SCIENTIFIC REPORT

MISSION

Title:	Online processing of streaming maritime trajectories
Action:	IC0903 – Knowledge Discovery from Moving Objects (MOVE)
Beneficiary:	Konstantinos Patroumpas (*Early Stage Researcher*)
Home Institution:	National Technical University of Athens (NTUA), Greece
Host:	Prof. Christophe Claramunt
Host Institution:	Naval Academy Research Institute (IRENav), Brest, France
Duration:	25 March 2013 - 19 April 2013.

SUMMARY

This mission initiated a fruitful and hopefully long-term collaboration between IRENav and the Knowledge & Data Base Systems Laboratory (KDBSL) at NTUA, on the basis of mutual research interests related to spatiotemporal data management and geographic information systems (GIS). Research conducted during this short visit has explored issues concerning streamlined processing, summarization and visualization of maritime trajectories. As a quite distinct instance of mobility data, it has emerged that vessel traces pose significant challenges for real-time evaluation, including their potentially large volumes and inherent uncertainty. Experimentation against simulated streaming collections of real vessel traces provided a clear evidence for the suitability of such a methodology. In that respect, this investigation is keeping pace with other approaches on management of moving objects, which currently attract considerable research interest worldwide.

PURPOSE & OBJECTIVES

The research topic of this short-term mission was very closely related to the main objective of the MOVE Action, i.e., developing and improving methods for knowledge extraction from massive amounts of data regarding moving objects. In our particular case, traces from vessels are collected, analysed and summarized in order to detect interesting trends and emerging events. In contrast to other related works on this topic, this approach can be seen as an attempt to strike a balance between the necessity for real-time monitoring of numerous objects while also retaining salient motion features from their recent history.

A major challenge is how information from such fluctuating, transient and possibly noisy positional streams can be suitably modelled and processed in order to maintain evolving trajectories across time. We advocate that a close synergy between inherent spatiotemporal properties and the data stream processing paradigm may provide a solid framework for intelligent online tracking and detection of mobility characteristics. Maritime trajectories can also serve as an excellent case study for capturing implicit spatiotemporal interrelationships, especially because no fixed underlying network can be assumed.

DESCRIPTION OF WORK

Before this mission, related work had been surveyed, mainly covering online techniques for maintenance of streaming locations, as well as trajectory compression and mining algorithms. From a modelling perspective, works on window specification for continuous queries and trajectory semantics were studied as well.

During the mission, we focused on efficient management and processing of streaming traces from ships sailing in the sea. We addressed several processing and summarization issues concerning evolving trajectories generated by such massive positional updates. Most effort was devoted to the design and initial development of a framework specifically tailored for online evaluation against maritime trajectories. How such fluctuating, transient, and possibly noisy positional data can be processed online has proven especially challenging from a streaming perspective, assuming a large number of ships are moving in a given area of interest.

So, this study has covered mostly algorithmic and exploration aspects, including:
(i) Online characterization of current motion features and identification of several “critical points” along trajectories.
(ii) Data reduction methods for summarizing motion paths, by simplifying their routes at high compression rates with the use of already detected critical points.
(iii) Visualization of processed spatiotemporal information after exporting results in standard file formats that can be used with GIS platforms.
(iv) Preliminary experimentation against several workloads extracted from real datasets of maritime trajectories.

DESCRIPTION OF OBTAINED RESULTS

The main ideas derived from the conducted study and validated through a preliminary experimentation can be outlined as follows:

After some initial discussions on semantics and peculiarities of maritime trajectories, it became evident that it would be important to track *significant changes* in each vessel's course. This mostly refers to instantly identifying *"critical points"*, e.g., indicating a stop, a sudden turn, or slow motion along each route. This method was successfully implemented with suitable data structures for in-memory maintenance of movement features. Thus, we can easily characterize in real time the current motion of each monitored ship with a particular annotation (e.g., stop, turn). Of course, such derived features can be used for map display with suitable symbology, but they are mostly valuable in emergency situations, e.g., issuing an alert when a passenger ship has stopped unexpectedly in the open sea, just in case this event required a rescue operation.

As a next step, we were able to take advantage of those online annotations and retain lightweight, succinct *synopses* of maritime trajectories over the recent past. Except for harsh weather conditions, traffic regulations, local manoeuvres etc., ships normally follow almost straight, predictable routes. It turns out that a large amount of raw positional updates can be suppressed with minimal losses in accuracy, as they hardly contribute additional knowledge about maritime motion patterns. Instead of resorting

to a costly simplification algorithm, we opt to reconstruct vessel traces *approximately* from already available critical points. This summarization is triggered automatically according to the type of detected motion features, so as to refresh each compressed trajectory accordingly.

An additional utility was developed, which allows processed results to be periodically exported into standard KML or CSV files for map display, involving not only critical points, but also compressed routes. This serves not only as a means of presenting results on maps, but also for effective verification of trajectory groupings and exploration of unexpected behaviours (e.g., noise, sudden turns) meaningful in a maritime context.

Finally, this methodology has been tested against an AIS dataset that records ship trajectories close to the port of Brest (France) for year 2009. We simulated a streaming functionality by reading records from files and accordingly feeding the algorithm with data batches periodically. As our preliminary investigation indicates, the implemented prototype executes very fast (less than 20 seconds suffice to process data for one week) and has been able to achieve more than 98% compression ratio for typical movements in this area. It is expected that soon this algorithmic framework will be further refined along with a more comprehensive empirical evaluation.

OTHER ACTIVITIES DURING THE MISSION

Throughout this mission, the visiting researcher had the opportunity to discuss and exchange ideas with many researchers and PhD students at IRENav GIS group.

The visiting researcher gave three seminars at IRENav on modelling, processing and application frameworks for geospatial streams and trajectories, each followed by very constructive remarks and feedback from the audience. Under the common subject "*Gone with the Stream: Online Processing Techniques for Moving Objects*", the topics of each talk were as follows:

- "*Event Processing & Real-time Monitoring over Streaming Traffic Data*" (29/3/2013);
- "*Multiplexing Trajectories of Moving Objects*" (10/4/2013); and
- "*Multi-scale Windowing over Trajectory Streams*" (18/4/2013).

In addition, the visiting researcher had motivating discussions with researchers and students alike, so he was better acquainted with current research activities at IRENav GIS group. It turned out that on certain issues (e.g., semantic trajectories, indoor movement, spatiotemporal modelling etc.) there is sufficient common ground that might be further explored.

FUTURE COLLABORATION WITH THE HOST INSTITUTION

Thanks to this mission, a very promising collaboration has started between IRENav and KDBSL at NTUA, on the basis of shared research interests regarding trajectory management. As an immediate action to complement our approach, we plan a comprehensive assessment in order to estimate the error induced (i.e., deviation of summarized routes from original traces), as well as an empirical performance study.

As a continuation of this work, there are several ideas for further joint investigation:

- Processing with a sliding window model could certainly offer important benefits, as more reliable information may be estimated based on recent motion and not just instantaneous features.
- Develop an online technique to anticipate whether any pair of objects could possibly come within reach of each other anytime soon, such that a risk of collision may be identified in advance.
- Moreover, the data reduction process might also integrate some qualitative data (e.g. decision points) for advanced refinement.
- Last, but not least, this framework could have broader applicability to other types of continuously moving objects, like GPS-enabled vehicles, animals, RFID-aware merchandise etc.

FORESEEN PUBLICATIONS

A brief report of results from this study has been already submitted to the forthcoming MOVE-COST workshop on "Moving objects at sea" to be held in June 2013. As soon as the framework is further refined and a more comprehensive evaluation gets finalised, we plan to submit the completed work to an international conference in 2013. In addition, we may also seek diffusion of this approach to the maritime community, e.g., professional conferences in the maritime domain.

Besides, we have already made an initial discussion about possible extensions, mostly towards interactions between maritime trajectories. In case that this latter investigation also materializes into concrete results, we may hopefully pursue its dissemination through a prestigious conference or refereed journal by the end of 2013.