A New Thin-Film Transistor Image Sensor for Estimation of Bacterial Colony Species on Agar Plates

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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 estimating bacterial colony species on agar plates. This system uses transmitted light, unlike conventional image analysis using reflected light.

Methods

To demonstrate the efficacy of this colony species estimation system, a lens-free imaging modality was built using the TFT image sensor consisting of a control printed circuit board, an image sensor array (542 x 872 pixels, pixel size = 80 µm) 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. The red, blue, and green LED lights are used in repeated order and the three types of transmitted lights are measured every 5 min.

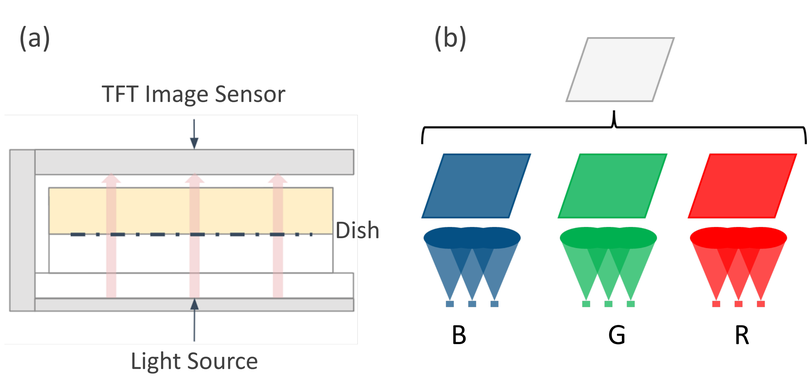

Figure 1. (a) Schematic of bacterial growth monitor using TFT image sensor. (b) Generation of pseudo-color images.

Verification of the sensor was conducted using *Enterobacter cloacae*, *Escherichia coli*, and *Klebsiella pneumoniae* spread on CHROMagar mSuper CARBA agar medium. Images of bacterial colonies cultured on agar plates were automatically collected at 5 min intervals. Triplicate experiments were conducted on each of the bacteria.

Results

Histogram Comparison (Rule-Based Algorithm)

Pseudo-color images were generated by correcting the intensity irradiated by red, blue, and green lights, with scaling factors to closely match human perception, and used for the following estimation.

Colony images were produced by removing the background and extracting only the bacterial regions. The color of the three bacteria was found to be significantly different when the intensity of the green channel was increased by 55-80 on a scale of 0-255 from the original image. The area of the bacteria in this range was extracted and cropped from the center of gravity to the extracted area.

The correct data set was created in advance using the above method with known bacteria. The HSV histograms of the query data and the correct data were compared, and the labels of the correct data with the highest similarity (correlation coefficient) were used as inferred labels for the test data.

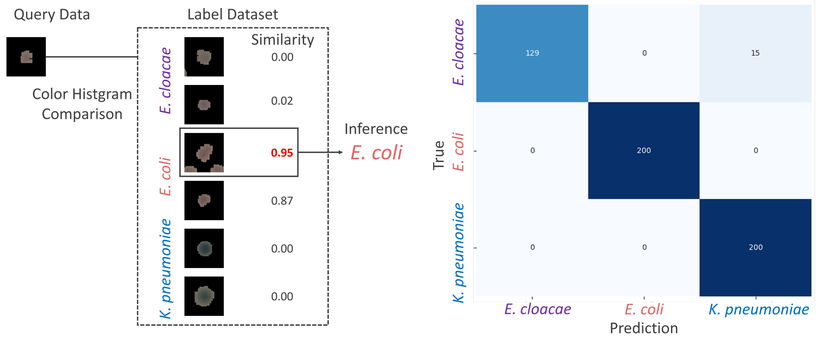

Figure 2. Schematic and the confusion matrix of the rule-based algorithm.

Table 1. The results using the rule-based algorithm.

Species	Precision	Recall	F1 score	Support
E.cloacae	1.00	0.90	0.95	144
E.coli	0.91	0.93	0.92	200
K.pneumoniae	0.91	0.93	0.92	200
Accuracy	—	—	—	0.97

Table Data (Machine Learning)

The pixel values and their frequencies for each channel of both RGB and HSV images were calculated and used as features of the table of data. Bacterial species estimation was performed using a Random Forest classifier based on these features.

Table 2. The results using Table Data.

Species	Precision	Recall	F1 score	Support
E.cloacae	0.88	1.00	0.94	300
E.coli	1.00	1.00	1.00	300
K.pneumoniae	1.00	0.83	0.91	225
Accuracy	—	—	—	0.96

Histogram Graph Image (Image Classification)

The pixel values and their frequencies were calculated for each channel of HSV images, and histogram images were generated for each channel, and then merged into 3-channel images as color images. Using these color images, an image classification model was created and species estimation was performed.

Table 3. The results using Histogram Graph Image.

Species	Precision	Recall	F1 score	Support
E.cloacae	1.00	0.91	0.95	300
E.coli	1.00	1.00	1.00	300
K.pneumoniae	0.89	1.00	0.94	225
Accuracy	—	—	—	0.97

Conclusion

We developed a bacterial species estimation method using images of bacteria obtained with a TFT sensor, which were then converted into color histogram information. We achieved high accuracy in estimating bacterial species using any of these methods. Notably, we were able to achieve equivalent accuracy using rule-based methods alone, without the need for complex techniques such as machine learning or deep learning. We will also work to conduct experiments on other media and bacterial species.