A New Thin-Film Transistor Image Sensor for Early Detection of Bacterial Growth on Agar Plates

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Revised Abstract

Background: Early detection and identification of pathogenic bacteria is an important public health issue. Conventional methods of culturing specimens on agar plates usually take overnight to obtain definitive results. Here, we developed and verified the performance of a new thin-film transistor (TFT) image sensor for measuring bacterial growth on agar plates.

Methods: The TFT image sensor consists of a control printed circuit board, an image sensor array (542 x 872 pixels, pixel size = 80µm) and flat surface illuminating module. The field of view (FOV) of 44 x 70 mm can cover 55% of the area of the 90 mm petri dish. Each pixel measures the intensity of light passing through the agar medium. Verification of the sensor was conducted using *Enterobacter cloacae* (GTC21793) spread on agar medium, which is positioned between the sensor and the illuminating module, in an incubator for 17.5 hours at 37℃. The intensity of light was measured every 5 minutes from all the pixels.

Results: In the area where the bacterial colonies were visually observed at the end of the measurement, the intensity of the light decreased over time forming a sigmoidal curve. In other areas, the intensity of the light was almost constant. To verify if the changes in light intensity could predict the colony formation, we used background subtraction and the slope of the intensity over time for each pixel and calculated the accuracy against the definite results: obvious colony formation at the end. With simple background subtraction we achieved 87% accuracy. Using the slope of the intensity, we achieved 94% accuracy. Subsequently, more advanced statistical background subtraction was used and compared with simple background subtraction to achieve earlier detection. This results showed that statistical background subtraction was able to detect about 10 minutes earlier than simple background subtraction.

Conclusion: The new thin-film transistor (TFT) image sensor was able to monitor bacterial growth on agar plates. By using background subtraction on each pixel which appears to reflect bacterial growth on each pixel, we were able to predict colony formation much earlier than the conventional overnight culture method. We will work to remove non-specific sensor noise and improve accuracy using various hardware and software techniques including computer vision.

Bacterial Colony Detection System

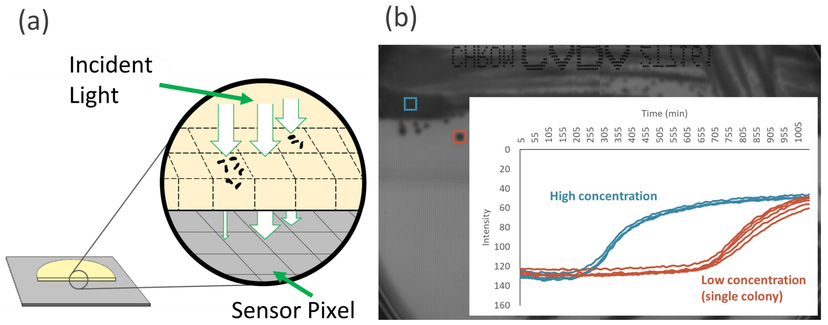

Figure 1. (a) Schematic of bacterial growth monitor using TFT image sensor. (b) Growth curves measured at the pixels in the high concentration area (blue square) and single colony (red square) superimposed on the transmitted light image of the last frame.

Initial Consideration

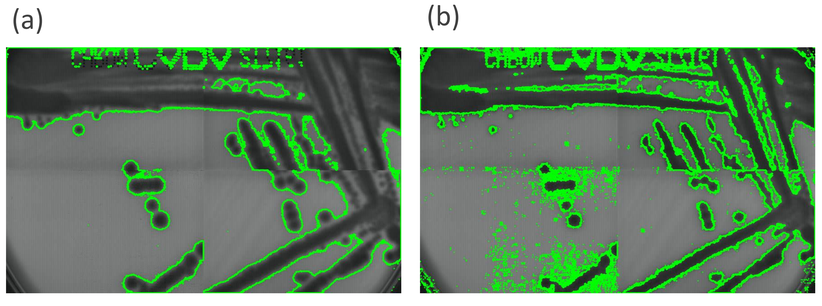

Figure 2. Results of signal detection using (a) simple background subtraction and (b) slopes in each frame. The green contour indicates detected signals. The slope method was found to be more likely to pick up fine noise at the pixel level.

Method	Accuracy	Precision	Sensitivity	Specificity	F1 score
Simple Background Subtraction	0.87	0.74	0.99	0.81	0.85
Slope	0.94	0.91	0.93	0.95	0.92

Table 1. Results of the evaluation of detection signals using simple background subtraction and slope methods against correctly annotated data

First Time to Detect Bacterial Signal

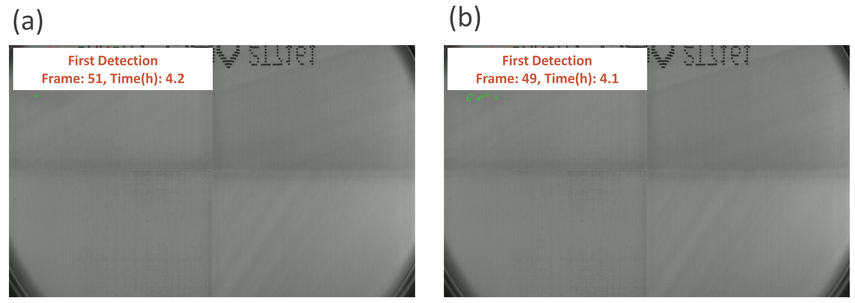

Figure 3. Images of the first detection of bacterial-derived signals using (a) simple and (b) statistical background subtraction. The green contour indicates bacterial-derived signals.

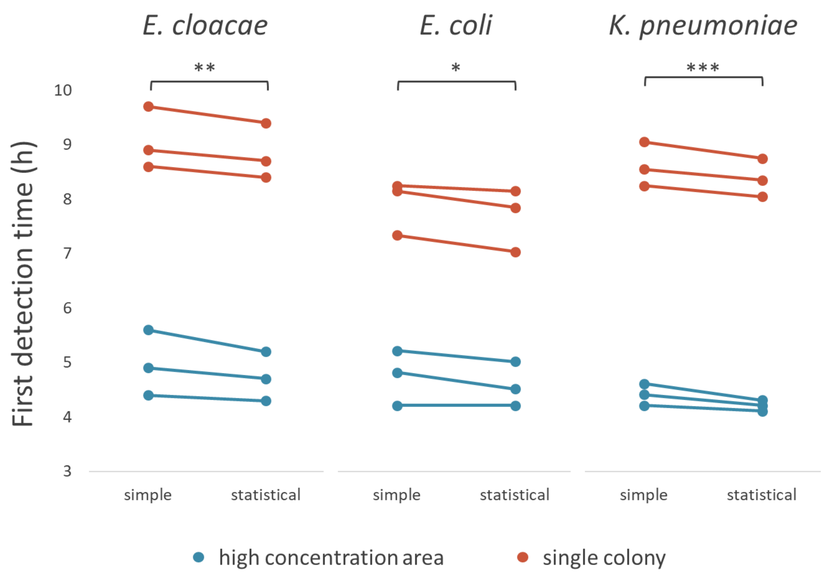

Figure 4. Comparison of first detection time of bacterial-derived signals using simple and statistical background subtraction. *Enterobacter cloacae* (GTC21793), *Escherichia coli* (ATCC BAA-2452), and *Klebsiella pneumoniae* (ATCC BAA-1705) were spread onto chromogenic agar medium. There was a statistically significant reduction in first detection time using statistical background subtraction instead of simple background subtraction (Paired t-test, *: $p<0.05$, **: $p<0.01$, ***: $p<0.001$). In terms of early detection of bacterial-derived signals, statistical background subtraction were shown to be superior to simple background subtraction.