Saturation channel extraction of HSV color space for segmenting Plasmodium parasite

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Abstract. Malaria is one of the dangerous diseases in the world. Despite it has been decreased every year, the number of patients for this disease is still reasonably a lot. Technical problems that arise in the malaria cases are due to malaria examination and diagnosis analysis, which are carried out manually. At the same time, there are still medical personnel scarcities in some rural areas including of some districts in Indonesia. Moreover, the required examination process demands accuracy and takes a long time. Thus, an effective solution is necessary to help parasitologist to reduce malaria cases. One of the alternative ways to solve those problems is by utilizing technology to assist medical personnel in conducting examinations and analyzing the diagnosis results. This research was conducted to reach this objective. In achieving this objective, an image segmentation approach for finding the Plasmodium parasites was developed. The proposed approach consisted of four stages, which are the pre-processing stage, the segmentation stage, the refinement of segmentation results stage, and the evaluation stage. This proposed method was performed on 25 digital microscopy images of the thin blood smear digital microscopic images. The experiment yielded a good performance with the accuracy, sensitivity, and specificity of 99.83%, 85.06%, and 99.90%, respectively. These results indicate that the proposed method has an outstanding performance in segmenting Plasmodium parasite and can be utilized as a preliminary project to assist doctors in examining or identifying the Plasmodium parasites location.

1. Introduction
Malaria is one of the leading causes of death in the world, where almost every year in some regions, there is an increase in the number of cases. In 2018, there were 282 million malaria cases worldwide, with 405,000 deaths [1][2]. In Indonesia, malaria is also one of the diseases with the highest number of patients. Based on data submitted by the Ministry of Health of the Republic of Indonesia through the Director of the Prevention and Control of Vector and Zoonotic Infectious Diseases of the Ministry of Health of the Republic of Indonesia in the mid-of 2019, malaria cases in Indonesia have decreased from 2017 to 2018. In 2017, there were 261,000 malaria cases, and in 2018 the number decreased to 220,000 cases. Those malaria infections occurred in 229 districts. Despite the decline, this number was relatively high that required special attention to be handled intensively [3].

The malaria examination process is carried out using a patient's blood sample, which is placed in a slide, then it is observed using a microscope. The utilized blood samples consist of two types of blood smear, i.e., thick and thin blood smear. Thick blood smear is used for an initial screening process, while thin blood smear is used to identify the species and stage or life-cycle of the Plasmodium parasite. Both
the screening and the identification process are carried out manually, so it requires time and thoroughness to avoid misdiagnosis. Hence, there is a need for an alternative solution that can be utilized to assist doctors both in the screening or identification processes so that the diagnosis analysis process can be carried out more quickly and accurately [4].

One alternative solution that can be applied is by utilizing technology for both the screening and identification processes to support and assist the doctors in administering diagnosis analysis. Currently, technology has developed rapidly in various fields, including medical field. Many studies have conducted investigations and experiments related to this topic. The technology utilization in the malaria case itself has developed rapidly. One utilization form that has been accomplished is by applying an image processing technique to detect Plasmodium parasite [4][5].

Image processing technique applications to detect Plasmodium have been carried out by several researchers [6]–[13]. In real cases, these studies significantly assist the screening process carried out by doctors. However, it is not qualified to be applied in a malaria diagnosis determining process, i.e., the stage or life-cycle identification process. Therefore, these studies need to be continued. One very important and helpful stage in the identification process is the segmentation process. The segmentation process is an initial stage of the Plasmodium parasite identification process before a patient's diagnosis is made. Hence, this process needs to be carefully carried out in order not to bias the diagnosis results [5].

Several segmentation methods can be used, such as histogram thresholding, edge detection, region-based segmentation, and other ways. Several methods have been tried with each of the different methods for detecting this Plasmodium, such as Edy et al. [14] with channel color space segmentation, Hanung et al. [15] with saturation channels on HSV staining, Suchada et al. [16] with Fuzzy Inference System, Hanif et al. [17] with dark stretching technique, and Madhumala et al. [18] with modified fuzzy divergence. Similar to the previous studies, this study aims to develop a segmentation method in digital microscopy images in order to conduct segmentation of Plasmodium parasite. What makes this study different from the previous studies is that this study utilized raw data from digital microscopy images instead of using cropped data (patch) from the detection process as carried out by previous studies [15] and [19].

2. Data and Methodology

2.1 Data

![Figure 1. Dataset examples: (a) original image and (b) ground truth of the image (a).](image)

The utilized data were image datasets of 25 infected red blood cells. These datasets are thin blood smear digital microscopic images. The data were taken from the Department of Parasitology, Faculty of Medicine, Public Health and Nursing Universitas Gadjah Mada and Eijkman Institute for Molecular Biology using OptiLab microscope camera with camera resolution of 5MP and microscope magnification of 100x. The image size was 1280 x 960 pixels in RGB format. The data was
complemented with segmentation ground truth created by doctors/medical personnel. Examples of data and ground truth can be seen in Figure 1.

2.2 Methodology
This study aims to develop a method to perform segmentation on Plasmodium parasite objects using image processing approach. To reach this objective, this study proposed a method consisting of four main processes, as illustrated in Figure 2. The four processes are pre-processing, segmentation, improvement of segmentation results, and evaluation processes. Each stage/process had its own role in producing the best segmentation results. The details of those processes are described in the following sub-chapters.

![Figure 2. Research block diagram.](image)

2.2.1 Pre-processing
A pre-processing stage is a stage that served to acquire the data and improve its quality, considering the data utilized in this research was medical data that had very sensitive characteristics with lots of noise and artifacts. In one image, there were several objects with almost similar characteristics. Some of these objects included Plasmodium parasites, red blood cells, background, white blood cells, and other objects. Because these objects had almost similar characteristics, this made the segmentation process more challenging to do.

Therefore, it was necessary to process data acquisition to sharpen the Plasmodium parasite characteristics in order to support the segmentation process. In achieving that objective, this research implemented color transformation methods. The color transformation process was carried out from RGB color space to HSV. After the process of color transformation into HSV color space was carried out, the saturation channel was taken to be used as an input image in the next process. The saturation channel was selected because the channel showed the Plasmodium parasite characteristics more clearly and distinctly.

2.2.2 Segmentation step
A segmentation stage is a process that aims to separate the background with the object. However, in this study, there were three parts that must be separated. The three parts were background, red blood cells, and Plasmodium parasites. It was carried out because it adjusted the shapes and characteristics of the digital image of utilized thin blood smear. Based on the HSV color channel extraction result, the saturation channel was capable of showing differences between those three parts well. From extraction results, the Plasmodium parasite object had a brighter color, red blood cells had a slightly darker color, and the background had dark characteristics. In separating those three sections, this study employed a Multi-Otsu's thresholding method [20].

The Otsu's thresholding would calculate the threshold value by measuring the image's grayscale distribution. A calculation iteration was carried out so that a possible threshold value was obtained. The minimum value of intra-class variance was obtained when the distribution amount in each class was a minimum value of each threshold [21]. A pixel distribution of the utilized data can be seen in Figure 3.
After obtaining the threshold value corresponding to the data, a segmentation process was carried out by applying those values to the image. Results of Multi Otsu's thresholding were then utilized as input for the thresholding process. This process was a stage to convert the image into a logical value with white-colored Plasmodium was worth 1, and the background was worth 0.

2.2.3 Segmentation results improvement stage
This stage aims to improve the segmentation results. It was conducted since the segmentation results still contained unwanted objects that could damage the segmentation performance. Thus, a morphological operation was applied in this study to improve the segmentation results. An opening area operation was used to remove segmented objects other than Plasmodium. The object with an area under the utilized parameters would be removed through this area-opening process [22]. From the ground truth analysis, the obtained Plasmodium area was between 3000 to 5000 px. Objects that were outside these values were removed. After that, the closing operation was carried out. This operation was used to connect the adjacent pixels appropriate to the structuring element size [22]. As a result, segmentation results would be finer.

2.2.4 Evaluation stage
To evaluate this method's performance, obtained results of segmentation and the ground were compared. There were three evaluation methods employed, i.e., accuracy, sensitivity, and specificity. The accuracy was used to calculate the chance of correctness of these results to detect which one was the Plasmodium and which one was not. The sensitivity was the chance that this method could detect the Plasmodium well. The specificity was the chance that this method was able to detect non-Plasmodium objects. Formulas for each parameter are written in equations (1-3) [15][19].

\[
\begin{align*}
    \text{accuracy} &= \frac{TP + TN}{TP + FP + FN + TN} \\
    \text{sensitivity} &= \frac{TP + FN}{TP} \\
    \text{specificity} &= \frac{TN}{FN + TN}
\end{align*}
\]

3. Results and Analysis
Figure 4 shows the application of the method, as explained in the previous sub-chapters. The figure illustrates the results of each stage in the segmentation process proposed in this study. Figure 4(a) is the original image processed in the method. Figure 4(b) is a saturation channel image which shows that characteristics of the Plasmodium parasite are sharper and more distinct in this channel. Figure 4(c) is an image of multi Otsu's thresholding application results. The image shows that multi Otsu's thresholding method is able to separate the background, red blood, and Plasmodium parasites. Figure
4(d) shows the thresholding results. In the picture, there are still many unwanted objects that are segmented. Therefore, a morphological operation was applied to improve the unwanted objects. The results of the morphological operation can be seen in Figure 4(e). Figure 4(e) shows the clean segmentation result. When compared with the ground truth in Figure 4(f), the two are similar.

Figure 4. Results of proposed method application: (a) original image, (b) saturation channel image, (c) multi Otsu's thresholding application result, (d) thresholding result, (e) morphological operation application result, and (f) ground truth data.

Subsequently, the result of segmentation depicted in Figure 4(e) was evaluated by comparing it with the ground truth image in Figure 4(f). The evaluation process was carried out by calculating the accuracy, sensitivity, and specificity. The results of those three parameters obtained the accuracy, sensitivity, and specificity of 99.83%, 85.06%, and 99.90%, respectively. This study also compared the segmentation performance result with previous studies. The comparison result is illustrated in the Table 1. The methods comparison shown in Table 1 indicates that the proposed method has a better performance compared to the previous two studies.
Table 1. Results of methods comparison.

| Study                    | Camera Resolution | Microscope Magnification | Accuracy (%) | Sensitivity (%) | Specificity (%) |
|--------------------------|-------------------|--------------------------|--------------|-----------------|-----------------|
| [15]                     | 5MP               | 100x                     | 97.99        | 82.23           | 99.33           |
| [19]                     | 5MP               | 100x                     | 96.74        | 76.77           | 99.74           |
| The proposed study       | 5MP               | 100x                     | 99.83        | 85.06           | 99.90           |

4. Conclusion
This research aims to carry out Plasmodium segmentation automatically. The proposed method comprised of four steps which are preparing image by taking the saturation channel, segmenting using multilevel Otsu’s thresholding, then conducting thresholding and morphological operation to refine the image. The obtained accuracy, sensitivity, and specificity are 99.85%, 85.06%, and 99.90%, respectively. From the obtained results, the segmentation results have quite a great false-negative value on the pixels around Plasmodium, causing a relatively low specificity. Nevertheless, this method is able to detect Plasmodium well on 25 data sets so that it can be used by pathologists as an alternative to detect the presence of Plasmodium.

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