Summary

Malaria is a blood-borne disease and a major cause of mortality in many parts of the world. Malaria is curable if diagnosed in time. Malaria can be diagnosed by microscopy analysis. Automatic malaria diagnosis has the potential to play an important role in reducing mortality due to malaria. The term parasitemia is used to reflect the severity of the malaria disease. This thesis aims to develop computer methods for automatic malaria diagnosis and parasitemia estimation.

According to the literature on biomedical image processing and an understanding of blood and malaria, colour intensity is a strong indicator for malaria parasite identification. In addition, natural characteristics of malaria, such as size, shape and appearance of parasites, and blood components are also considered to play an important role in malaria identification and parasitemia estimation. However, the role of these natural characteristics in automatic malaria diagnosis is unknown and the contribution of automatic estimation of malaria parasiatemia has received relatively little attention.

The focus of this thesis is to include the natural characteristics of blood components and malaria parasites in automatic malaria diagnosis and parasitemia estimation based on microscopy images. Parasitemia can be described as the number of malaria parasites in one microlitre (μl) of blood fluid. The location and the colour of malaria parasites in blood are known to characterize infected erythrocytes in visual images. In addition, the maximum parasitemia suffered in the human body has been clinically determined. Biologically, the composition and size of blood components have been also recognized. The role of these natural characteristics is to transform the knowledge of microscopy malaria diagnosis to automatic malaria diagnosis and parasitemia estimation.

A number of experiments were conducted to determine the best parasitemia estimation based on erythrocyte classification in thin blood film images and parasite classification in thick blood film images. This study made use of the natural characteristics of blood components and malaria parasites to set adaptive thresholds for segmenting leukocytes and parasites. Colour intensity and location features of leukocytes, erythrocytes, and parasites were extracted and measured. Discriminant

analysis was used to classify the leukocyte footprints as leukocytes or phagocytes, the parasite footprints as parasites or non-parasites, and identify erythrocyte footprints as normal or infected. Classification performance was evaluated by informal readers using confusion matrices. Subsequently, the percentage of infected erythrocytes in thin blood films and the number of parasites and leukocytes in thick blood films were converted to estimate parasitemia scores. Parasitemia estimation was validated by parasitemia scores from expert readers.

Results indicate that the parasitemia estimation fitted well with parasitemia scores from expert readers both in thin blood films ($r = 0.97$, p-value = 0.54) and thick blood films ($r = 0.79$, p-value = 0.40), at $\alpha = 0.05$ level. In thin blood films, the performance of erythrocyte classification based on the combination of the colour intensity features of parasites and location features perfomed better than that based on the only grayscale intensity features of erythrocytes. Meanwhile, morphological features may not be optimal for an automatic parasitemia estimation in thick blood films.

In addition, a number of discoveries were made in the course of the study. The combination of the natural characteristics of blood components and malaria parasites is an essential feature to set an adaptive threshold for segmenting parasites in thin blood film images. Based on the fact that thrombocytes are naturally located outside of erythrocytes, this location feature is another essential feature to distinguish infected erythrocytes from thrombocytes in thin blood film images. In other words, better erythrocyte identification and parasitemia estimation were obtained by involving the natural characteristics of blood components and malaria in the parasite segmentation and erythrocyte identification in thin blood film images. In thick blood film analysis, the presence of leukocytes is vital for estimating parasitemia scores with leukocytes generally having the highest intensity in inverse thick blood film images. Accordingly, leukocyte intensity may be well utilized as a reference in setting adaptive thresholds for leukocyte and parasite segmentation.

These discoveries have potential contributions to the fields of automatic malaria diagnosis and parasitemia estimation based on both thin and thick blood film images, and so form natural seeds for future work.