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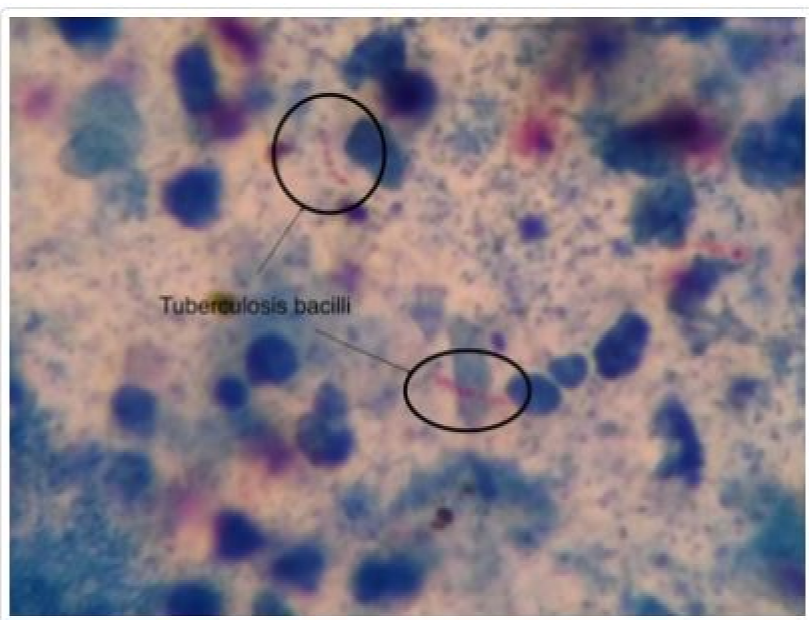
Automated tuberculosis interpretation using tensor voting

PROBLEM

Tuberculosis (TB) is an infectious disease usually caused by Mycobacterium tuberculosis (MTB) bacteria. Most infections show no symptoms and it is also time consuming to manually interpret each image to decide whether the patient is affected or not. Therefore, automation in interpretation and detection of this disease is important. We will use a pattern recognition technique called tensor voting that allows you to automatically detect and classify patterns in such images and test to see the efficiency of this approach. We will be using the open-source Tuberculosis dataset from Kaggle.



Tuberculosis bacilli

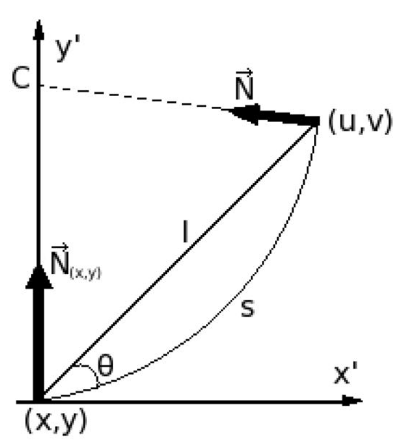
SOURCE : https://www.kaggle.com/datasets/saife245/tuberculosis-image-datasets/code

RESEARCH DESIGN & DEVELOPMENT PLAN

Tensor voting is a fast and efficient image analysis technique which can be defined as an approach to tackle vision problems in 2-D, 3-D and even N-Dimensions.

Perceptual grouping is achieved by vote casting between tokens of an image. These tokens are referred to as inputs in the form of points, disks, edges, or any surface elements, it can also be a combination of these and is represented in the form of a matrix. In 2-Dimension, these tensors can be represented and identified as second order (secondary importance) non-negative matrices, or even geometrically as an elliptical surface, shaped by the eigenvalue's magnitude and eigenvector's direction.

Voting is accumulation of all tensors with their magnitudes and directions, and are supposed to follow the gestalt principles of similarity, continuation, closure, proximity, figure/ground, and symmetry & order. The tensor's size and shape are given by its eigenvalues ($\lambda 1, \lambda 2; \lambda 1 \geq \lambda 2 \geq 0$), while its orientation is given by the respective eigenvectors (e1, e2). For example, consider two tensors, positioned at (x, y) and (u, v), in the (x′, y′) coordinate system, as shown in Figure below.



Two tensors and their geometrical relationship to produce the vote V (u, v) expressed by

$$V(u,v) = e^{-\frac{s^2+c\kappa^2}{\sigma^2}} \overrightarrow{N} \overrightarrow{N}^T$$

Here,
N is the vector normal to the tangent of the same osculating circle at **(u, v)**, which points to the center **C** of the circle. It can be calculated by **[−sin(2θ) cos(2θ)]T**. The scale factor **σ** is the only free parameter in this expression and determines the extension of the voting neighborhood. The parameter **c** is a function of the scale and has been optimized at **c = −16ln(0.1) × (σ − 1) × π−2** to control the decay at high curvature areas

SOURCE : https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3298375/

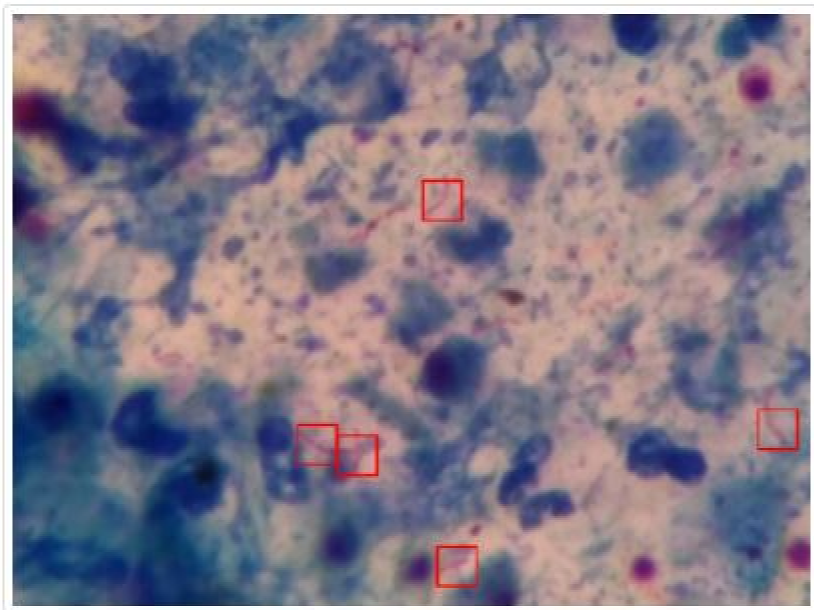
How can the vote from (x, y) be cast onto (u, v) subject to smoothness and proximity as stated before? The simplest way is to model smoothness and proximity as curvature and arc length, respectively. Let l be the distance between the two positions, and θ be the angle between the tangent of the osculating circle at (x, y) and a line that connects (x, y) to (u, v). The arc length and curvature are given by s = θl/sin(θ) and κ = 2sin(θ)/l, respectively.[1]

Although initialized with random size, orientation and shape these input tensors can get deformed due to accumulation of vote casting by neighboring tensors.

[1] L. Loss, G. Bebis, and B. Parvin, Iterative Tensor Voting for Perceptual Grouping of IllDefined Curvilinear Structures, IEEE Transaction on Medical Imaging, Vol. 30 (8), pp. 1503- 1513, 2011 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3298375/

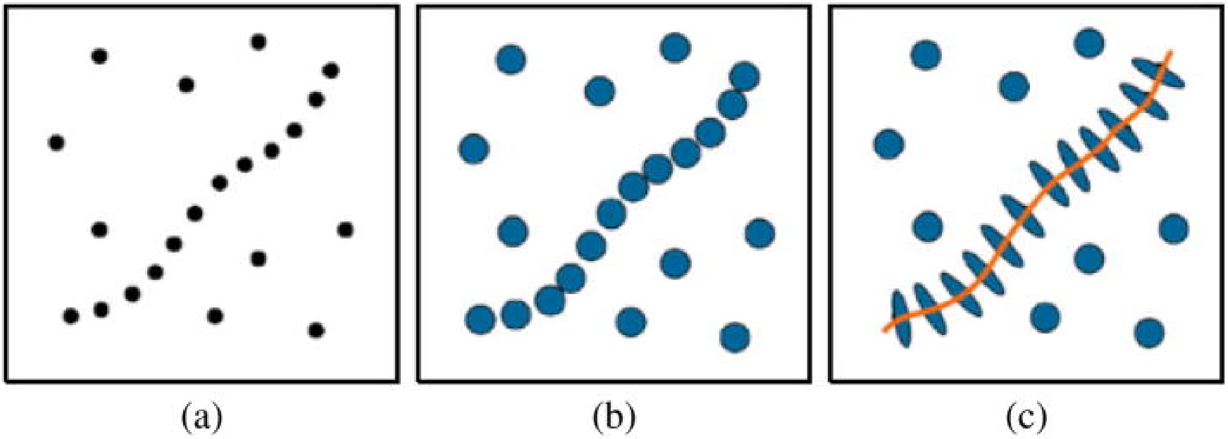
DATASET

This dataset is all about Tuberculosis, where it is taken from a sputum sample. Special software and hardware is designed to take a sample from sputum. As it contains 928 sputum images with bounding boxes of 3734 bacilli. while XML file contains bounding box details of images. See the sample Image:-



Detection of tuberculosis bacilli in sputum sample.

SOURCE : https://www.kaggle.com/datasets/saife245/tuberculosis-image-datasets/code



Example of perceptual grouping through tensor voting. A set of (a) input primitives are (b) encoded as tensors, whose (c) resulting deformations reveal a curve.

SOURCE : https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3298375/

The tensor deformation imposed by accumulating the strength and orientation of the votes eventually reveals behavioral coherence among image primitives. The vote accumulation is simply tensor addition (e.g., summation of matrices), which can be algebraically represented by $T_{uv} = \Sigma T_{xy} V(u, v)$, where Tuv is the resulting tensor at location (u, v), after receiving the votes V (u, v) from its neighboring tensors Txy at locations (x, y). Each kind of structure is expected to produce tensors of a particular shape: for example, very elongated tensors (high $\lambda 1 - \lambda 2$) for lines, and more rounded ones (low $\lambda 1 - \lambda 2$) for regions. [2]

[2]L. Loss, G. Bebis, and B. Parvin, Iterative Tensor Voting for Perceptual Grouping of IllDefined Curvilinear Structures, IEEE Transaction on Medical Imaging, Vol. 30 (8), pp. 1503- 1513, 2011 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3298375/

RELEVANT LITERATURE & REFERENCES

1. Tensor voting tutorial slides by P. Mordohai

https://mordohai.github.io/public/TensorVotingTutorial_2007.pdf

- This presentation explains the process of tensor voting (in 2-D, 3-D and N-D), analysis of Ill-defined Curvilinear Structures, and the application of machine learning in analyzing and identifying these structures.

2. L. Loss, G. Bebis, and B. Parvin, **Iterative Tensor Voting for Perceptual Grouping of IllDefined Curvilinear Structures**, IEEE Transaction on Medical Imaging, Vol. 30 (8), pp. 1503- 1513, 2011

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3298375/

- This research paper explains an iterative approach of tensor voting for perceptual grouping and localization of ill-defined curvilinear structures.

3. Tuberculosis Dataset -

https://www.kaggle.com/datasets/saife245/tuberculosis-image-datasets/code

- This is an annotated tuberculosis image dataset. Thanks to AI Research and Automated Laboratory Diagnostics for these images. This image is only for research and education purposes only.

4. Tang, C.-K., Lee, M.-S., & Medioni, G. (n.d.). **Tensor Voting**. Retrieved October 2, 2022, from

https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.35.3142&rep=rep1&type=pdf

- This chapter explains a non-iterative approach of tensor voting. The proposed methodology is non-iterative, requires no initial guess or

thresholding, and can handle the presence of multiple curves, regions, and surfaces in a large amount of noise while still preserving discontinuities, and the only free parameter is scale.