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Applications of the Bounded Total Variation Denoising Method to Urban Traffic Analysis

Shanshan Tang[1] and Haijun Yu[2,*]

[1]*School of Mathematical Sciences, University of Chinese Academy of Sciences; LSEC, Institute of Computational Mathematics and Scientific/ Engineering Computing, Academy of Mathematics and Systems Science, Beijing 100190, China.*
[2]*NCMIS & LSEC, Institute of Computational Mathematics and Scientific/ Engineering Computing, Academy of Mathematics and Systems Science, Beijing 100190, China.*

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Abstract. An easily implementable noise strength estimation algorithm to analyse the urban traffic is developed. It improves the accuracy of the road velocity predictions. Using real urban traffic data from Beijing Taxi GPS system, we demonstrate the efficiency of the algorithm. It is also shown that the BV denoising method with the best noise-strength estimates significantly improves the road clustering.

AMS subject classifications: 65M10, 78A48

Key words: Urban traffic prediction, bounded variation denoising, noise estimate, cluster analysis.

1. Introduction

Transportation is a very important part of everyday life, but it can cause numerous problems. For example, many big cities like Beijing become more and more congested because of the enormous grow of private car population. Various methods have been developed in order to analyse and alleviate traffic congestion problems. The vehicle information from the Global Positioning System (GPS) turns out to be extremely valuable. GPS data are used for studying the cause and propagation of traffic jams [15, 33], finding the fastest driving routes [44], introducing clustering methods for trajectories to characterise the patterns of traffic [11,20], evaluating the volume of citywide transportation [45], predicting taxi destinations [3] and velocity forecasting [18,25]. All these studies are based on trajectories and utilise temporal, spatial or spatio-temporal characteristics. In this work, we are interested in velocity prediction. The accurate and robust forecast of the traffic velocity is the base

*Corresponding author. *Email addresses:* hyu@lsec.cc.ac.cn (H. Yu),tangshanshan@lsec.cc.ac.cn (S. Tang)

for routine planning, congestion control, analysis, etc. In practice however this is a difficult goal to accomplish because of method restrictions and the quality of the data. Urban traffic is an extremely complex system, so that very often the data collected contain noise. Noise is coming from two sources. First, the number of cars on an urban road in a short time interval is very limited. Therefore, on the corresponding road the average number of cars and the average velocity have to be considered as stochastic processes. On the other hand, measurement and processing errors — e.g. the GPS mapping errors, can be also introduced in data collection and post-processing procedures. Accordingly, there are two approaches to deal with noisy data. One is to accept the data as correct and develop new methods to improve accuracy — cf. [3, 11, 18, 20, 25]. The other consists in reducing noise in the collected data [49] and to use the denoised data in forecasting [37, 48]. Here, we prefer the latter. This is because the data that can be used for urban traffic analysis without expensive cost, are often sparse comparing to the complexity of the problem. So we have to efficiently use limited data resources rather than the noisy data directly. The second reason is that although some existing methods tolerate noise — cf. [12, 41], the real performance of networks depend on many factors and we believe that under the same conditions these methods perform better with properly denoised data. In fact, a number of neural network methods are not robust to noise [30], so that the overfitting appears. In order to prevent it, one uses early stopping, regularisation, soft weight sharing [19], denoising autoencoders [31, 32] and dropout [16, 28]. The third reason is that the use of dedicated and robust denoising algorithms, shallow neural networks and other simple models working with small amounts of data, can provide fairly good urban traffic predictions. This is preferable in real-time and online applications.

We recall that various efficient methods have been developed for image and video denoising — cf. Refs. [1,2,4,7,9,10,13,17,21,24,26,27,34,35,40,42,43,46]. Some of them, such as wavelet method [37, 47] and the compressive sensing method [39, 48, 49], are also used in traffic analysis. Although for a number of denoising applications such methods work fairly well, they are based on specific noise assumptions and bases. Here we would like to use methods without strong assumptions about noise and basis functions. Therefore, we rely on the bounded total variation (BV) denoising method from [24]. It has the edge preserving property [29], which is consistent with the sudden jump of traffic speed. Our goal is to find the reconstructed velocity in the space of functions of bounded total variation and also to estimate the noise strength in the process of denoising without numerous assumptions about the noise type. To this end we propose two methods, which satisfy the above requirements.

The rest of the paper is organised as follows. In Section 2, we review the method of BV denoising and show how to apply it to traffic data with two different ways for estimating the noise strength. In Section 3, we apply the proposed methods to Beijing urban roads with the taxi GPS system velocity data. Our concluding remarks are in Section 4.

2. BV Denoising Algorithm for Traffic Velocity Data

Let us start with a brief introduction of the BV denoising method.