases}, \qquad I_2 = \begin{cases} 0, for\ I \geq t \\ I, for\ I < t \end{cases}.$$

For the given $t \in (0,1)$ differences are considered

$$\min_t |S(I_1(\mathrm{t})) - S(I_2(t))| \text{ i } \min_t |S(I_1(\mathrm{t})) - S\big(I_2(t)\big) + 0.5|.$$

Two or three values of the variable *t* are obtained, after monotonic ordering, the mask from the object is given as $t_1 < I < t_2$ as $t_2 < I < t_3$.

Results

The results of segmentation analysis of lung medical images using various methods are presented below.

Figure 1. *Canny algorithm*

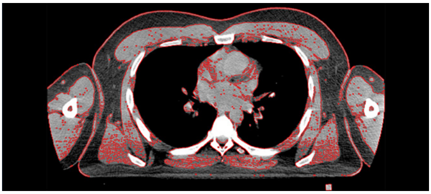


Figure 2. *Prewitt algorithm*

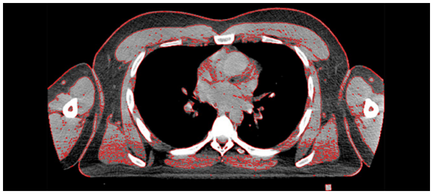


Figure 3. *Roberts algorithm*

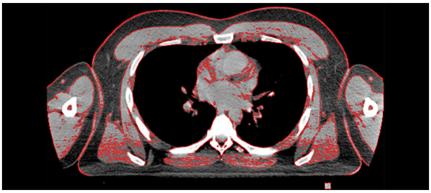


Figure 4. *Sobel algorithm*

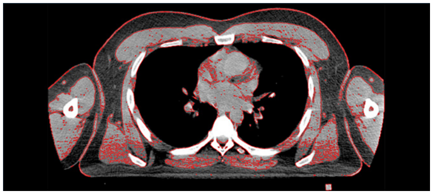


Figure 5. *Log algorithm*

Figure 6. *Fuzzy C-means algorithm*

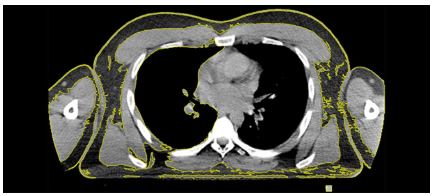


Figure 7. *Edge binarization*

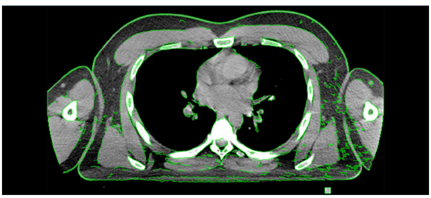


Figure 8. *Genetic alg. K-means*

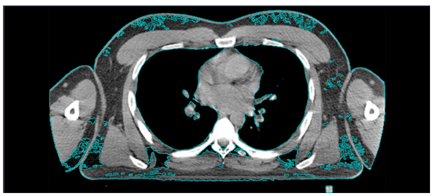


Figure 9. *K-nearest neighbors*

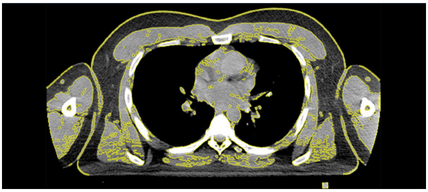


Figure 10. *Percepton networks*

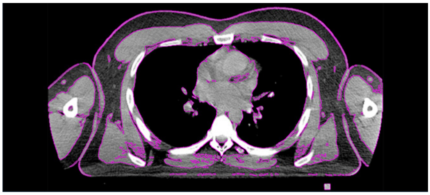
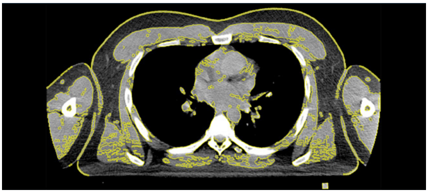
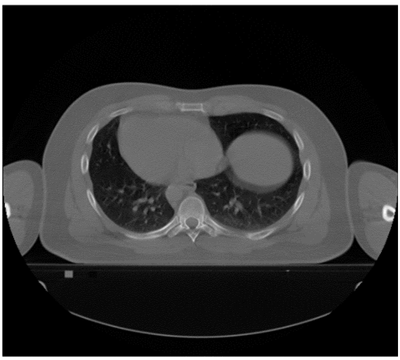


Figure 11. *Neural networks and fuzzy sets*



Segmentation analysis of the heart on a CT image

Figure 12. *CT image*



To determine the contour of the heart from the CT image (Figure 12), the following operations are performed:

1. Determination of the rectangle containing the heart (Figure 13)

2. Normalizing photos with the formula $NI = (I + mx) / Mx$, where mx – minimum pixel value from photos containing a heart, Mx – maximum pixel value from photos containing a heart
3. Determination of thresholds for segmentation using the maximum entropy thresholding method (Figure 14)
4. Morphology removing spinal and lung connections
5. Delineate the areas mono-consistently and pick the one that is closest to the center as the area with the heart (Figure 15)
6. Morphology leaving the contour of the area alone (Figure 16)

Figure 13. *The area containing the heart*

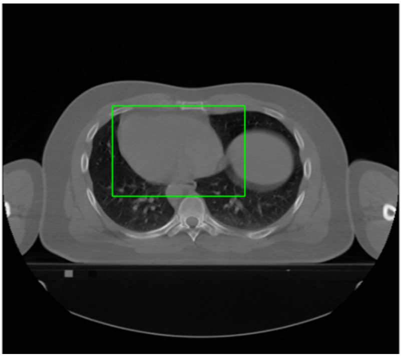


Figure 14. *The mask obtained from the maximum entropy thresholding method*

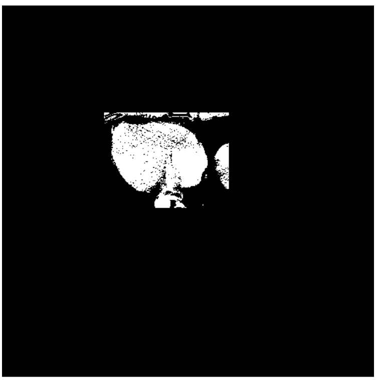


Figure 15. *The final mask*

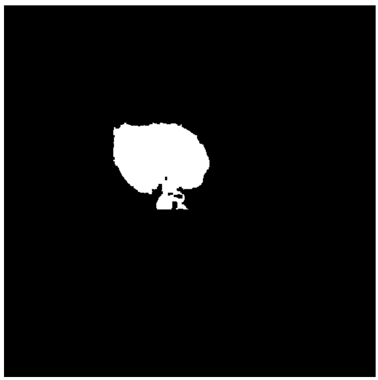
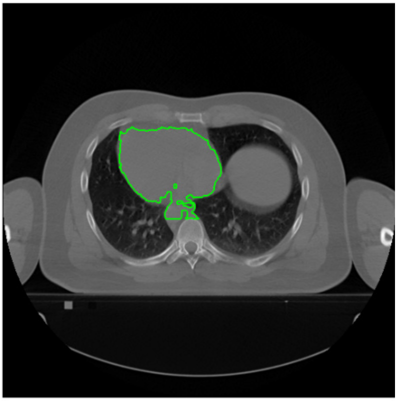


Figure 16. *The result*



Conclusions

This article compares the performance of various methods for segmenting medical lung images from CT scan data. Edge algorithms, such as those of Canny, Prewitt, Roberts, Sobel, and Log, have shown high accuracy in detecting the edges of lung structures on CT images. Methods based on clustering, including Fuzzy C-means, genetic K-means, and k-nearest neighbour algorithms, have also achieved good results in lung segmentation. Neural networks, such as perceptron and fuzzy set neural networks, have also shown potential in segmenting lung images. Obtaining the heart contour from CT images demonstrates that the accuracy of segmenting anatomical structures can be important for further medical analysis and diagnosis. This process can be crucial for detecting and monitoring various heart diseases and evaluating the effectiveness of treatment.

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