University Transportation Research Center - Region 2

Final Report

Compression and Querying Multiple GPS Traces for Transportation Planning

Performing Organization: University at Albany, SUNY

July 2013

Sponsor:
Research and Innovative Technology Administration (RITA)/USDOT

University Transportation Research Center - Region 2

The Region 2 University Transportation Research Center (UTRC) is one of ten original University Transportation Centers established in 1987 by the U.S. Congress. These Centers were established with the recognition that transportation plays a key role in the nation's economy and the quality of life of its citizens. University faculty members provide a critical link in resolving our national and regional transportation problems while training the professionals who address our transportation systems and their customers on a daily basis.

The UTRC was established in order to support research, education and the transfer of technology in the field of transportation. The theme of the Center is "Planning and Managing Regional Transportation Systems in a Changing World." Presently, under the direction of Dr. Camille Kamga, the UTRC represents USDOT Region II, including New York, New Jersey, Puerto Rico and the U.S. Virgin Islands. Functioning as a consortium of twelve major Universities throughout the region, UTRC is located at the CUNY Institute for Transportation Systems at The City College of New York, the lead institution of the consortium. The Center, through its consortium, an Agency-Industry Council and its Director and Staff, supports research, education, and technology transfer under its theme. UTRC's three main goals are:

Research

The research program objectives are (1) to develop a theme based transportation research program that is responsive to the needs of regional transportation organizations and stakeholders, and (2) to conduct that program in cooperation with the partners. The program includes both studies that are identified with research partners of projects targeted to the theme, and targeted, short-term projects. The program develops competitive proposals, which are evaluated to insure the mostresponsive UTRC team conducts the work. The research program is responsive to the UTRC theme: "Planning and Managing Regional Transportation Systems in a Changing World." The complex transportation system of transit and infrastructure, and the rapidly changing environment impacts the nation's largest city and metropolitan area. The New York/New Jersey Metropolitan has over 19 million people, 600,000 businesses and 9 million workers. The Region's intermodal and multimodal systems must serve all customers and stakeholders within the region and globally.Under the current grant, the new research projects and the ongoing research projects concentrate the program efforts on the categories of Transportation Systems Performance and Information Infrastructure to provide needed services to the New Jersey Department of Transportation, New York City Department of Transportation, New York Metropolitan Transportation Council , New York State Department of Transportation, and the New York State Energy and Research Development Authorityand others, all while enhancing the center's theme.

Education and Workforce Development

The modern professional must combine the technical skills of engineering and planning with knowledge of economics, environmental science, management, finance, and law as well as negotiation skills, psychology and sociology. And, she/he must be computer literate, wired to the web, and knowledgeable about advances in information technology. UTRC's education and training efforts provide a multidisciplinary program of course work and experiential learning to train students and provide advanced training or retraining of practitioners to plan and manage regional transportation systems. UTRC must meet the need to educate the undergraduate and graduate student with a foundation of transportation fundamentals that allows for solving complex problems in a world much more dynamic than even a decade ago. Simultaneously, the demand for continuing education is growing – either because of professional license requirements or because the workplace demands it – and provides the opportunity to combine State of Practice education with tailored ways of delivering content.

Technology Transfer

UTRC's Technology Transfer Program goes beyond what might be considered "traditional" technology transfer activities. Its main objectives are (1) to increase the awareness and level of information concerning transportation issues facing Region 2; (2) to improve the knowledge base and approach to problem solving of the region's transportation workforce, from those operating the systems to those at the most senior level of managing the system; and by doing so, to improve the overall professional capability of the transportation workforce; (3) to stimulate discussion and debate concerning the integration of new technologies into our culture, our work and our transportation systems; (4) to provide the more traditional but extremely important job of disseminating research and project reports, studies, analysis and use of tools to the education, research and practicing community both nationally and internationally; and (5) to provide unbiased information and testimony to decision-makers concerning regional transportation issues consistent with the UTRC theme.

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16. Abstract

In recent years, there has been a significant increase in the number of vehicles which have been equipped with GPS devices. These devices generate huge volumes of trace data, and information extracted from these traces could significantly help transportation planners with routine tasks and special studies. However, extracting information from trace data is a challenging problem because of the proliferation of GPS devices and the rate at which trace data is generated. One approach for handling this problem is to compress the GPS data in such a way that the amount of information lost due to compression is as small as possible. During the period of this project, our focus was on the design, implementation and evaluation of GPS trajectory compression algorithms that can achieve specified compression rates while minimizing the information loss due to compression. Our work has led to new algorithms for compressing single and multiple GPS traces.

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(Note: The project duration includes a no-cost extension from January 1, 2013 to June 30, 2013.)

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Contents

1 Executive Summary

In recent years, there has been a significant increase in the number of vehicles which have been equipped with GPS devices. These devices generate huge volumes of trace data, and information extracted from these traces could significantly help transportation planners with routine tasks and special studies [4, 10, 12, 13, 16, 17, 26, 32]. However, extracting information from trace data is a challenging problem because of the proliferation of GPS devices and the rate at which trace data is generated. One approach for handling this problem is to compress the GPS data in such a way that the amount of information lost due to compression is as small as possible.

During the period of this project, our focus was on the design, implementation and evaluation of GPS trajectory compression algorithms that can achieve specified compression rates while minimizing the information loss due to compression. Our work has led to new algorithms for compressing single and multiple GPS traces. Outcomes from our research include the following.

(a) Papers in peer-reviewed conferences and a prestigious journal.

(b) Software tools for compressing single and multiple GPS traces.

(c) Software tools for generating synthetic GPS traces.

(d) A benchmarking suite of software tools for evaluating existing and new algorithms for GPS trajectory compression.

(e) A collection of synthetic and real GPS trajectory data sets that can be used to evaluate trajectory compression algorithms.

(f) A Ph.D. thesis[1] and several Master's projects.

The software tools developed as part of this project will be released to the research community by early Fall 2013.

This report is organized as follows. A brief description of the completed research is provided in Section 2. This is followed by a detailed list of all the outcomes from our research (Section 3). Finally, some directions for future research are provided in Section 4.

[1] This thesis received the "Distinguished Dissertation Award" for 2013 from the College of Computing and Information at the University at Albany – State University of New York.

2 Description of Completed Research

2.1 Overview

As GPS devices have become inexpensive, the number of vehicles with GPS devices has been increasing rapidly over the past few years. These devices generate large volumes of trace data. Generally, each trace represents the position of a vehicle over time. However, with more sophisticated sensors [28] it is also possible to collect other information such as the velocity/acceleration of the vehicle, the temperature/humidity level inside the vehicle, etc. Analysis of this data can provide very useful information to transportation planners (see for example, [4, 11, 12, 31]). However, extracting useful information from traces is a challenging task because of the proliferation of the devices and the rate at which the data is generated.

The PI (Dr. Lawson) and Co-PIs (Drs. Hwang and Ravi) were supported by a UTRC grant during the calendar year 2010 to investigate techniques for compressing and mining GPS trace data. The focus of that work was on developing techniques for compressing individual traces. The research work completed during the period January 1, 2012 through June 30, 2013 (which includes a six month no-cost extension) explored several new directions that significantly extend the previous work. A brief discussion of our research accomplishments is provided in this section. More detailed information regarding our work can be found in the publications listed in Section 3.1. (Each of these publications includes a detailed review of the relevant literature.)

Note: Throughout this report, the words "trace" and "trajectory" are used synonymously.

2.2 An Improved Algorithm for Single Trace Compression

Many algorithms for compressing single traces are known (e.g. [1, 6, 8, 9, 14, 15, 18–20, 23, 29, 30]). Through a detailed study of these algorithms, we noticed that the algorithms had at least one of the following limitations:

(i) they do not handle traces in an online fashion (i.e., they need the complete trace as input) or

(ii) they do not provide ways to simultaneously control the compression ratio (i.e., the ratio of the size of the compressed trace to that of the original trace) and the error due to compression (e.g. the maximum synchronized Euclidean distance (SED) between the original trace and the compressed trace).

To address the above limitations, we developed an extended version of our previous algorithm (SQUISH) presented in [23]. The extended version provides the following features.

(i) Given a bound on the SED error, the algorithm automatically achieves the highest compression ratio while guaranteeing that the SED error is within the specified bound.

(ii) Given a compression ratio, the algorithm automatically achieves the specified compression ratio while achieving the smallest possible SED error for that ratio.

The design of the algorithm involved the development of rigorous correctness proofs. Appropriate data structures were used in the implementation of the algorithm so that running time of the algorithm remains low.

We also carried out a comprehensive performance comparison of our new algorithm with several existing algorithms. This comparison was carried out using several collections of actual and synthetic traces and across many error metrics (including SED, speed and heading errors). Results from this research are part of a student's Ph.D. thesis [24] and will also appear in a prestigious journal [21].

2.3 A Benchmarking Framework for Evaluating Trajectory Compression Algorithms

As mentioned above, a number of algorithms have been proposed for compressing GPS traces. Further, motivated by various applications, researchers are likely to develop new algorithms in the future. When we started this research, software tools that can measure the effectiveness of a compression algorithm and compare its performance against other known algorithms were not available. We have developed a benchmarking framework that fills this void. The facilities provided by our framework include the following.

(a) It provides efficient implementations of many compression algorithms proposed in the literature.

(b) It permits comparisons of algorithms based on various error metrics defined in the literature.

(c) It provides several synthetic trace generators that can produce traces with specific properties to test compression algorithms. (For example, the framework can generate traces where the speed varies according to a specified distribution. It can also generate traces with drastic changes in speed or heading to simulate a vehicle which is moving erratically.)

(d) The framework has an extensible architecture which facilitates the addition of new compression algorithms.

In particular, the framework enables users to try various parameter values for compression algorithms in a very convenient manner.

A detailed description of the facilities provided by the benchmarking framework and its architecture appears in [22]. This reference also describes the synthetic trace generators supported by the framework and several examples that illustrate how the framework can be used. We have also submitted a system demo paper [27] based on the benchmarking framework to the ACM SIGSPATIAL Conference to be held during November 2013. We are planning to make this framework available under the open-source licensing scheme during early Fall 2013.

2.4 A New Algorithm for Multi-Trace Compression

While many algorithms are available for compressing single GPS traces, the problem of compressing multiple traces has received only a limited amount of attention in the open literature [5, 25]. We have developed a new algorithm for compressing multiple traces, based on the following approach.

(i) Split traces into sub-traces depending upon similarities among the traces.

(ii) For each collection of sub-traces, store the spatial data of just one representative trace; other sub-traces are stored using an appropriate mapping with respect to the representative trace.

The strong correlation between the mappings from sub-traces to the representative trace allows the algorithm to store the mappings themselves in a very concise fashion. In turn, this enables the algorithm to achieve high compression ratios while keeping the SED error as low as possible. A detailed description of the algorithm is presented in [2].

We implemented the above algorithm and compared its performance against the method used by the TrajStore system [5]. Our experiments show that the algorithm performs very well compared to the method used by TrajStore. Our algorithm has the additional advantage that the sub-traces can be compressed using *any* single trace compression algorithm. Additional details regarding the performance of our algorithm appear in [2].

3 List of Project Outcomes

3.1 Papers in Peer-Reviewed Conferences and Journals

(a) J. Muckell, P. W. Olsen, Jr., J. Hwang, C. Lawson and S. S. Ravi, "Compression of Trajectory Data: A Comprehensive Evaluation and a New Approach", *GeoInformatica*, July 2013 (online version).

(b) J. Muckell, P. W. Olsen, Jr., J. Hwang, C. Lawson and S. S. Ravi, "A Benchmarking Framework for Efficient and Convenient Evaluation of Trajectory Compression Algorithms", to appear in *Proc. Fourth International Conference on Computing for Geospatial Research & Applications* (COM.Geo 2013), San Jose, CA, July 2013.

(c) J. Birnbaum, H. Meng, J. Hwang and C. Lawson, "Similarity-Based Compression of GPS Trajectory Data", to appear in *Proc. Fourth International Conference on Computing for Geospatial Research & Applications* (COM.Geo 2013), San Jose, CA, July 2013.

(d) K. Park, J. Birnbaum, P. W. Olsen, Jr., Y. Ma, J. Vijayan, J. Muckell, J. Hwang, C. Lawson and S. S. Ravi, "Demonstration of a Benchmarking Framework for Trajectory Compression Algorithms" (Demo paper), Submitted to the *21st ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems* (SIGSPATIAL 2013), Orlando, FL, Nov. 2013.

3.2 Software Tools Developed

(a) Efficient implementations of many known GPS trajectory compression algorithms including Douglas-Peucker, TD-TR, Opening Window algorithm, etc. and a new algorithm (SQUISH) developed as part of this project.

(b) A benchmarking tool that allows efficient comparisons of existing and new algorithms for compressing GPS trajectories.

(c) A software tool that implements multi-trace compression using a new algorithm developed as part of this project.

(d) Modified versions of existing synthetic trace generators to produce traces that represent several types of roads (e.g. highway or city) and erratic drivers.

(e) A new trace generator that can generate traces where speed and heading follow specified Gaussian distributions.

3.3 New Trajectory Data Sets Produced

(a) A clean version of the Microsoft GeoLife dataset originally discussed in [33, 34].

(b) A clean version of the GPS data from buses traveling along several routes in Albany, NY.

(c) Many synthetic GPS traces generated using trace generation tools developed as part of this project.

3.4 Ph.D. Thesis and Master's Projects Produced

(a) Jonathan Muckell, "Compression of GPS Trajectory Data: A Benchmarking Framework and a New Approach", Ph.D. Thesis, Department of Informatics, College of Computing and Information, University at Albany – SUNY, May 2013. (Winner of the Distinguished Dissertation Award for 2013 from the College of Computing and Information.)

(b) Hsiang-Cheng Meng, "Similarity-Based Compression of GPS Trajectory Data", Master's Project, Department of Computer Science, College of Computing and Information, University at Albany – SUNY, May 2013 (completed).

(c) Kyu Park "A Framework for Efficient and Convenient Evaluation of Trajectory Compression Algorithms, Part I: Algorithmic Aspects", Master's Project, Department of Computer Science, College of Computing and Information, University at Albany – SUNY (ongoing).

(d) Yuchao Ma, "Efficient Implementation of a Benchmarking Framework for for Trajectory Compression Algorithms, Part II: User Interface Aspects", Master's Project, Department of Computer Science, College of Computing and Information, University at Albany – SUNY (ongoing).

4 Suggestions for Future Work

During this project, our focus was primarily on the development of algorithms for compressing single and multiple GPS traces. We believe that the goals we set for this area of research have been successfully met. However, more research is needed to unlock the information contained in the GPS traces. To this end, we would like to propose developing techniques for processing traces and extracting information from compressed and uncompressed traces. For example, we now would like to begin extracting the wealth of information available within the GPS trace structures with user-based queries, and to learn whether compression techniques should differ with respect to such queries. While our most recent algorithm, SQUISH-E, has the characteristics desired for high quality compression outcomes, will it also expand our ability to perform advanced queries? At the same time, it is not yet known whether such compression techniques could hamper some queries as well. This could also be the case with multiple trace compression algorithms and the extraction of critical information at various stages in the compression process (e.g., when is the best time to extract certain types of information from the trace pre or post compression?). In addition, we see opportunities with some specific directions for compression and query research as follows.

(a) All of the compression algorithms reported in the open literature are sequential algorithms. Given the large volume of GPS trace data, it is of interest to develop parallel algorithms for compressing single and multiple-trace data.

(b) It is important to identify queries on traces that are of interest to transportation planners and to develop techniques for efficiently processing such queries.

(c) Extracting semantic information from traces is an interesting research direction. For example, one may try to identify trip purpose or mode of travel from compressed traces.

(d) Bus bunching is a common problem in several cities [3,7]. It will be useful to develop techniques for analyzing trace data from buses to predict when and where bus bunching is likely to occur and to suggest strategies to reduce bus bunching.

(e) A more ambitious direction is to develop techniques for analyzing trace data from commercial vehicles in conjunction with other archived transportation, socio-economic and context data to gauge the economic health of a geographic region.

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