High Precision Localization of bacterium and Scientific Visualization

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Abstract

Bacteria reproduce simply and rapidly by doubling their contents and then splitting in two. The majority of bacteria in the human body are countered by the human immune system, however some pathogenic bacteria survive and cause disease. A small variation of bacterium size has great impact on their ability to cope with the new environment. This variation is not traceable in bacterium images as they may be less than a pixel width. In this paper, we present a method for high precision localization and dimension estimation of bacteria in microscopic images. To create a safe environment for scientist to interact with bacteria images in sterile environment a Human Computer Interaction (HCI) system is developed using Creative Interactive Gesture Camera as a touchless input device to track a user's hand gestures and translate them into the natural field of view or point of focus as well. Experiments on simulated data, shows that our method can achieve more accurate estimation of bacterium dimension in comparing with state-of-the-art sub-pixel cell outlining tool. The visualization of augmented biological data speed up the extraction of useful information.

1. Introduction

Segmentation is usually a starting point for bacteria length estimation. Image thresholding is a common segmentation approach to differentiate bright bacterial cells against background [2]. Utilizing interpolated-contour analysis for accurate and precise determination of cell borders [3] will produce high precision cell contours in well-separated cells, but fails to identify touching or hard-to-resolve cells. Image segmentation methods such as watershed, level set or edge detection [4] [1] [6] although good at separating densely packed cells are limited to one pixel precision. MicrobeTracker claims to be a sub-pixel precision algorithm designed to detect and outline bacterial cells in microscopy images by finding edges or ridges in the image intensity [2]. In this paper we use a different approach. Our approach is to find a model with small number of parameters, that can fit the blurred bacterium image. The model then can be used as an approximation of bacterium for accurate localization. Image review and manipulation within sterile environments [5] and maintaining boundaries between sterile and non sterile areas of the work environment are essential in biology studies. The traditional mouse and computer keyboard paradigm is not an acceptable Human- Computer Interaction method in an environment where safety is important. Interest in touchless image manipulation interfaces has resulted in the development of a gesture recognition system using a hand gesture recognition camera. The outline of the paper is as follows. In the next section we use prior information about rod shaped bacterium to define a reasonable initial model. In later section, we present an iterative optimization algorithm for computing a model which best fits the bacterium from initial model. In experiment section we validate our model through experiments. In section 5 we will describe the configuration of our touchless system and end the paper with conclusions.

2. Initialization

The model initialization starts by approximating the bacteria boundary in the image. A simple edge detector after deducting the background intensity is used to estimate the bacteria border line. The boundary pixels and those inside create an area that we refer to as ellipse in the rest of this paper.

Inflection points of the bacterium center line (after skeletonization) are calculated. A first-degree polynomial is fit-

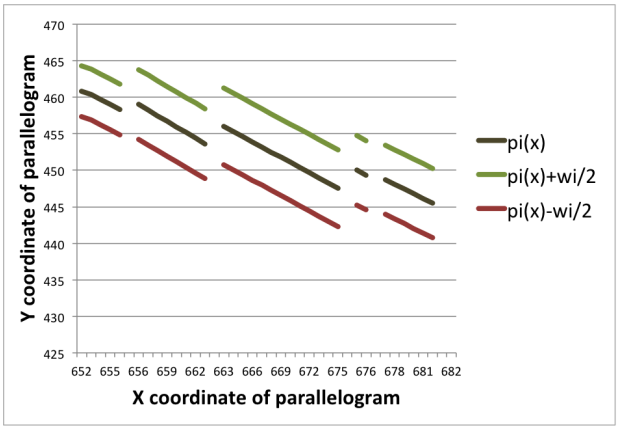

Figure 1: I(x,y) domain

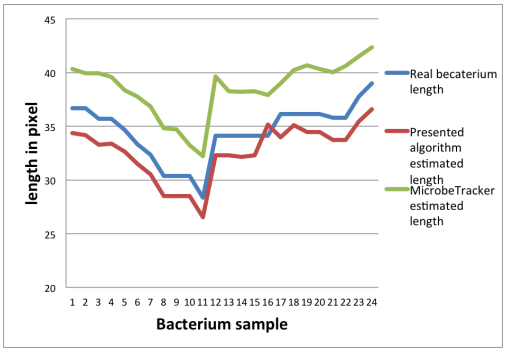

Figure 2: Length estimation

ted between every two adjacent inflection points. Each first-degree polynomial is then used to create a parallelogram with two lines drawn parallel to the first degree polynomial. The distance between two lines is initialized as the bacterium width (Figure 1). If $p_1, p_2, ..., p_n$ are first degree polynomials:

$$\begin{cases} p_1(x) = \tan(o_1)x + b_1 \\ p_2(x) = \tan(o_2)x + b_2 \\ \quad ... \\ p_n(x) = \tan(o_n)x + b_n \end{cases} \quad (1)$$

where $o_1, o_2, ..., o_n$ are first-degree polynomial orientation, then $I(x, y)$ as an initial model can be defined as follows:

$$\begin{cases} h & \text{if } x_0 \le x \le x_1, p_1(x) - \frac{w_1}{2} \le y \le p_1(x) + \frac{w_1}{2} \\ h & \text{if } x_1 \le x \le x_2, p_2(x) - \frac{w_2}{2} \le y \le p_2(x) + \frac{w_2}{2} \\ ... & \end{cases} \quad (2)$$

In this model $x_1, x_2, ..., x_n$ are the x coordinates of inflection points and $w_1, ..., w_n$ are parallelogram widths. The next stage is to find the best combination of $o_1, o_2, ..., o_n$ and $w_1, w_2, ..., w_n$ that

$$B(x, y) \approx \int\int I(u, v)PSF_\sigma(x - u, y - v)dudv \quad (3)$$

where $B(x, y)$ is the blurred bacterium image and $(u, v) \in ellipse$. The effect of the microscopic device PSF is modeled as a normal distribution, while the variance is not known for different types of microscopic devices. $PSF(x, y)$ can be expressed as

$$PSF_\sigma(x, y) = \frac{1}{2\pi\sigma^2} e^{\left(-\frac{1}{2}\left[\left(\frac{x}{\sigma}\right)^2 + \left(\frac{y}{\sigma}\right)^2\right]\right)} \quad (4)$$

3. Optimization method

The linear least square method is used for estimating the parameter values: In this formula the parallelogram width, orientation and PSF standard deviation are variable. Levenberg-Marquardt iterative method is used to solve the least square error problem. For every bacterium the optimal combination of $w_1, ..., w_n$ and $o_1, ..., o_n$ $(w_{1opt}, ..., w_{nopt}, o_{1opt}, ..., o_{nopt})$ is used to define the best fitted model $I_{opt}(x, y)$

The average of $w_1, ..., w_n$ and sum of parallelogram lengths of optimal model can be used to approximate the real dimension of the bacterium to high precision. The bacterium width can be estimated by averaging the optimal values.

4. Experiments and results

To evaluate the efficiency of the high-precision method, a series of artificial isolated blurred bacterium images, with random length and orientation created. The reason for using the simulated data is because we can access to exact length and width measurement, while for real bacterium it was not possible for us at this stage of experiment. The bacteria samples dimensions are estimated and compared with MicrobeTracker results (refer to [2] for further information) against bacterium real dimensions. The estimated dimension is pixel based. As Figures 2-3 reveal, the method outperforms MicrobeTracker for estimating bacterium dimensions. In all cases, deviation from bacterium real dimension is less than 10% of real bacterium dimension using the high-precision method. On the other hand the MicrobeTracker deviation from bacterium real length is almost higher than 10% in all cases.

5. Touchless System

The touchless system that we have designed is based on a hand gesture recognition camera that reacts to predefined gestures. The system configuration is shown in Figure 4.

$$\min_{o,w} \sum_{X} \sum_{Y} \left(B(x,y) - \int\int I(u,v) PSF(x-u, y-v) du dv \right)^2 \quad (X,Y) \in ellipse \tag{5}$$

$$\begin{cases} h & \text{if } x_0 \le x \le x_1, \tan(o_{1opt})x + b_1 - \frac{w_{1opt}}{2} \le y \le \tan(o_{1opt})x + b_1 + \frac{w_{1opt}}{2} \\ h & \text{if } x_0 \le x \le x_1, \tan(o_{2opt})x + b_2 - \frac{w_{2opt}}{2} \le y \le \tan(o_{2opt})x + b_2 + \frac{w_{2opt}}{2} \\ \dots & \\ h & \text{if } x_0 \le x \le x_1, \tan(o_{nopt})x + b_n - \frac{w_{nopt}}{2} \le y \le \tan(o_{nopt})x + b_n + \frac{w_{nopt}}{2} \end{cases} \tag{6}$$

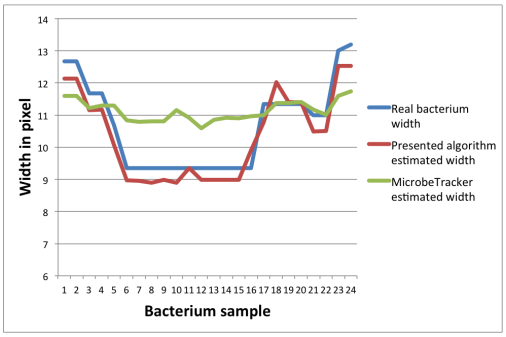

Figure 3: Width estimation

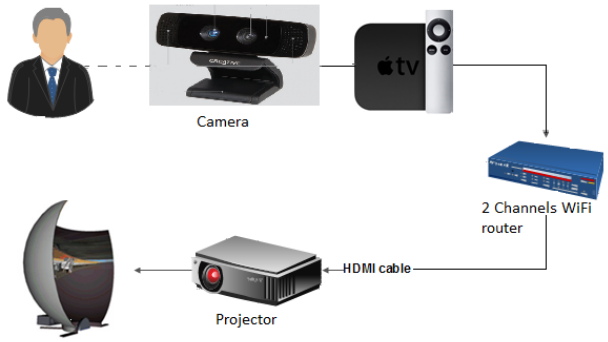

Figure 4: Touchless system configuration.

Results from last sections for bacteria height precision localization is utilized in the touchless system. When applied to biofilm images, it produces morphological data such as length and orientation in a series of frames for every individual bacterium. The information is stored in a database and can be projected on a visualization display screen to provide detailed understanding of bacteria and biofilm morphological properties. HCI takes place utilizing user's natural interfaces such as hand gesture. Creative Interactive Gesture Camera is used as an input device to track the user's hand gestures and translate them into change of the virtual camera field of view. The gestures can also be translated to extract information from the database, which can then be overlaid onto the final image. The final image is then sent to a projector through a 2 channel WiFi router , which projects the images on a hemi-spherical dome through an apple tv. In Table 1, a list of our predefined gestures and their corresponding action is provided.The camera is located in front of an hemispherical dome, as shown in Figure 5.

Table 1: Predefined Hand Gestures for touchless system.

Hand Gesture	Action
	Thumbs Up: pause the biofilm evolution movie.
	Palm central position: controls pointer on the display screen that can be used to select the bacterium of interest.
	Close hands: extracts information from database for an individual bacterium. The information is then displayed on the image and zoomed in to provide more detailed view.
	Waving hand: in a paused video, will show the previous or next frame.
	Thumbs down: resumes video play.

6. Conclusion

The high-precision method for estimating bacterium dimension by searching for the best model that fit bacterium has been discussed. This method may be applied for estimating other real object dimensions viewed in microscopic devices or satellite images that are affected by a PSF. The strength of this method is its independence of any knowledge about the device's PSF attribute. Scientific visualization of bacteria and touchless interaction with images , create a safe environment for scientist in experimental lab, where safety is an important issue.

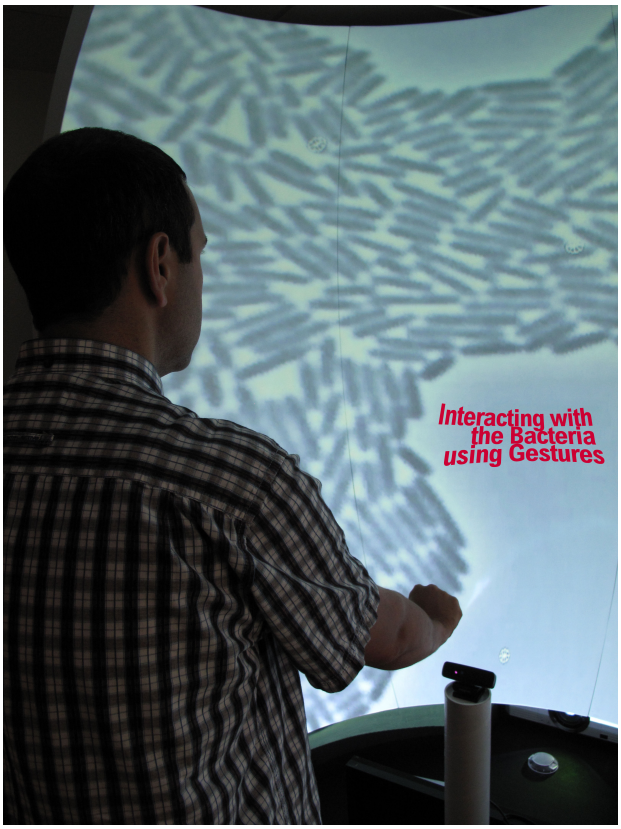

Figure 5: Interacting with camera.

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