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# TUBERCULOSIS BACTERIA DETECTION TOOL ON MICROSCOPIC IMAGES BASED ON YOU ONLY LOOK ONCE (YOLO)

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**ABSTRACT** Tuberculosis (TB) is an infectious disease caused by the bacterium *Mycobacterium tuberculosis*, which attacks the lungs and is one of the leading causes of death worldwide. This research aims to develop an automatic system for detecting tuberculosis bacteria from sputum microscopic images using the You Only Look Once (YOLO) v11 method, which is a branch of Deep Learning. The development process includes dataset collection and annotation, image preprocessing, model training, and system testing. The model is implemented using Python and OpenCV and is equipped with a Raspberry Pi 4-based GUI for easier user interaction. The detection results are visualized in the form of bounding boxes, accompanied by the number of bacteria and the severity of the infection (scanty, 1+, 2+, 3+). Based on testing 10 samples, the device successfully achieved 94% accuracy, and the system successfully reached a Precision value of 0.967 or 96.7%, Recall of 0.936 or 93.6%, mAP of 0.974 or 97.4%, and an F1 Score of 0.951 or 95.1%. These results indicate that the system is capable of effectively detecting TB bacteria with high accuracy.

**INDEX TERMS** Tuberculosis, Microscopic, YOLO, Sputum, Raspberry Pi.

## I. INTRODUCTION

Tuberculosis (TB) is an infectious disease caused by the bacterium *Mycobacterium tuberculosis* and commonly affects the lungs. According to a report by the World Health Organization (WHO), in 2022 tuberculosis caused approximately 1.30 million deaths worldwide. The number of new cases diagnosed that year reached 7.5 million people. A total of 30 high-burden TB countries account for approximately 87% of global cases, with two-thirds of cases concentrated in eight countries: India (27%), Indonesia (10%), China (7.1%), the Philippines (7.0%), Pakistan (5.7%), Nigeria (4.5%), Bangladesh (3.6%), and the Democratic Republic of Congo (3.0%). In the same year, the distribution of TB patients was 55% male, 33% female, and 12% children aged 0–14 years. According to the Global TB Report 2023, Indonesia ranks second with the highest number of TB cases after India, followed by China. It is estimated that there are 1,060,000 cases of tuberculosis with 134,000 deaths per year due to this disease in Indonesia [1].

Microscopic images are used as a visual representation to observe objects that are not visible to the naked eye, in this case, tuberculosis bacteria. These images are obtained through an enlargement process using a microscope, allowing the details of the bacteria to be clearly observed. Microscopic examination is usually performed on patient sputum samples that have undergone a special staining process, such as the Ziehl-Neelsen method. This staining technique aims to make acid-fast TB bacteria stand out with a bright red color when observed under a light microscope [2].

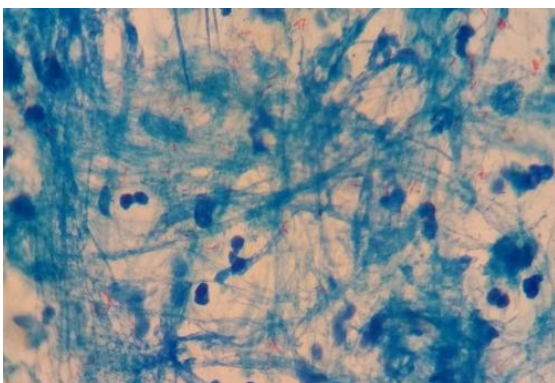
The development of information technology is driving the increased use of Machine Learning as a system capable of learning automatically without direct intervention for each use. Machine Learning is now a widely studied field and has been extensively applied in various sectors, including industry, agriculture, and education. One branch of Machine Learning is Deep Learning, which continues to be developed due to its high accuracy and processing speed, supported by advancements in high-performance computing devices and cloud computing technology [3]. Deep Learning

has a derivative object detection method called You Only Look Once (YOLO). The YOLO algorithm is designed to detect objects in real-time by reusing classifiers or locators for the detection process. YOLO architecture is based on a Convolutional Neural Network (CNN), which extracts visual features from images while simultaneously generating predictions for object position and type in a single inference step [4].

In the study titled "Performance Analysis of Pre-trained Convolutional Neural Network Models in Detecting Tuberculosis" (Ovy Rochmawanti, Fitri Utaminingrum, Fitra A. Bachtiar, 2020), the test results showed that the larger the dataset size, the higher the accuracy obtained, although the computation time also increased. The accuracy level achieved by the study is 91.57% [5]. Meanwhile, the research "Tuberculosis Disease Detection Based on X-Ray Images Using Convolutional Neural Network" (Adila Zahra Faradisa, 2021) showed that the model with VGG16 architecture was able to produce 96% accuracy, ResNet101V2 reached 93%, and the standard CNN architecture only produced 52% accuracy [6]. Furthermore, in the research "Development of a Tuberculosis Detection System on X-Ray Images Using the Convolutional Neural Network (CNN) Method with the Laravel Framework" (Aldi Akbar Alimi, Ahmad Rio Adriansyah, Pudy Prima, 2024), testing using the blackbox testing method achieved a success rate of 87.5%. The model used in that research had an accuracy of 93% on training data and 85% on test data [7].

Based on the explanation, there is a need for technological innovation that can help laboratory analysts more easily count the number of TB bacteria and provide fast and accurate diagnostic results for patients. This way, the severity of TB can be determined earlier, allowing for immediate follow-up medical action.

#### A. TUBERCULOSIS BACTERIA



**FIGURE 1.** There are TB bacteria that appear rod-shaped and red after the Ziehl-Neelsen staining process, visible under a microscope.

Tuberculosis (TB) is an infectious disease caused by the bacterium *Mycobacterium tuberculosis*. Some species of *Mycobacterium* included in this group are *M. tuberculosis*, *M. africanum*, *M. bovis*, *M. leprae*, and others, known as Acid-Fast Bacilli (AFB). Tuberculosis is transmitted thru the air (airborne disease) when an infected person releases bacterial-containing droplets while coughing, speaking, or singing. Individuals around the patient are at high risk of contracting the bacteria. Morphologically, TB bacteria have the following characteristics: a. Rod-shaped with a length of 1–10 microns and a width of 0.2–0.6 microns. b. Acid-fast in the staining process using the Ziehl-Neelsen method. Ziehl-Neelsen method (using a light microscope) [8]:

1. Negative: No bacteria were found after observing 100 fields of view.
2. 1–9 bacteria in 100 fields of view: Results are reported as an absolute number or scanty (few bacteria).
3. 10–99 bacteria in 100 fields of view: Results are reported as + or 1+.
4. 1–10 bacteria per field of view (from 50 fields of view): Results are reported as ++ or 2+.
5. >10 bacteria per field of view (from 20 fields of view): Results are reported as +++ or 3+.

#### B. MICROSCOPIC IMAGE

A microscopic image is the visual result of observation using a microscope, which functions to magnify biological objects such as tissues and cells. In detecting the bacteria that cause tuberculosis, namely *Mycobacterium tuberculosis*, microscopic images are generally obtained thru staining techniques, such as the Ziehl-Neelsen or Auramin-O methods, which help to clearly visualize the bacteria when observed under a microscope [9].

#### C. Machine learning

Machine Learning (ML) is a technology designed to enable machines to learn independently without direct instruction from their users. Its development is based on disciplines such as statistics, mathematics, and data mining, allowing machines to analyze data without needing to be reprogrammed. The term "Machine Learning" was first introduced in the 1920s by several mathematical scientists, including Adrien Marie Legendre, Thomas Bayes, and Andrey Markov, who formulated the foundation and initial concepts of Machine Learning [10].

#### D. Deep Learning

Deep Learning is one of the approaches in machine learning that allows systems to automatically understand and classify objects. This method is widely used in the field of object and image recognition, such as image recognition, face recognition, object detection, and medical image classification. Deep Learning falls

under the branch of Artificial Intelligence (AI) and utilizes layered Artificial Neural Networks (ANNs) to learn from data [11].

### E. YOLO (You Only Look Once)

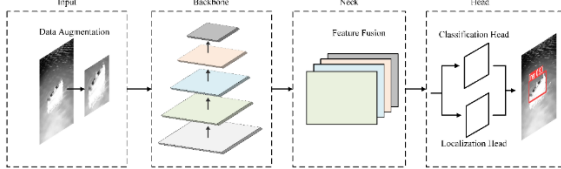


FIGURE 2. The architecture or hidden layer of YOLOv11 from the Input, Backbone, Neck, and Head processes [12].

You Only Look Once (YOLO) is an algorithm that applies artificial neural networks to learn patterns, enabling real-time object detection. YOLO is an object detection architecture based on a Convolutional Neural Network (CNN) that functions to detect defined objects and generate bounding boxes around them simultaneously. This algorithm predicts object positions and class probabilities by processing the image only once, hence the name You Only Look Once [13].

### F. Roboflow

Roboflow is a platform that plays a role in managing datasets for computer vision purposes. This platform provides a framework for developers to collect, preprocess, and train models with better data quality. During the data acquisition phase for object detection, Roboflow is used to manage relevant image datasets so they can be used effectively in both the training and testing processes [14].

### G. Google Colab

Google Colaboratory, or more commonly known as Google Colab, is a cloud-based platform that allows users to write, run, and share Python code thru a web browser. This service is intended for analysts, researchers, developers, and educators in the fields of data science and machine learning. Google Colab provides a flexible computing environment at no additional cost and supports the use of Jupyter Notebook an open source application that directly integrates code, text, and data visualizations thru a browser without requiring additional configuration [15].

### H. Python

Python is a versatile programming language that is interpreted and emphasizes code readability. It combines syntactic simplicity with extensive capabilities and comes with a large and comprehensive standard library. Python can be used for various cross-platform software development purposes and supports a wide range of operating systems [16].

### I. Visual studio code

Visual Studio Code (VSCode) is a source code editor developed by Microsoft and available for Linux, macOS, and Windows. VSCode is written in the TypeScript, JavaScript, HTML, and CSS programming languages. One of the main advantages of VSCode is its support for extensions, which allows users to add additional features such as support for specific programming languages, debugging, integration with Git, and various other productivity-enhancing tools [17].

### J. GUI (Graphical User Interface)

A Graphical User Interface (GUI) is a user interface that displays visual elements such as windows, buttons, menus, and dialogs, making it easier for users to interact with software or computer systems. GUIs are designed to replace text-based interfaces (Command-Line Interface/CLI), which are often difficult for non-technical users to operate. With a GUI, interaction becomes more intuitive because it doesn't require understanding complex text commands [18].

### K. Raspberry Pi

The Raspberry Pi is a credit card-sized mini-computer built on a single circuit board. Despite its small size, this device is capable of running operating systems like Linux and various other software. The Raspberry Pi is equipped with input/output ports, including USB, HDMI, and GPIO (General Purpose Input/Output), making it suitable for a variety of computing applications [19].

### L. LCD HDMI Touchscreen

The LCD screen on this system is used to display the microscopic images resulting from image acquisition, as well as show the detection output in the form of bounding boxes that mark the presence of TB bacteria. This makes it easier for users to visually analyze the detection results.

## II. RESEARCH METHODS

### A. RESEARCH DESIGN

In this study, the author used experimental research, which is a research approach aimed at testing the effectiveness and performance of the developed model thru a series of trials. In this study, the You Only Look Once (YOLO) method was chosen as the appropriate deep learning approach, considering the ability of YOLO v11 to identify and analyze complex visual patterns in images.

### B. DATASET PROCESSING

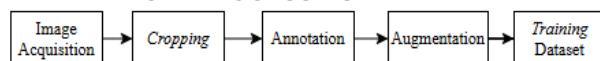


Figure 3. The block diagram for processing the dataset consists of image acquisition, cropping, annotation, augmentation, and dataset training.

In Fig. 3, to explain each process in the block diagram of dataset processing, the following is provided:

1. Image Acquisition

The process of acquiring microscopic images to detect TB bacteria begins with the preparation of a sputum smear sample from the patient. This sputum sample is first thinly smeared onto a microscope slide using the smear method to form a layer that can be observed microscopically. After drying, the object glass was fixed using heat, and then stained using the Ziehl-Neelsen method.

To obtain an optimal visual appearance, the binocular microscope used was an Olympus CX23 microscope with 100x lens magnification, used in conjunction with immersion oil to help improve image sharpness. Then the microscope will be focused and its lighting adjusted so that the bacterial image appears clear and not blurry.

2. Cropping

The selected portion was then cropped from the full 3060 x 4080 pixel image, resulting in a smaller image of 640 x 480 pixels that still contained the part with the tuberculosis bacteria object. This pixel size of 640 x 480 is a predetermined size on the Roboflow platform to ensure that the image data has the same dimensions.

3. Annotation

Annotation is the process of labeling or boxing objects containing tuberculosis bacteria to mark their presence so that they can be recognized by the model later. This annotation process is done on the Roboflow platform.

4. Augmentation

After the annotation process is complete, the augmentation process is still carried out on the Roboflow platform. The augmentation process is the process of increasing the variety of training data without the need to acquire new images. Some types of augmentation used include rotation, horizontal and vertical flipping, brightness or contrast changes, grayscale, exposure, and noise. This process is useful because it can make the model better at recognizing objects under various lighting conditions, orientations, and image qualities. The purpose of augmentation is to improve the model's ability to generalize and prevent overfitting. Thus, a total of 11,968 datasets were obtained with a data split ratio of 70% training, 20% validation, and 10% testing, which will be used in the training process.

5. Training Dataset

This training process was carried out using Google Colab, where the training process is done automatically and the results are obtained, including the model, training and validation graphs, and metrics such as precision, recall, and mAP50. The training process in Google Colab was performed using the Yolo11n parameters with

epochs = 50 and batch = 32. This symbol n (nano) is an internal parameter of the Yolo11 model; this parameter determines the complexity and capacity of the model.

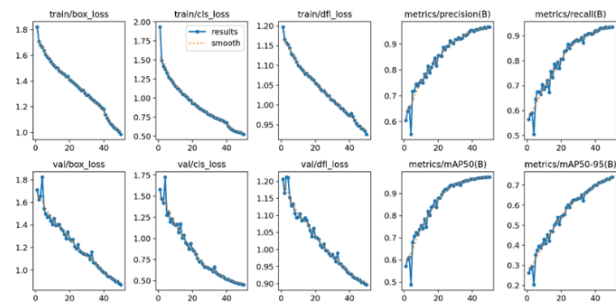


FIGURE 4. A graph of the training results in Google Colab, showing the training and validation results of the dataset.

In Fig. 4, the graph shows the results of box\_loss and cls\_loss on the training and validation datasets from the training results in Google Colab, where the closer the value is to zero, the better the model is at detection.

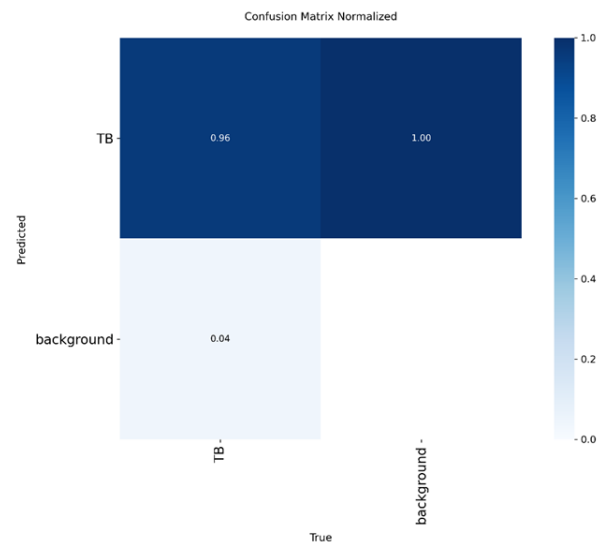


FIGURE 5. The results of the Confusion Matrix from the dataset training process with an accuracy value of 0.96 from the validation data results.

Meanwhile, Fig. 5 shows the confusion matrix results from the training dataset, with an accuracy of 0.96 or 96%, which is considered very good for detecting TB bacteria, although there is still some background noise, meaning the model misclassifies negative backgrounds as positive.

C. TOOL DESIGN

At the design stage, this tool uses the Oneshape platform to create an initial sketch for a tool design suitable for placement with appropriate dimensions and ports for the LCD and Raspberry Pi used.

Fig. 6 shows the front view design of the device for the LCD screen. Fig. 7 shows the back view design

of the device, which also includes the ports for the LCD screen and Raspberry Pi.

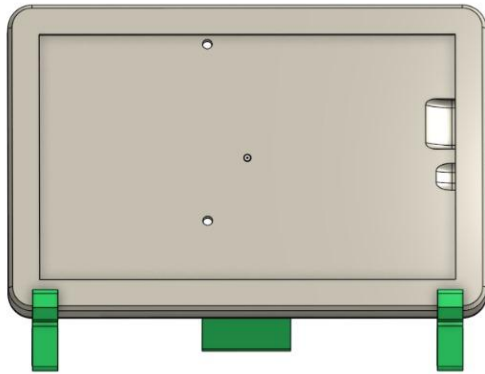


FIGURE 6. The front view of the device, with the front being the location for the LCD HDMI Touchscreen as the user interface display.

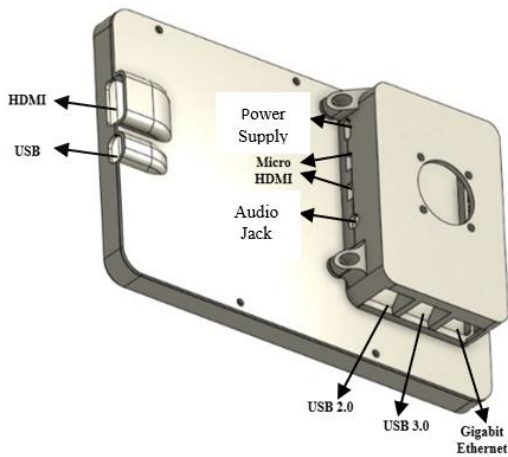


FIGURE 7. The back view of the device showing the ports for connecting the Raspberry Pi connection cables to the LCD.

D. GUI APPEARANCE

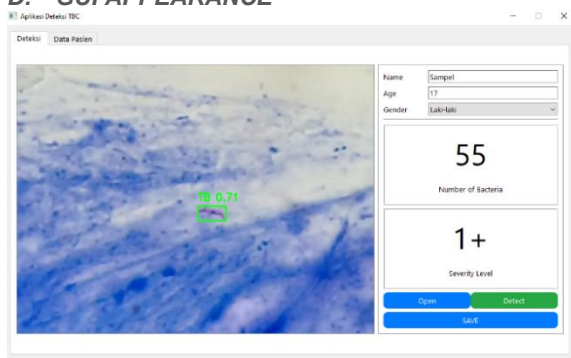


Figure 8. User interface display with applications appearing on the instrument monitor screen.

On the right side of Fig. 8, there are fields for name, age, and gender that can be filled in with personal information. There are also boxes providing information about the number of bacteria and severity level, an "open" button to open the folder containing microscopic images, a "detect" button to start the

detection process, and a "save" button to save the results after the detection process is complete. The saved files can be viewed in the patient data folder on the top left.

E. FLOWCHART

This flowchart explains the process of how the system performs the steps in determining the severity level, from the initial image upload process to the application being able to display the results of the uploaded image. This flowchart is used in the application system.

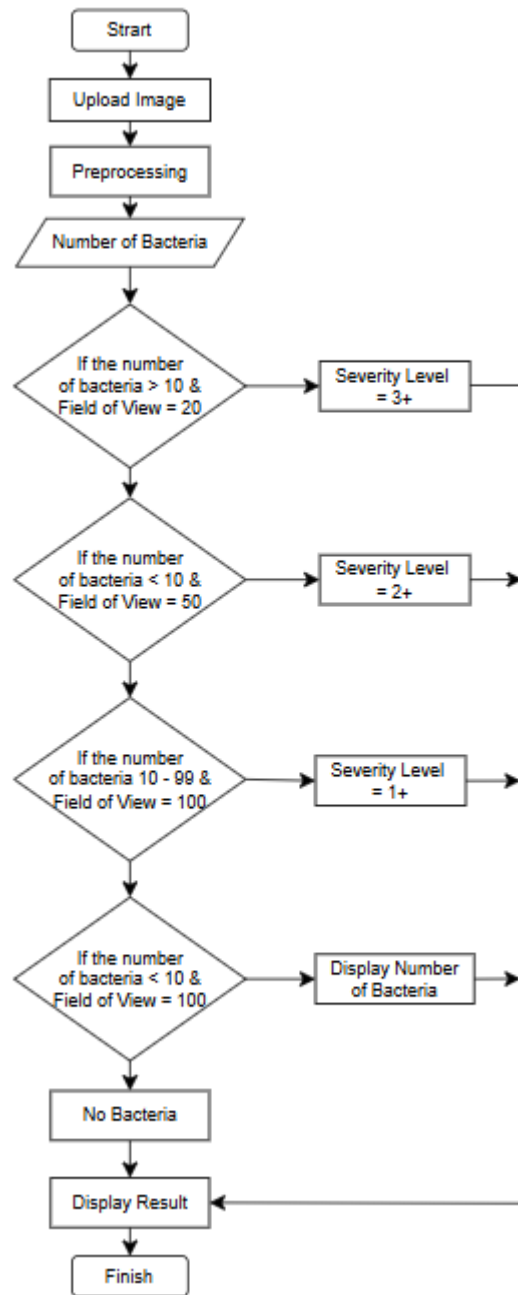


FIGURE 9. Flowchart from the initial process to how to determine the severity level of a large number of visual fields and bacteria detected.

To explain the flowchart in Fig. 9, the process begins with an initial step indicating the start of the process for detecting TB bacteria. Then, Upload Image allows the user to upload microscopic image files for analysis. The next step is Preprocessing, where the uploaded image data is processed first. After that, the system will begin counting the number of bacteria in the processed image. The branching in the flowchart divides each severity level category based on the number of bacteria and the field of view. Then, the system displays the final results, which are the number of bacteria and/or the severity level, according to the analysis performed. Then the analysis process is complete.

**F. DATA ANALYSIS TECHNIQUES**

		Predicted class	
		P	N
Actual Class	P	True Positives (TP)	False Negatives (FN)
	N	False Positives (FP)	True Negatives (TN)

**FIGURE 10.** A confusion matrix is a technique in data analysis that uses TP, TN, FP, and FN [20].

In Fig. 10, the explanation of the confusion matrix consists of [20]:

1. True Positive (TP): The number of data points that are actually positive and successfully predicted as positive by the model.
2. True Negative (TN): The number of data points that are actually negative and successfully predicted as negative by the model.
3. False Positive (FP): The number of data points that are actually negative but are predicted as positive by the model.
4. False Negative (FN): The number of data points that are actually positive but are predicted as negative by the model.

$$Accuracy = \frac{\text{bacteria detected by the device}}{\text{actual number of bacteria}} \times 100\% \quad (1)$$

$$Precision = \frac{TP}{TP+FP} \quad (2)$$

$$Recall = \frac{TP}{TP+FN} \quad (3)$$

$$F1 \text{ Score} = 2 \times \frac{Precision \times Recall}{Precision + Recall} \quad (4)$$

**III. RESULTS AND DISCUSSION**

**A. PHYSICAL APPEARANCE OF THE TOOL**



**FIGURE 11.** Front view of the finished device, already equipped with a monitor or LCD screen.

Fig. 11 is a view of the front physical appearance of the device, which is ready to use and already displays the initial initialization screen in the application.

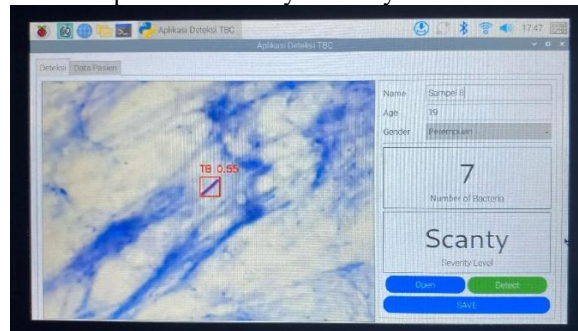


**FIGURE 12.** Rear view of the finished device, already equipped with a Raspberry Pi.

Fig. 12 is the physical view of the back of the device, which already contains the Raspberry Pi and the ports that will eventually be connected to the HDMI touchscreen LCD and the adapter for voltage supply.

**B. METODE PENGUJIAN**

**1. Samples with "Scanty" severity level**



**Figure 13.** Data collection testing method for TB cases with "scanty" results

In Fig. 13, testing with a "Scanty" severity level yielded a bacterial count of 7, which means that if there are 1-9 TB bacteria in 100 sample uploads or 100 fields of view.

2. Samples with "1+" severity level

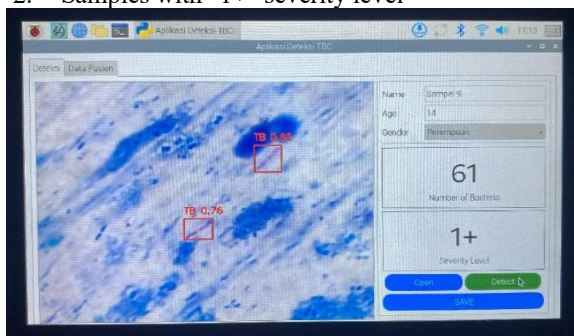


Figure 14. Data collection testing method for TB cases with "1+" results

In Fig. 14, testing with a "1+" severity level yielded a bacterial count of 61, which means that if there are 10-99 TB bacteria in 100 sample uploads or 100 fields of view.

3. Samples with "2+" severity level

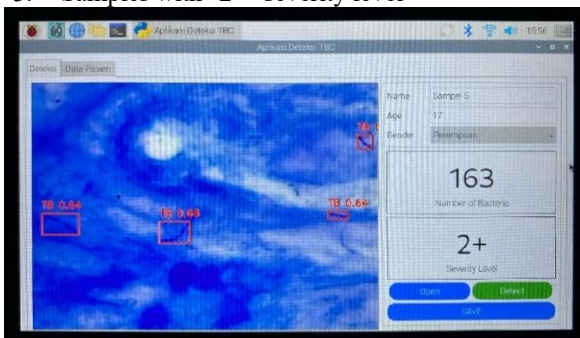


Figure 15. Data collection testing method for TB cases with "2+" results

In Fig. 15, testing with a "2+" severity level yielded a bacterial count of 163, which means that if there are 1-10 TB bacteria in 1 field of view and 50 sample uploads or 50 fields of view.

4. Samples with "3+" severity level

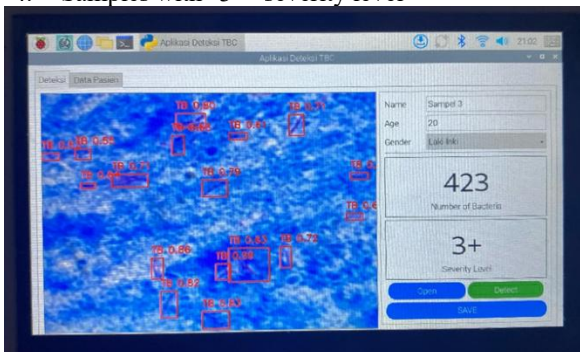


Figure 16. Data collection testing method for TB cases with "3+" results.

In Fig. 16, testing with a "3+" severity level yielded a bacterial count of 423, which means that if there are >10

TB bacteria in 1 field of view and 20 sample uploads or 20 fields of view.

C. TEST RESULTS DATA

After completing the training and validation process, the evaluation of the system's performance in detecting tuberculosis (TB) bacteria was carried out using 10 test samples with varying severity levels. The assessment was conducted by comparing the results from laboratory experts or analysts with those obtained using the developed tool. The outcomes of the tool's testing are presented in Table I, including the comparison of bacterial counts, severity levels, and accuracy.

TABLE I  
CALCULATION OF BACTERIAL COUNT, SEVERITY LEVEL, AND ACCURACY

Sample	Calculation Results			
	Bacteria detected by the device	Actual number of bacteria	Severity Level	Accuracy (%)
1	72	72	1+	100%
2	571	680	3+	84%
3	423	520	3+	81%
4	238	284	2+	84%
5	158	183	2+	86%
6	8	8	Scanty	100%
7	54	54	1+	100%
8	7	7	Scanty	100%
9	61	61	1+	100%
10	87	87	1+	100%
Total	1679	1956	-	94%

From testing with 10 samples, there were 2 samples with a scanty severity level, 4 samples with a severity level of 1+, 2 samples with a severity level of 2+, and 2 samples with a severity level of 3+. The accuracy for each sample was not 100% because of factors such as overlapping bacteria, which could make it difficult for the model to distinguish object boundaries.

IV. CONCLUSION.

Based on the test results and analysis conducted in this study, it can be concluded that the system successfully and effectively implemented the You Only Look Once (YOLO) v11 method architecture for identifying

tuberculosis bacteria in microscopic images. Thus, the accuracy rate of the device was found to be 94%, while the accuracy of the YOLO v11 architecture for architecture was 0.967 or 96.7% for Precision, 0.936 or 93.6% for Recall, 0.974 or 97.4% for mAP, and 0.951 or 95.1% for F1 Score. From this process, a system can be formed that is capable of detecting the presence of bacteria and also counting the number of bacteria detected in each microscopic image. Thus, it can be used as a basis for predicting severity levels such as negative, scanty, 1+, 2+, 3+. The system integration utilizes various supporting libraries like OpenCV for image processing in training the YOLO model, resulting in an interface and detection function that operate automatically and efficiently.

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