Development of a map-matching algorithm for dynamic sampling rate GPS signals to determine vehicle routes on a MATSim network

Jacobus B Vosloo
044431200

A dissertation in partial fulfilment of the requirements for the degree

Master of Engineering (Industrial Engineering)

in the

Faculty of Engineering, Built Environment, and Information Technology

University of Pretoria

November 2018

Abstract

Development of a map-matching algorithm for dynamic-sampling-rate global positioning system (GPS) signals to determine vehicle routes on a MATSim network

by Jacobus Benjamin Vosloo

Supervisor	:	Prof. Johan W. Joubert
Department	:	Industrial and Systems Engineering
University	:	University of Pretoria
Degree	:	Masters of Engineering (Industrial Engineering)

The rapid development and proliferation of GPS-enabled systems and devices has led to a significant increase in the availability of transport data, more specifically GPS trajectories, that can be used in researching vehicle activities. In order to save data storage- and handling costs many vehicle tracking systems only store low-frequency trajectories for vehicles. We analyzed a number of existing methods used to map GPS trajectories to a digital road network and implemented such an algorithm in Multi-Agent Transport Simulation (MATSim), an open source collaborative simulation package for Java. The map-matching algorithm was tested on a simple grid network and a real and extensive network of the city of Cape Town, South Africa. Experimentation showed the network size has the biggest influence on algorithm execution time and that a network must be reduced to include only the links that the vehicle most likely traversed. The algorithm is not suited for trajectories with sampling rates less than 5 s as it can result in unrealistic paths chosen, but it manages to obtain accuracies of around 80% up until sampling sizes of around 50 s whereafter the accuracy decreases. Further experimentation also revealed optimal algorithm parameters for matching trajectories on the Cape Town network. The use case for the implementation was to infer basic vehicle travel information, such as route travelled and speed of travel, for municipal waste collection vehicles in the city of Cape Town, South Africa.

Keywords: MATsim, Map-Matching, GPS data Processing, GPS trajectory, road network, route inference, trajectory analysis

Acknowledgements

"For I can do everything through Christ,
who gives me strength."
— Philippians 4:13 —

I also wish to express my sincerest appreciation to:

– My supervisor at the Department of Industrial and Systems Engineering, Prof Johan W. Joubert for his mentorship, support and guidance over the last few years.

– The Technology and Human Resources in Industry (THRIP) program, for providing financial support for some of the work presented in this thesis (Grant TP14082093002).

– My wife, Jana Vosloo, for her love, encouragement, and patience.

– My family, friends for their encouragement and support during this journey.

Contents

List of figures vi

List of tables vii

Acronyms viii

1 Introduction 1
- 1.1 Defining map-matching . . . 3
- 1.2 Research design . . . 3
- 1.3 Research methodology . . . 5

2 Literature review 7
- 2.1 Map-matching methods . . . 7
  - 2.1.1 Local methods . . . 8
  - 2.1.2 Global methods . . . 9
  - 2.1.3 Multi-track methods . . . 10
- 2.2 Evaluation criteria . . . 12

3 Algorithm development 16
- 3.1 Definition . . . 16
- 3.2 Candidate preparation . . . 20
- 3.3 Spatial analysis . . . 22
- 3.4 Temporal analysis . . . 24
- 3.5 Result matching . . . 26
- 3.6 Analysing results . . . 28

4 Experimentation and results 31
- 4.1 Experiment setup . . . 31
  - 4.1.1 Analysis of existing road networks . . . 31
  - 4.1.2 Methodology for setup of experimental road network . . . 33
- 4.2 Experiment replication . . . 35
- 4.3 Network size . . . 36
  - 4.3.1 Network size increase with a fixed path . . . 36
  - 4.3.2 Network size on creation of quadtree . . . 37
  - 4.3.3 Network and path increase . . . 38
- 4.4 Number of GPS points . . . 40
  - 4.4.1 Efficiency . . . 41
  - 4.4.2 Accuracy . . . 42
  - 4.4.3 Speed analysis . . . 44
  - 4.4.4 Probability analysis . . . 44

4.5 Number of closest links . . . 45
4.5.1 Efficiency . . . 46
4.5.2 Accuracy . . . 46
4.5.3 Speed analysis . . . 47
4.5.4 Probability analysis . . . 48
4.6 Experiments on real-world road network . . . 48
4.6.1 Efficiency . . . 49
4.6.2 Accuracy . . . 51
4.6.3 Speed analysis . . . 51
4.7 Conclusion and future work . . . 53

5 Real-world data analysis **55**
5.1 Exploratory data analysis . . . 55
5.2 Map-matching on actual trajectories . . . 56
5.3 Conclusion and future work - Case Study . . . 57

Bibliography **63**

List of Figures

1.1 Example of a low-sampling GPS trajectory between Rondebosch train station and University of Cape Town Middle Campus . . . 2
1.2 Possible routes with low-sampling GPS trajectories . . . 4

2.1 Urban map-matching framework (Ying et al., 2014) . . . 11
2.2 Differences between single- and multi-track map-matching (Li et al., 2013) . 12
2.3 Example of ARR and IARR . . . 13

3.1 Edges on a road network . . . 17
3.2 MATSim network of sample data . . . 19
3.3 Search radius required when searching for candidate links . . . 21
3.4 Point projection on candidate links . . . 21
3.5 Example of candidate links . . . 23
3.6 Transmission probability example . . . 24
3.7 Temporal analysis example . . . 25
3.8 Schematic view of candidate graph $\boldsymbol{G}_T^{'}(\boldsymbol{L}_T^{'}, \boldsymbol{N}_T^{'})$ . . . 26
3.9 Candidate graph for sample data . . . 27
3.10 Analyses of example map-matching results . . . 29

4.1 Analysis of Cape Town full network road segment . . . 32
4.2 Example of simple grid network, true path and GPS trajectory . . . 33
4.3 Efficiency analysis on number of replications . . . 35
4.4 Increase in network size grid analysis . . . 36
4.5 Increase in network size efficiency analysis . . . 37
4.6 Analysis of quadtree creation duration . . . 38
4.7 Network and path increase examples . . . 39
4.8 Map-matching duration versus network size and true path increase . . . 39
4.9 200×200 grid with 50s and 100s GPS trajectory . . . 41
4.10 Efficiency analysis for number of GPS points . . . 42
4.11 Accuracy analysis of GPS period versus network size . . . 43
4.12 Examples of true path versus matched routes on simple grid network . . . 43
4.13 Speed analysis versus GPS period . . . 44
4.14 Probability versus accuracy ratio of route by length, total matched route (ARR), grouped by network size . . . 45
4.15 Map-matching duration versus number of closest links . . . 46
4.16 Accuracy versus number of closest links . . . 47
4.17 Speed analysis versus number of closest links . . . 48
4.18 Probability versus ARR, grouped by number of closest links . . . 49
4.19 GPS trajectory on portion of real-world road network . . . 50
4.20 Efficiency versus number of closest links . . . 50

4.21 Overview of GPS trajectory on entire real-world road network 51
4.22 Accuracy versus number of closest links 52
4.23 Erroneous road segments identified 52
4.24 Speed analysis versus number of closest links 53

5.1 Exploratory data analysis of waste collection vehicle trajectory data 56
5.2 inferred path (IP) of real-world data sample 57
5.3 Comparison of inferred speed versus free speed on the IP 58
5.4 Inferred speed versus free speed on inferred path 59
5.5 Analyses of abnormal inferred speeds 60

List of Tables

3.1 GPS trajectory from example data 16
3.2 GPS trajectory of example data with SA-Albers projection 18
3.3 GPS point candidate links for GPS point 2 22
3.4 Graph link spatial-temporal (ST) probability data 28
3.5 Example results analyses against true path (TP) 28

Acronyms

Al	accuracy by length, longest match
ARP	accuracy ratio of plot matched to correct links
ARR	accuracy ratio of route by length, total matched route
ARR2	accuracy ratio of route by length, correctly matched route
ARRn	accuracy ratio of route by number of links
GPS	global positioning system
IARR	inaccuracy ratio of route by length
IP	inferred path
ITS	intelligent transport systems
MATSim	Multi-Agent Transport Simulation
ST	spatial-temporal
TP	true path
UCT	University of Cape Town
WGS84	World Geodetic System 84