AUTOMATIC ANALYSIS OF TRAJECTORIES OF MOVING OBJECTS

JACEK DĄBROWSKI

Gdansk University of Technology
Narutowicza 11/12, 80-233 Gdansk, Poland
jacek.dabrowski@eti.pg.gda.pl

Ongoing monitoring is essential to providing security and safety of maritime and air operations. This paper presents the research in the area of automatic analysis of movement of unrestricted vehicles like ships and airplanes. The analysis is aimed at extraction of trajectory information, and the results can be used to identify anomalous behavior in archived and real-time data.

In this paper we focus on data acquired using the GPS by the vehicle and transmitted to a ground station using a dedicated system (AIS for ships and ADS-B for aircraft). However, the methods could be applied to positional information obtained by other means, e.g. a radar or sonar installation. We also present a low cost solution for gathering ASD-B data.

INTRODUCTION

Maritime and air transport are an important part of the economy, and the need to maintain their safety is unquestionable. The methods used to control the increasing volume of traffic can be divided into two categories. The first one can be defined as sets of rules, ranging from general (e.g. right of way) to location-specific, or even location-time-specific (e.g. restricted areas). The location-time restrictions in this category are known to the person in command of the vehicle well before the it arrives at the location. These rules could be referred to as “offline” in contrast to ongoing monitoring and management of traffic in a specific area, provided either by port authorities or air traffic control (ATC).

Ongoing monitoring and management relies on human operators, and as their attention is limited many tools have been developed to assist them. The tools will include systems that detect important, yet regular events (e.g. entering/leaving the area, take off/landing, mooring, etc.) and anomalous situations (e.g. entering a restricted area, deviating from flight path). Most of those detectors are be based on a set of very specific rules. However in recent years it has become feasible to gather huge amounts of positional information for a given location over time and apply different techniques for automatic and assisted data analysis. This has been recognized by the European Science Foundation in the form of MOVE Action of the COST Programme aimed at developing improved methods for knowledge extraction from massive amounts of data about moving objects. The research areas include the representation of movement data, its analysis and visualization [1].

The investigation into the representation of the data has two main objectives. The first one is to find efficient methods for recording and preprocessing movement data for storage in a database. The second objective is to structure it into trajectory data and make it available for query by analysis or visualization tools. Preprocessing of the raw movement data is often required as it can contain errors or gaps that need to be eliminated or smoothed. Depending on the application the data might be resampled to equidistant temporal or spatial intervals. Another challenge in this area is the use of real-time time data. Any system that is used for ongoing monitoring must be able handle interruptions in the data stream and restore it state after a failure.

The analysis of the movement data can start from simple algorithms to detect specific movement patterns (or lack of them). However, the interesting area is the analysis of trajectories: similarity detection using different criteria and measures, and generalization of groups of trajectories into spatial, or spatial-temporal channels. This generalized data can either be used by other analysis tools (e.g. for classification) or for presentation.

The last topic covered by the MOVE Action is the visualization of the movement data. As mentioned before many monitoring systems rely on human operators, and due to several reasons it is not likely that this will change quickly. Until fully automated systems are deployed the results of trajectory analysis can be used to improve the visibility of anomalous behavior.

In this paper we begin with comments on the source of positional data and presentation of a low-cost receiver used for gathering ADS-B data in Gdańsk area. In Section 3. the methods used for analyzing and generalizing movement data are described. We discuss the possible applications of movement anomaly detection in Section 4. The paper is concluded with some general observations and ideas for future research.

1. THE SOURCE OF THE DATA

Over the years several methods for tracking ships and aircraft from shore/ground have been used. These methods include optical, radio and sound wave positioning. From the point of view of the vehicle these methods are passive, or almost passive (a vehicle might carry a beacon, for example navigational lights for improved visibility, but it is tracked by an external entity). The introduction and development of global navigation satellite systems (GNSS) and the lowering cost of equipment allowed for a broad adoption of a different approach, in which the vehicle retrieves its own position and then broadcasts it. The radio transmission may be received by ground stations and/or other vehicles. The transmission standards in current commercial use are the Automatic Identification System (AIS) for ships, and the Automatic Dependent Surveillance-Broadcast (ADS-B) for aircraft. Both systems allow for messages with other types of data, for example ships characteristics (name, dimensions, draught, etc.) are transmitted every six minutes in the AIS. Some of this additional data might be useful for classification purposes, however most researchers only use the time-stamped position reports.

The reliance on data from AIS and ADS-B introduces some limitations. The first one is the accuracy of the GPS itself, where the error can easily exceed 10 meters in its commercial variant. Although there are methods for improving accuracy, for example by using Differential GPS the error may be reduced to one-meter or even sub-meter range, we depend on data provided by the users, and cannot force them to upgrade their systems. Another closely tied limitation is that sometimes AIS transmitters are not configured correctly – they lack the proper registration information, ship name or the extra data mentioned previously in this section. While it might be easy to simply exclude such data from the data set, it is important to remember that these are actual vehicles that have influence on the safety of traffic.

One must also note that relying on vehicle-provided position data is fine for safety purposes, in all security applications one must consider the possibility of forging position data – all that is required is a transmitter that accepts GPS data from a serial port and some computer software.

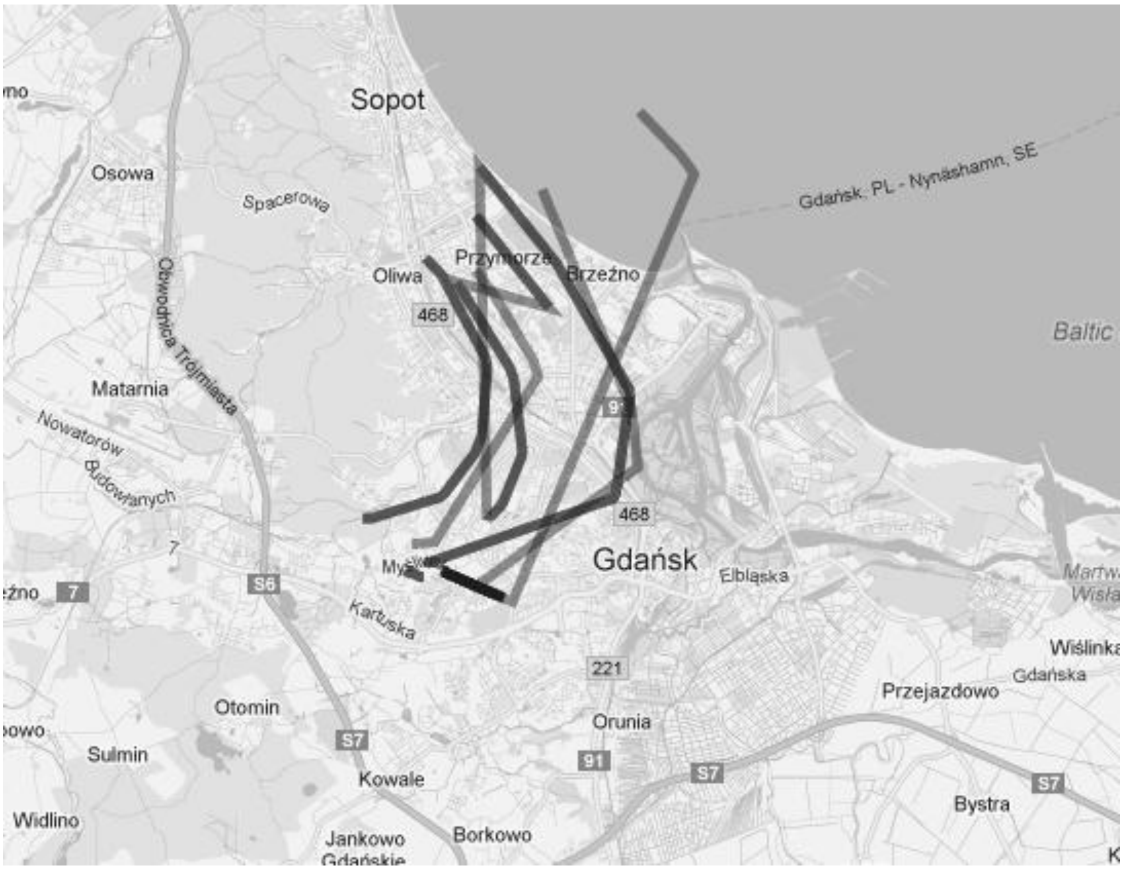

Fig.1. Collected ASD-B data points in Gdańsk area. Background: Google Maps.

Fig. 1. presents AIS data received using a consumer grade digital television tuner based on a Realtek RTL 2832 demodulator chip. Aside from its primary function such devices can be used as a broad-spectrum software-defined radio (SDR) receivers. Depending on the specific tuner chip the frequency range will differ, but it usually starts with tens of megahertz and can reach over 2GHz. In this research it was a Terratec T Stick USB receiver with Elonics E4000 tuner.

The data was received using software dedicated for receiving arbitrary radio transmissions and decoding the signals in software. For Windows based PCs most software is based on *sdrsharp,* an open source project written in C#, while for Linux the *gnuradio* toolkit is the de facto standard. In this work we used *ADSBSharp*, a dedicated tool for detecting and receiving ADSB signals based on *sdrsharp*.

Initial test with the receiver have shown that reception from beyond 100 km range is possible even when using the small TV antenna included with the receiver. However, probably due to interference, the range from the building of the Faculty of Electronics, Telecommunications and Informatics is much smaller, as can be seen in Figure 1. In future we plan to use more devices in different locations to create a more robust system.

2. ANALYSIS OF SPATIO-TEMPORAL DATA

Once gathered, the information about movement of vehicles may be subject to a number of data-mining methods aimed at extracting general knowledge about traffic in the given area. However, before any methods are applied, it is important to pre-process the raw position stream. There are two common problems with the raw data. First, within the data stream there are single reports containing erroneous position information. These can be quite easily identified by assigning a numerical value to each report corresponding to how much it deviates from the path between its neighbors. Since we are considering large vehicles, incapable of rapid turns, removing points far from that path is usually sufficient.

The second class of errors in the data stream are gaps. Some of the gaps are small (e.g. gaps created by removing erroneous positions) and they can be either ignored or repaired simply by inserting an interpolated value. Other, longer gaps are usually a result of the radio transmission being disrupted (due to range or other interference) or a malfunction/misconfiguration of the transmitter. The treatment of the long gaps will depend on their position within the stream. If the gap is at its beginning or ending the best choice would be to shorten the trajectory. If the gap is between parts of good quality, but is beyond fixing by interpolation, then it should be split into two separate trajectories. The result of data preprocessing is a set of trajectories, which themselves are sets of time-ordered position reports. A single position report, aside from the geographical position and timestamp, may also include additional data, for example about the speed, climb and bearing of the vehicle.

The last, optional stage of preprocessing is trajectory compression. Often vehicles follow the same bearing, with constant speed for a long period of time (several position reports). These sections of trajectories may be simplified to single segments without loss of significant data [2]. A simple, yet practical solution with good results is to use dynamic programming and progress along the trajectory. We build the set of segments by considering if each data point can be considered an extension of the current segment (the direction nor speed haven't changed), or should we end the current segment at the previous position and start a new one. An example of trajectory compression is presented in Fig. 2B. The quality of compression can be improved if we allow the segments endpoints to lay outside the original data set (Fig. 2C).

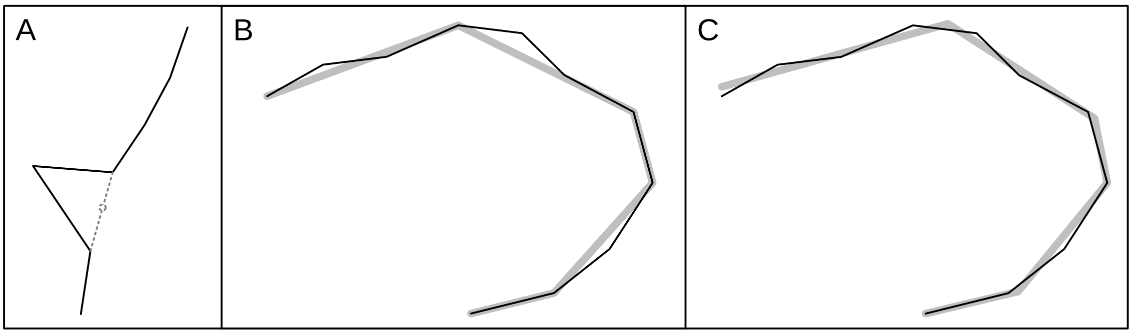

Fig.2. A: A typical GPS error with a corrected equitemporal position;
B and C: Results of trajectory compression.

A simple model for anomaly detection has been presented in [3]. The authors restrict their analysis to trajectories of vehicles of a specific class (e.g. large vessels) that usually follow predefined shipping lanes. Based on the set of smoothed trajectories a movement density map for the specific area is generated. This map is then used as a background in live-traffic visualization and allows the operator to quickly identify vessels deviating from typical routes.

A typical set of data from the AIS will contain trajectories of vessels of several types. The most general approach would be to include a vehicle classification mechanism in the anomaly detection system. However, this is not a trivial task, and for a given application a more practical approach would be to simply restrict the input data to vehicles of a specific type. In [4] the authors analyze the movement of ferries providing public transport in the Brest area. They define a zone graph with vertices that represent interesting locations (e.g. ports, areas where routes separate and merge). An itinerary is a path within the zone graph, and it is relatively simple to identify trajectories that follow a specific itinerary. Data for a specific edge of the graph is then be used to create a spatial-temporal channel – a data structure that improves over a movement density map, as it allows to identify vessels within an itinerary that are ahead of schedule or late.

In this section we have only covered analysis of singular trajectories, without considering interactions between vessels. In real-life applications trajectories that would appear anomalous on their own might be simply a result of a typical maneuver – giving the right of way or passing another vessel. This topic may be subject of future work.

3. APPLICATIONS

The two main applications of anomaly detection in marine and air traffic are safety and security. The obvious safety application would be online monitoring and real-time detection of situations that may lead to an accident. However, as we discuss below, accidents are too rare to be detected using only statistical methods. A more likely online application is a support tool for a human operator monitoring the traffic that will direct his attention to vehicles behaving abnormally, but leave the classification at his discretion. The density map described in the previous section is an example of such a tool.

Detection of so called near miss situations is an interesting application for trajectory analysis. Accidents happen too rarely to directly provide information on safety levels and training material. Study of situations that could have resulted in an accident, but that were narrowly avoided can provide valuable information. However, they are often not reported to the authorities due to possible liability of the vehicles commanders. An automated anomaly detection system may be used to identify such situations for safety analysis [5].

When consider applications in providing security two problems arise. The first one is the dangerous reliance on user provided data in case of AIS and ADS-B, already discussed in Section 2. If this can be mitigated by using other positioning method then still one problem remains, which is the lack of training data for positive detection of threats (similar to the situation with accident detection). This means that anomaly detection for security application can only be considered a support tool, not a standalone system.

In this paper we have focused on analysis of movement of large vehicles: ships and aircraft. However, many of the presented methods could also be applied to analyzing movement of people, animals and other types of objects, for example cargo containers. An application to detection of anomalies in human behavior is particularly interesting as most people already carry a positioning device – a cell phone.

4. CONCLUSION

Maritime and air traffic has several similarities. Although the medium allows for almost unrestricted movement, most of the traffic will follow typical routes, especially near points of interest. These points of interest include destinations, like ports and airports, but also other areas influencing vehicle trajectories, most commonly the geographical features of the area. The requirement of using AIS and ADS-B transmitters on commercial vehicles has allowed for gathering and analyzing huge amounts of raw positional data. This data may be used to create anomaly detection systems based on statistical methods rather than a strict set of rules that needs to be defined for each area by a qualified operator.

In this paper we have presented some of those methods and discussed possible applications. We have also presented a simple receiver for ADS-B data, that due to its low-cost, and a relatively large range could be used to create a robust network for gathering aircraft movement data. In the next year we plan to create a database containing an archive of ADS-B data for the Gdańsk area for future research.

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