Implementation of Kernel function based on Ramanujan sums for computer vision to diagnose pulmonary diseases

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Introduction:

The new digital technologies like robotics, Artificial Intelligence(AI), 3D printing etc are creating more opportunities for automation in various industry groups. Health care will also become more efficient, less error-prone and sustainable because these technologies improve healthcare processes to provide more efficient and much earlier treatment to patients. This in turn results in shifting the focus from the traditional treatment towards targeted therapies, which are personalized with unique composition of drugs resulting in a much precision medicine and seamless healthcare. The monotonous repetitive tasks of the medical professionals can be replaced with more creative and challenging assignments.

To diagnose the cause of unexplained respiratory symptoms and to monitor patients with known respiratory diseases, Pulmonary Function Tests (PFTs) are used. American Thoracic Society (ATS), National Asthma Education and Prevention Program and Global Initiative for Chronic Obstructive Lung Disease (GOLD), recommend using these tests [5]. Amongst the common examinations in the field of medicine, chest radiography plays an important role in diagnosing the lung diseases.

Physicians generally use the stepwise approach to interpret PFTs and determine when to go for further testing and how to use PFT results to formulate a differential diagnosis. This would be consuming a lot of time to prescribe a precision and personalized medicine to the patients. If the chest radiography can be used for automatic detection of lung diseases, the time required for the diagnosis can be drastically reduced, in addition to helping the physicians in doing the precise diagnosis. Artificial Intelligence and machine learning technologies assist the doctors in doing the precise diagnosis, thereby enhancing the treatment processes. This may also help in eliminating the wrong diagnosis done sometimes.

In this project an attempt has been made to make the machines learn by using the computer vision technique, specifically edge detection. On a chest x-ray, lung abnormalities will either be present as areas of increased density or as areas of decreased density. Lung abnormalities with an increased density, also called opacities are the most common. Whenever there is an area of increased density within the lung, it must be the result of one of the four patterns as consolidation, interstitial, nodules or masses and

Atelectasis[4]. Therefore, if the machines can learn how to detect the edges, further classification into any of these categories can be done through machine learning classification algorithms.

Problem Statement:

Amongst the common examinations in the field of medicine, chest radiography plays an important role in diagnosing and excluding the lung diseases. Physicians generally use the stepwise approach to interpret PFTs and determine when to order further testing and how to use PFT results to formulate a differential diagnosis. This would be consuming a lot of time to provide a precise and personalized medicine to the patients. If the chest radiography can be used for automatic detection and monitoring of lung diseases, the time required for the diagnosis and monitoring can be drastically reduced, in addition to helping the physicians in doing the precise diagnosis. Artificial Intelligence technologies assist the doctors in doing the precise diagnosis, thereby enhancing the treatment processes. This may also help in preventing the wrong diagnosis done sometimes. Therefore, the techniques to read these x-ray images accurately will help the machines to learn and classify accordingly. In this project, computer vison technique called Ramanujan Sums Kernel Function is used to detect the edges of the x-rays which is an important step towards developing a machine learning solution.

Problem solution:

Various image processing procedures can be applied on these radiographs to detect the specific type of a disease such as tuberculosis, pulmonary nodules, effusion, infiltration etc. Accurate image detection will be the fundamental requirement for achieving these diagnoses and categorizing them based on various parameters like contrast, intensity etc.

Kernel methods have proved successful in all areas of image processing such as optical character recognition, object classification, action recognition, image segmentation, content-based image retrieval mainly because of their interpretability and flexibility. Kernel methods have been established as powerful tools for computer vision. The paper titled “Ramanujan Sums Based Image Kernels for Computer Vision” is the reference paper which proves the validity of kernel function theoretically and depicts the application of the kernel in image vision. The paper discusses about the applicability of the kernel in various context of image processing. To process the x-ray images accurately as required by the health industry, Ramanujan Sums Kernel function has been implemented and checked for the accuracy of image processing.

Kernel methods have proved successful in all areas of image processing such as optical character recognition, object classification, action recognition, image segmentation, content-based image retrieval mainly because of their interpretability and flexibility as mentioned in the reference paper. By constructing a good kernel function, it is aimed to integrate the prior knowledge of humans for a particular problem. Once a promising kernel function has been designed, it can be re-used in any kernel-based algorithm, not just in the context it was originally designed[1]. Referenced paper gives an introduction to kernel methods in computer vision from geometric perspective, introducing not only the ubiquitous support vector machines, but also less known techniques for regression, dimensionality reduction, outlier detection and clustering [5]. Application of Ramanujan summation formula in digital signal processing to weigh the coefficients to compute their imaginary Discrete Fourier Transform integer valued coefficients is mentioned.

The traditional method to get the values of Ramanujan sums follow the definition and formula in number theory, which need factorization information. But it is complex, and the amount of time needed is unpredictable and hence various programmable approach based models have been proposed. Ramanujan sums, a trigonometric summation is defined as the sums of n^{th} powers of the q^{th} primitive roots of unity and has the form shown below in the equation.

$$C_q(n) = \sum_{\substack{k = 1 \\ (k,q) = 1}}^{q} \cos(2\pi kn/q)$$

The notation (k, q) denotes the greatest common divisor of k an dq. If (k, q) = 1 it implies that k and q are relatively prime, or they co-prime each other. Ramanujan sums have special properties that they run over only those values of k that are co-prime to q and they are periodic functions with period q. Any Ramanujan sum is a real symmetric and periodic sequence in n. Image kernel is a small matrix used for applications like feature extraction, a technique for determining the most important portions of the image. Compared to a general kernel, Ramanujan kernel is a kernel matrix which is positive semidefinite. A matrix M is positive semidefinite if and only if it arises as the Gram matrix of some set of vectors. In contrast to the positive definite case, these vectors need not be linearly independent.

Implementation:

Objective of this project is to implement the kernel function for the detection and segmentation of pulmonary diseases. Properties of Ramanujan sums have been explored and used to build an image kernel, which is a matrix used to apply effects like the ones that are found in Photoshop or Gimp, such as blurring, sharpening, outlining or embossing. They're also used in machine learning for 'feature extraction', a technique for determining the most important portions of an image. An implementation of a novel kernel matrix based on Ramanujan Sums for computer vision, presented in this paper has been successfully done.

The data set for the given project contains the data samples provided in the 2nd reference paper collected from JSRT dataset, Shenzhen dataset and chest X ray14 dataset. Image Gradient Using Ramanujan Kernel and Edge detection using RS Kernel are implemented and tested on the data set chosen.

In the reference paper taken for the implementation in this project, an integer image kernel function based on Ramanujan Sums which finds its place in image vision. The paper proves the validity of kernel function theoretically and shows the application of the kernel in image vision. Ramanujan Sums are based on number theory and hence the new kernel matrix will contain only the integer values.

Since the image processing involves complex matrix manipulations, the processing based on the new kernel will be computationally effective.

For q = 2 kernel matrix is given by

$$M_q = \begin{matrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{matrix}$$

Given input image can be represented as a matrix which contains numbers between 0 and 255, each of which correspond to the brightness of one pixel in the picture.

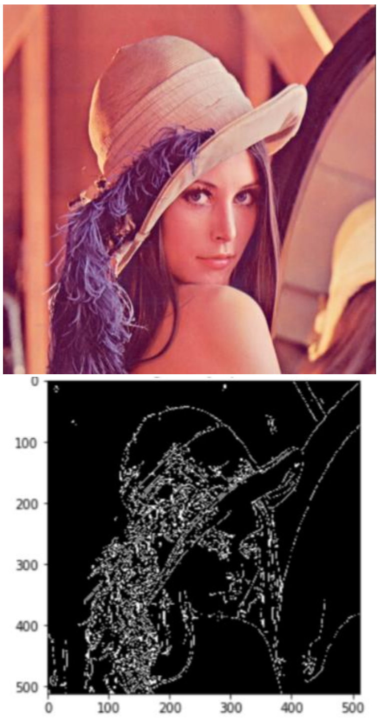


Fig 1 : experimental image

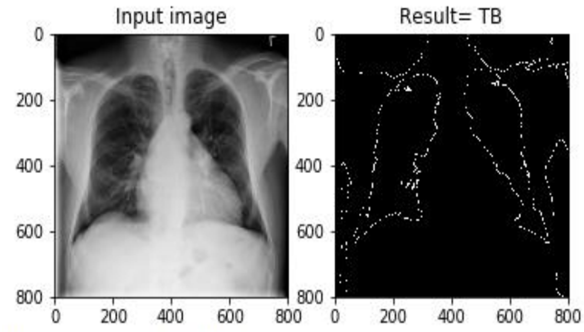
For each 3×3 block of pixels in the image, each pixel is multiplied by the corresponding entry of the kernel and then the sum is taken. That sum becomes a new pixel in the image.

Given a blurred image, it is also possible to produce the gradients for an image. For a surface such as an array of pixels, the gradient is the direction in which the color changes the fastest. Filters can be used to implement the image gradients. Two gradients are produced as x and y gradients to mention how fast the color changes along each row and column respectively The kernels used are [-1 1] for x gradient and $\begin{matrix} 1 \\ -1 \end{matrix}$ for y gradient.

Edge detection using Ramanujan Sums kernel is implemented using 3rd order kernel matrix. The input image is converted into a matrix of values between 0 and 255 and Ramanujan image kernel matrix of order three is applied. The results after applying kernel is as shown in the below diagrams.

Python code has been implemented as a function to find Ramanujan sums by initializing the vector and convert the list type into array to calculate Ramanujan sum easily. The condition is applied to decide whether k and q are co- prime. The main function is implemented with q= 3 and the data set is loaded as various samples and the corresponding responses are plotted.

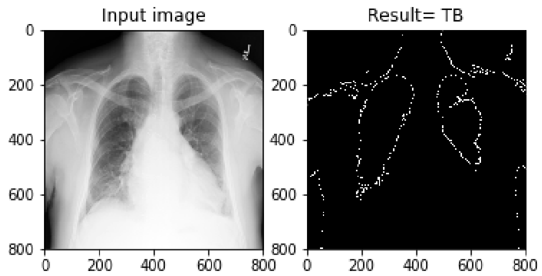
The images choses are chest X-ray images, the data set is given in reference paper 2 and the input and resulting images after edge detection are shown in figures 2 to 18 for various samples of the given data set.



data/test/00000001_001.png : TB

Fig 2: Input and the resulting Images

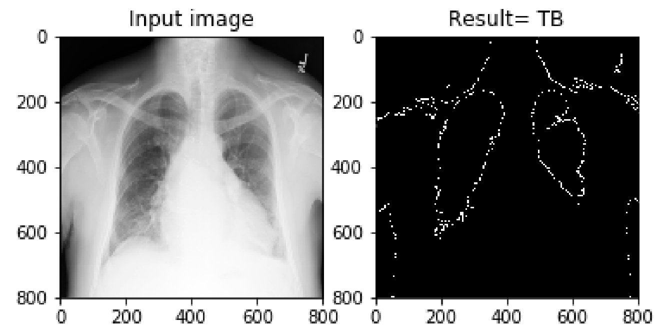
Algorithm detected TB as some of the inner edge of the left lung inside the image is faded to some extent



data/test/00000003_000.png : TB

Fig 3: Input and the resulting Images

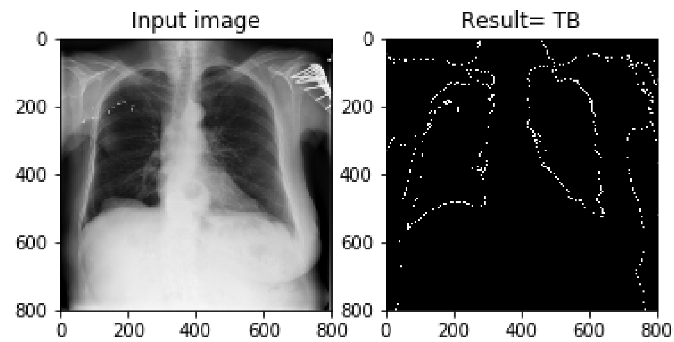
Algorithm detected TB as bottom of the left lung in the image is not visible enough.



data/test/00000003_000.png : TB

Fig 4: Inut and the resulting Images

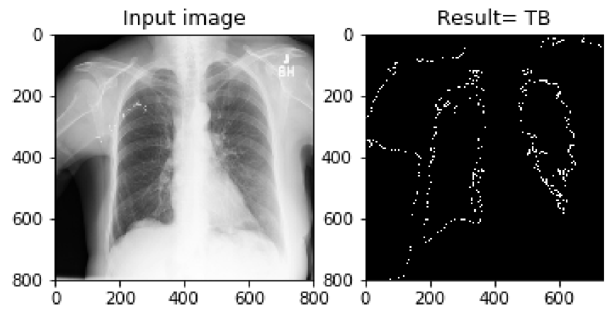
Algorithm detected TB as bottom of the left lung in the image is faded away.



data/test/00000003_001.png : TB

Fig 5: Input and the resulting Images

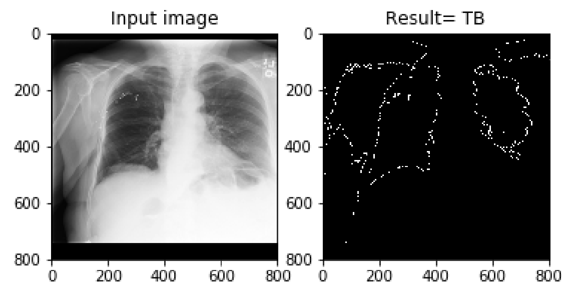
Algorithm detected TB as some of the inner edge of the left lung inside the image is starting to fade and also due to the increase in aperture between two lungs.



data/test/00000003_002.png : TB

Fig 6: Input and the resulting Images

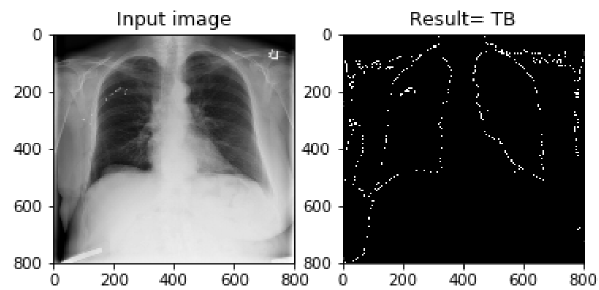
Algorithm detected TB as we can see in the right image, the bottom of the left lung is not detected.



data/test/00000003_003.png : TB

Fig 7: Input and the resulting Images

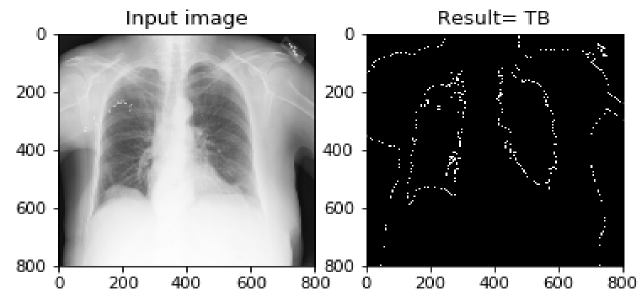
Algorithm detected TB as we can see in the right image, the bottom of the left lung is not detected.



data/test/00000003_004.png : TB

Fig 8: Input and the resulting Images

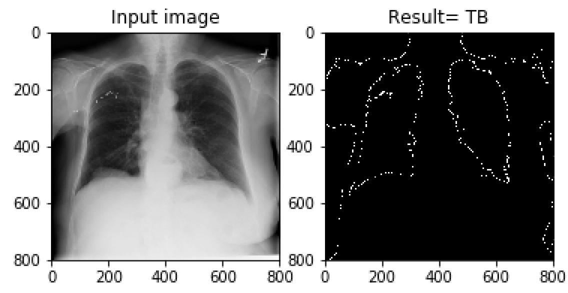
Algorithm detected TB as we can see in the right image, the bottom of the left lung is not detected.



data/test/00000003_005.png : TB

Fig 9: Input and the resulting Images

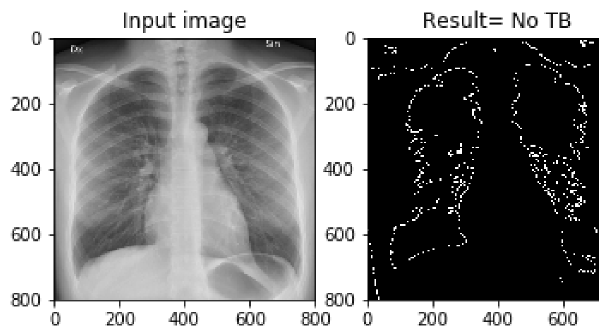
Algorithm detected TB as we can see in the right image, the bottom of the left lung is not detected.



data/test/Healthy 1.jpg : No TB

Fig 10: Input and the resulting Images

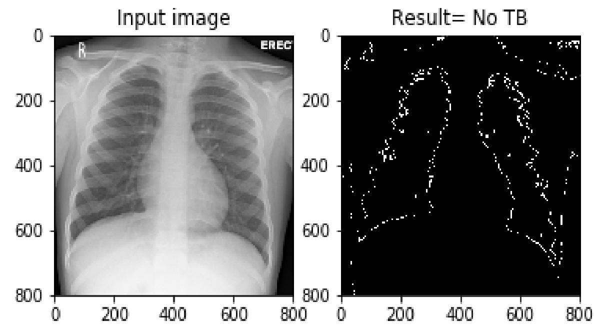
Algorithm's output was not a TB as the every edge in the image is detected.



data/test/Healthy 2.jpeg : No TB

Fig 11: Input and the resulting Images

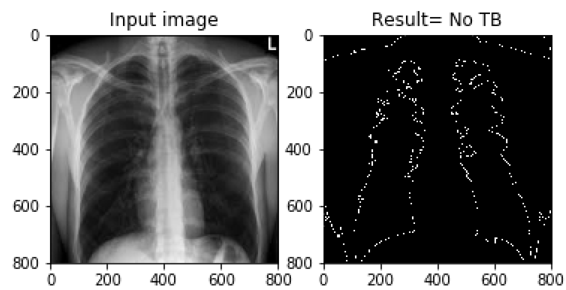
Algorithm's output was not a TB as the every edge in the image is being detected.



data/test/healthy FULL lungs.jpg : No TB

Fig 12: Input and the resulting Images

Algorithm's output was not a TB as the every edge in the image is detected.



data/test/Infected 1.jpg : TB

Fig 13: Input and the resulting Images

Algorithm's output was not a TB as the every edge in the image is detected.

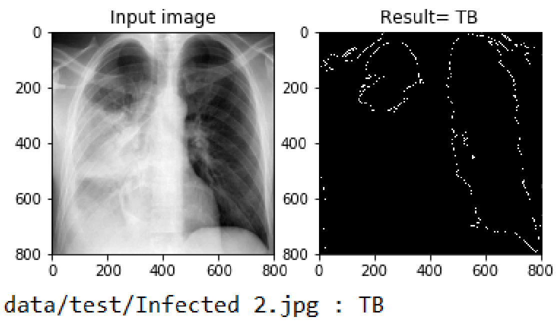


Fig 14: Input and the resulting Images

Algorithm’s output showed this image as TB infected as the every edge in the image is not detected, and the bottom left side is not at all being detected.

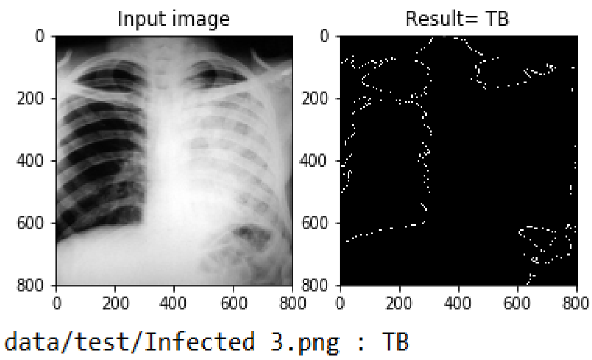


Fig 15: Input and the resulting Images

Algorithm’s output showed this image as TB infected as the every edge in the image is not detected, and the bottom left side is not at all being detected.

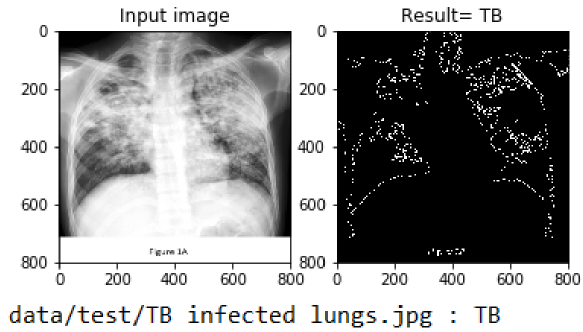


Fig 17: Input and the resulting Images

Algorithm detected TB as the input image lungs is disrupted.

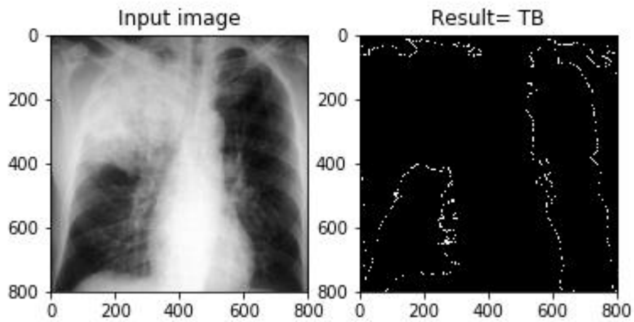


Fig 18: Input and the resulting Images

Algorithm detected TB as the top left of image is masked and it shows it has TB.

Results and Conclusion:

The edge detection of the chest x-ray images have been done very effectively and efficiently using 3rd order kernel matrix and it can definitely be applied in the health care sector, where accuracy and precise image detection is of utmost importance.

The image kernel based on the Ramanujan Sums adds one more kernel to the pool of image kernels. Since the new kernel is entirely based on the numerical computations, the computational effectiveness of the new kernel can not be questioned. The results of 3rd order kernel matrix for edge detection is promising. Since the Ramanujan Sums based kernel relates theory of machine learning with numerical mathematics, the unexplored powers of the kernel should be mined.

Further work:

In this project the edge detection has been done with the help of Ramanujam sums kernel function and the accuracy of image detection is very good. The same kernel function can be further applied on CT scans with the Natural Language Programming to process the radiologists recommendations to provide a complete solution for diagnosis of pulmonary diseases. The same procedure can be further used for diagnosis of any disease using X-rays and CT scans.

In addition, various other techniques specified in the reference paper can be tested and compared for accurate detection.

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