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Bacterial image analysis using multi-task deep learning approaches for clinical microscopy

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ABSTRACT

Background. Bacterial image analysis plays a vital role in various fields, providing valuable information and insights for studying bacterial structural biology, diagnosing and treating infectious diseases caused by pathogenic bacteria, discovering and developing drugs that can combat bacterial infections, *etc*. As a result, it has prompted efforts to automate bacterial image analysis tasks. By automating analysis tasks and leveraging more advanced computational techniques, such as deep learning (DL) algorithms, bacterial image analysis can contribute to rapid, more accurate, efficient, reliable, and standardised analysis, leading to enhanced understanding, diagnosis, and control of bacterial-related phenomena.

Methods. Three object detection networks of DL algorithms, namely SSD-MobileNetV2, EfficientDet, and YOLOv4, were developed to automatically detect *Escherichia coli* (*E. coli*) bacteria from microscopic images. The multi-task DL framework is developed to classify the bacteria according to their respective growth stages, which include rod-shaped cells, dividing cells, and microcolonies. Data preprocessing steps were carried out before training the object detection models, including image augmentation, image annotation, and data splitting. The performance of the DL techniques is evaluated using the quantitative assessment method based on mean average precision (mAP), precision, recall, and F1-score. The performance metrics of the models were compared and analysed. The best DL model was then selected to perform multi-task object detections in identifying rod-shaped cells, dividing cells, and microcolonies.

Results. The output of the test images generated from the three proposed DL models displayed high detection accuracy, with YOLOv4 achieving the highest confidence score range of detection and being able to create different coloured bounding boxes for different growth stages of *E. coli* bacteria. In terms of statistical analysis, among the three proposed models, YOLOv4 demonstrates superior performance, achieving the highest mAP of 98% with the highest precision, recall, and F1-score of 86%, 97%, and 91%, respectively.

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Conclusions. This study has demonstrated the effectiveness, potential, and applicability of DL approaches in multi-task bacterial image analysis, focusing on automating the detection and classification of bacteria from microscopic images. The proposed models can output images with bounding boxes surrounding each detected *E. coli* bacteria, labelled with their growth stage and confidence level of detection. All proposed object detection models have achieved promising results, with YOLOv4 outperforming the other models.

Subjects Artificial Intelligence, Computer Vision, Data Mining and Machine Learning, Neural Networks
Keywords Bacteria detection, Bacteria classification, Deep learning, Object detection, YOLOv4, EfficientDet, SSD-MobileNetV2, Microscopic images, Image analysis

INTRODUCTION

Microorganisms, including unicellular and multicellular organisms, provide vital functions in the natural environment and human existence. These microorganisms, such as bacteria, fungi, algae, viruses, and protozoa, can provide advantages. In contrast, a significant number of microorganisms can provide risks by causing various diseases, including but not limited to typhoid and cancer. On the one hand, specific microbes play an essential role in several processes, including fermentation in food production, sewage treatment, soil fertility management in agriculture, and drug formulations in medicine. Conversely, some microbes present substantial risks, giving rise to various diseases that span from commonplace infections to grave afflictions, such as acquired immunodeficiency syndrome (AIDS) and specific forms of cancer. Microorganisms are generally the species that play the most crucial role in the Earth's ecosystem. However, humans must be aware that microorganisms pose a significant threat to other organisms (*Kotwal et al., 2022*; *Zhang et al., 2021*).

Bacteria are tiny, primitive, unicellular, prokaryotic, and microscopic organisms with simple structures and without nucleus cytoskeletons, as well as membranous organelles. They range in size from less than ten micrometres (μm); therefore, they cannot be observed with the naked eye and must be studied with a microscope. Bacteria are classified into different groups based on their morphology, which refers to their shape. This classification includes spherical bacteria known as *cocci*, spiral-shaped bacteria known as *spirilla*, rod-shaped bacteria known as *bacilli*, comma-shaped bacteria referred to as *vibrio*, and corkscrew-shaped bacteria known as *spirochaetes* (*Kotwal et al., 2022*; *Mishra & Chauhan, 2016*; *van Teeseling, de Pedro & Cava, 2017*; *Wahid, Ahmed & Habib, 2018*; *Yang, Blair & Salama, 2016*).

Bacteria can be found everywhere in general; however, humans serve as ideal hosts for them (*Kotwal et al., 2022*). Every individual consists of normal flora, also referred to as nonpathogenic bacteria, within various body systems, particularly the digestive tract. These nonpathogenic bacteria protect humans from disease by competing with the nutrients pathogenic bacteria require to thrive and reproduce. Pathogenic bacteria can produce toxins that harm human tissues, act as parasites within human cells, or form colonies within the