CHAPTER 6 CONCLUSION

6.1 Introduction

The aim of this dissertation was to describe the design, implementation and evaluation of a new method for inferring lane level road information from vehicle GPS trajectory data. This research made several new contributions to science. The aim of this chapter is to present these contributions as well as to highlight the directions for future research in this area. In addition, major challenges faced during the course of the research are also outlined.

6.2 Contributions

During the course of the literature analysis, it was seen that initial work on using GPS data for map generation and improvement has basically focused on the generation and improvement of the road centerline. Even the few attempts that have tried to generate a lane level map use DGPS or improved GPS traces rather than ordinary GPS traces. Our contribution is a novel approach that has following features not found in previous work:

- uses ordinary GPS data
- does not use prior assumptions on the lane width and lane parallelism
- can accommodate varying road width
- works well in different lane geometries such as lane splits and merges
- estimates the probability density function of the trajectories across the road using a completely non-parametric approach.

It is worth to highlighting the following contributions made by this research:

- **A comparative analysis of the existing techniques used for vehicle GPS trajectory based map generation and refinement.**

  Chapter 2 presented a comprehensive analysis of existing approaches to GPS trajectory based map generation and refinement outlining their methods, strengths, limitations and results. It also discussed the trends and directions for future research. This analysis is very useful for future research in this area.

- **A comparative analysis of the evaluation methods used by existing methods of vehicle GPS trajectory based map generation and refinement.**

  One important aspect of GPS trajectory based map generation and refinement is the evaluation: the generated map has to be evaluated against a ground truth. This kind of an evaluation is challenging due to the unavailability of a ground truth and due to the nature of data involved. This analysis not only helps designing evaluation criteria for this kind of research, but also indicates directions for future research on evaluation techniques itself.

- **A method for removing outliers in trajectories constrained by the road network.**

  GPS measurements are subjected to different types of errors. Therefore, the trajectories may not represent the real driving path of the vehicle. In certain cases, it can deviate considerably from the true path. These trajectory outliers definitely affect the lane location calculation criteria. Therefore, a new method was developed to remove outliers present in trajectories constrained by the road network.

- **A comprehensive comparative evaluation of popular kernel functions and kernel bandwidth calculation methods.**

  The proposed approach for calculation of lane centers involves estimation of the probability density function of trajectories across the road using the non parametric Kernel Density Estimation (KDE) technique. It requires two parameters, kernel function and the bandwidth. The value used for the bandwidth is crucial in generating the correct probability density function that reveals the true underlying structure. Therefore, a detailed comparative evaluation of the popular bandwidth selection methods was done to select a suitable method for the dataset. This kind of an evaluation, which involves spatial data, is not available in literature to the best of our knowledge.

- **A method for calculating lane centers and lane width of a road segment from vehicle GPS traces.**

  A novel method for calculating the lane centers of a given road segment was developed. Existing methods for calculating lane centers either use highly accurate GPS data such as DGPS data or make stringent assumptions on the geometry of lanes such as constant lane width and lane parallism. Our method which uses ordinary GPS data is completely independent of the lane/ road width and does not assume lane parallelism. Furthermore, it has been tested in different road geometries such as straight road parts, bended parts and parts that contain lane splits.

- **A method for calculating lane boundaries and lane width from vehicle GPS traces.**

  A new method for finding the locations of lane boundaries based on the probability density function of trajectories across the road was also introduced. However, it was seen that this method need further enhancements and evaluation.

6.3 Challenges

The main challenge in this research was to develop a robust evaluation criterion. In order to properly evaluate the proposed method for the calculating the lane centers, an accurate lane level map of the road is required. Currently, such maps are not available. Otherwise, a lane level map should be created using a highly accurate DGPS system specifically for this purpose. In our case, both the possibilities were unpractical. Therefore, a simple twofold method was used. First, the proportion of instances in which the number of lanes in the learned map differs from the actual number of lanes (lane error) was examined against the number of traces available. Second, the generated lane centerlines were overlaid on Google and visually compared with the satellite image.

6.4 Directions for Future Research

Some interesting areas of future research has become apparent during the course of this research. In this section these promising areas are briefly outlined as follows:

- **Extend the method for the calculation of lane centers to junctions and roundabouts.**

  The lane geometry is complex at junctions and roundabouts. However, existing research suggests that using GPS data to model these complex geometries is technically feasible. One possible approach would be to study the possibility of using concept of Principle Curves for this purpose.

- **Use of two dimensional (2-D) Kernel Density Estimation for calculating lane centers and comparing with the one dimensional approach (1-D) proposed in this research.**

  This research considered the two dimensions separately. However, 2-D KDE could also be used to generate the probability density function of trajectories across the road. Investigating how this could be done and comparative evaluation with the 1-D approach is also worth considering.

- **Evaluation of the proposed method using a highly accurate lane level map.**

  As already discussed in Section 6.3, a proper evaluation of the proposed method for the calculation of lane centers could only be done using a highly accurate lane level base map. Generating such a map and conducting the evaluation could be an interesting short term research.

- **Comparative evaluation of the existing methods for lane centerline calculation using a benchmark dataset.**

  Currently, there exist a number of methods developed for lane centerline calculation. Although they use different types of GPS data (for example, DGPS, PPP-GPS, ordinary GPS) and have their own assumptions like lane parallelism, it is worth conducting a comparative evaluation of these methods with a benchmark dataset.

- **Estimate the PDF of GPS points (instead of GPS trajectories) across the road and use the same approach to find the locations of lane centers.**

  The approach proposed in this research calculates the PDF of GPS trajectories across the road and used it to find the locations of lane centers. It is also worthwhile to investigate whether the PDF of GPS points across the road could also be used to generate the same results.