Chapter 9

Conclusion and Future Directions

This chapter presents the outcome of the study undertaken in this thesis to investigate bacterial cell image analysis using digital image processing techniques and concludes with a number of possible avenues for future research being identified.

9.1 Conclusions

The thesis deals with the studies relating to the analysis of images of various bacterial cells, for Gram-staining characterization, identification, classification and cell growth phase analysis and cell division time determination. Several segmentation techniques, namely, color segmentation, edge-based segmentation, thresholding and active contour segmentations, have been used. The geometric features for cell regions are extracted. Different classification techniques, namely, $3\sigma$, K-NN, Neural Network, fuzzy and neuro-fuzzy classifiers, are used for automatic Gram-characterization, identification and classification of bacterial cells images, which assists the microbiologists for faster, proper diagnosis and treatment of the various diseases. The extensive experimentation has been done to demonstrate the effectiveness of the methods.

The main significant research contributions that fulfill the objectives set in the present thesis are:

(i) Automatic Gram-staining characterization of bacterial cell

(ii) Automatic identification and classification of bacterial cells and their subgroups, namely:

- Bacilli
  - bacilli, diplobacilli and streptobacilli
• Cocci
  - coci, diplococci, streptococci, tetrad, Sarcinae and staphylococci

• Spiral
  - vibrio, Spirillium and spirochete

(iii) Automatic cell growth phase and cell division time determination for individual cell.

These research contributions are expected to be useful for the design and development of software tools to support biologists and clinicians in their analysis procedures and for implementing the same in automated diagnostic systems. The aspects of bacterial cell growth phase and cell division time determination is useful for automatic drug susceptibility tests conducted during drug design for effective control of disease caused by the bacteria. Also, the efforts have been made to bundle the proposed algorithms into a GUI application software package for Gram-staining characterization, bacterial classifications and sub-classifications, cell growth phase analysis and cell division time determination. The details of this GUI application package are given in the Appendix-IV.

9.2 Future directions

The development of computer vision systems for a fully automatic identification and classification of overlapping bacterial cells in digital microscopic images is a challenging task. The research work reported in this thesis points to several future directions in which research work can progress. They are:

- The building up of suitable effective feature space library as knowledge base for various microscopic bacterial cell images.
- The design of efficient feature extraction algorithms, which are computationally inexpensive and yet yield good classification results.
- The design of efficient and intelligent computer vision systems which accept video streaming images from microscope and output quantitative and qualitative results.

It is envisaged that the research in this direction eventually leads to the design and production of efficient intelligent computer vision systems for assisting the microbiologists and pathologists in their task of speedy accurate diagnosis of diseases and prescribing appropriate treatment of the patients.