Proactive Monitoring of Moving Objects

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Abstract: Positioning systems, combined with inexpensive communication technologies, open interesting possibilities to implement real-time applications that monitor moving objects and that support decision making. This paper first discusses basic requirements for proactive real-time monitoring applications. Then, it proposes an architecture to deploy applications that monitor moving objects, are pro-active, explore trajectory semantics and are sensitive to environment dynamics. The central argument is that proactive monitoring based on process models, such as workflows, is a promising strategy to enhance applications that control moving objects. Finally, to validate the proposed architecture, the paper presents a prototype application to monitor a fleet of trucks. The application uses workflows to model truck trips and features a module to extract data from the Web which helps detect changes on road conditions.

1 INTRODUCTION

Positioning systems, combined with inexpensive communication technologies, open interesting possibilities to implement real-time applications that monitor moving objects and that support decision making. An example would be an application to monitor a fleet of tank trucks that distribute fuel to gas stations in an urban environment. Every trip is carefully planned to follow pre-defined routes, avoiding sensitive areas (such as school areas) and periods of the day or routes where the transportation of dangerous cargo is banned and to pro-actively re-route the truck in case of traffic accidents and other events that might cause delays.

We may classify such applications according to different perspectives. The application may use *trajectory semantics*, such as stopping at a point of interest, or the application may use just *raw trajectory data*, such as speed and direction. We cite Alvares (2011), Siqueira and Bogorny (2011) and Moreno, Times, Renso and Bogorny (2010) and as related works in trajectory semantics.

A *reactive* application uses just the past behavior of the objects, as opposed to a *proactive* application that features models of the predicted (future) behavior of the objects and perhaps suggests alternative actions. Proactive computing is investigated in Tennenhouse (2000), which advocates a paradigm shift from human-centered to human-supervised computation. In his perspective, a system to be proactive must: (1) have a direct connection with the real world; (2) be able to execute actions in response to external stimuli; (3) execute actions faster than the human response. In other words, a system with proactive behavior must detect interesting situations before they happen and must be able to handle such situations without human supervision.

Finally, the application may be *sensitive to environment dynamics*, meaning that it monitors the current state of the environment (or even estimates future states of the environment) where the object is moving to base its decisions. Environmental facts are considered when they directly affect the moving object behavior. By contrast, the application may be *insensitive to environment dynamics*, in the sense that it has just a static model of the environment (such as a road map) where the object is moving.

In this paper, we first discuss basic requirements for proactive monitoring applications. Then, we propose an architecture for applications that monitor moving objects, are pro-active, explore trajectory

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semantics and are sensitive to environment dynamics.

To achieve proactive behavior, the proposed architecture includes models of the processes behind the moving objects. The prototype application uses workflows to model truck trips. To monitor moving objects, the architecture includes support for real-time trajectory data stream processing. Finally, to account for trajectory semantics and support sensitivity to environment dynamics, the architecture features additional data sources, classified as *(geospatial) static structured data sources (SSD sources)* and *dynamic structured data sources (DSD sources)*. The prototype application uses geospatial databases and georeferenced facts posted in feeds and tweets about the road conditions that may affect the predicted behavior of the trucks.

The contributions of the paper are therefore threefold: a discussion of the basic requirements for proactive monitoring applications; a proposal for an architecture for such applications; and a prototype application to assess the proposed architecture. The central argument is that proactive monitoring based on process models, such as workflows, is a promising strategy to enhance applications that control moving objects.

The rest of the paper is organized as follows. Section 2 describes a motivating scenario. Section 3 discusses basic requirements for proactive monitoring. Section 4 introduces an architecture for proactive monitoring applications. Section 5 presents a prototype application to validate the ideas. Section 6 discusses related work. Finally, Section 7 contains the conclusions.

2 A MOTIVATING APPLICATION

Consider an application to monitor a fleet of delivery trucks, abstractly defined as follows.

Each truck is modeled as a *moving object* M and each trip is described as a *workflow* W_M that defines the customers to be serviced in the trip and the routes to be followed. Each *step* p of W_M either represents *delivering* merchandize at a customer C_p located at place L_p, or *moving* from a place O_p, called the *origin* of p, to a place D_p, called the *destination* of p, through a *route* R_p.

For each moving object M, the system receives a data stream containing the date, time, geographic position and speed. The system transforms this raw data into meaningful events with the help of a geospatial database storing the location of points-of-interest.

The application monitors several trucks, sharing the same underlying road network and the same emergency workflows. A centralized application is desired to integrate the monitoring of the individual trucks, as well as of the events that affect the road network where the trucks move. The application also reduces human interference on the monitoring process to minimize failures due to fatigue.

Consider now the problem of improving the truck monitoring application to become proactive and sensitive to the environment.

Briefly, the first change in the application design is to use the truck delivery workflows to infer their future behavior. The second change is to detect anomalies in the conditions of the roads where the trucks are expected to drive in the next steps of their trips (defined by their workflows). As an example, the system may issue an alert to the driver to proceed more carefully (or even to take an alternate route) when detected that a vehicle, carrying a flammable load, is driving along a road with wet floor ahead.

Finally, we note that we may describe similar scenarios related to other classes of moving vehicles, such as planes and ships. Workflows in this case will be abstractions for flight or sailing plans.

3 PROPOSED ARCHITECTURE

Figure 1 illustrates the proposed architecture. The *Proative Central Monitor (PCM)* is the core component that, as the name implies, coordinates the other components to pro-actively monitor moving objects. The *Planning Manager (PM)* stores and controls the workflows that model the behavior of the moving objects. The *Application Databases* contain auxiliary data such as names and addresses of customers, the road network, etc. The *Moving Objects Monitor* (*MOM*) sends to the *PCM* the structured data stream containing information relative to the real-time monitoring of moving objects: position, trajectory semantic data (i.e., interpreted trajectory data) and other signals from moving objects. The *Mediators* facilitate access to either dynamic or static external data sources.

4 A PROTOTYPE APPLICATION

This section outlines some of the features of a prototype application to monitor a fleet of delivery trucks, along the lines of the application presented in

Section 2. The prototype follows the architecture proposed in Section 4 and the discussion focuses on some aspects of the *Dynamic Structured Data Mediator* and the *Proactive Central Monitor*.

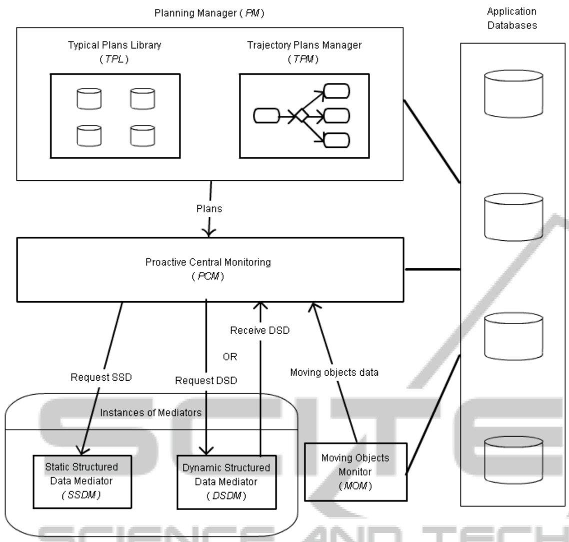

Figure 1: General view of architecture proposal.

4.1 Dynamic Structured Data Mediator

Proactivity is two-fold: situations may be detected from past behavior of the object or from external agents that affect the application.

Santos and Moreira (2010) propose an input for proactive computing by predicting the next step of moving objects based in its current location and road data. Previous moving object data is not used. The success of prediction may vary according to the scenario and variables.

The second approach to proactivity is based on the extraction of relevant facts that potentially affect the future behavior of moving objects.

The prototype implementation of the *Dynamic Structured Data Mediator* (*DSDM*) uses Twitter as the main dynamic structured data source. Similar applications were deployed by Carvalho, Sarmento and Rossetti (2010) and MacEachren et al. (2011). The prototype considers tweets from a predefined list of institutions, assessed as trustworthy sources, as well as from users related to the primary sources (e.g. followers).

The implementation follows the second strategy listed in Section 4.2, that is, the *DSDM* is responsible for post-processing the results returned by the wrappers. As illustrated in Figure 2, the *DSDM* receives raw data containing text body, source, user, location (when available), number of re-tweets, hashtags and time stamp. It then filters tweets according to their creation date and keeps only the most recent ones. At the classification step, the *DSDM* selects only the text body and the source. It classifies tweets according to the occurrence of relevant facts in the text body (e.g. car crashes, floods and road blocks). After filtering the relevant tweets, the *DSDM* extracts the spatial reference for the reported fact, with the help of a street gazetteer stored in the *SSDM*. Finally, the *DSDM* transforms the extracted data into a predefined structure before sending the data to the *PCM*.

4.2 Proactive Central Monitor

The prototype implementation of the *Proactive Central Monitor (PCM)* processes facts and events it receives from the *DSDM* and the *MOM* as follows.

For each moving object *M*, with workflow W_M, the *PCM* uses the events the *MOM* sends to monitor the step *c* that W_M is executing. It then simulates the steps of W_M that may follow *c*, up to a certain depth, and collects the routes that *M* may traverse.

Next, the *PCM* verifies if such routes are affected by a fact that the *DSDM* has already sent. If this is the case, the *PCM* warns the (human) controller or the driver, or both, that future steps planned for *M* may have to be changed or aborted.

For simple facts, the *PCM* just generates warnings both to the controller and the driver, but it does not recommend that W_M be necessarily changed. For example, a fact reporting heavy traffic in a route generates just a delay warning to the driver or even suggests an alternative route.

However, some facts may imply restrictions to traffic, even if temporarily. In this case, the *PCM* recommends to the controller that W_M be changed or aborted. The controller then invokes the route planning component (outside the scope of this paper) to create a new version of W_M.
The route planning component is prepared to create routes that consider a list of traffic restrictions (usually maximum load and maximum height permitted, forbidden cargo traffic hours, etc…).

Finally, the *PCM* may also receive events from the *MOM* that represent incidents involving *M* (e.g. a mechanical problem with *M*). It then invokes workflows, stored in the *TPL*, to mitigate the incident and eventual damages to the environment (e.g. to clean up an oil spill).

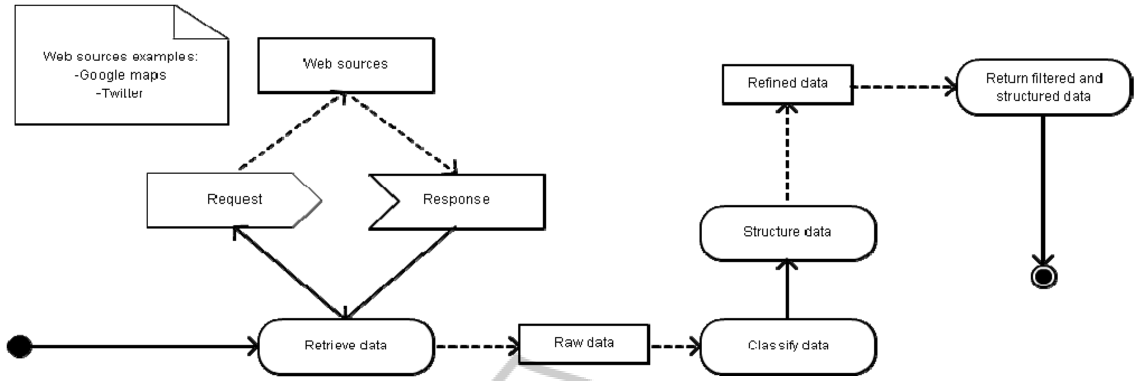

Figure 2: Data flow of the *DSDM*.

5 CONCLUSIONS

In this paper, we first discussed basic requirements to achieve proactive monitoring of moving objects. Then, we proposed an architecture that meets the requirements. The first key point of the discussion is to model the process behind a moving object as a workflow to be able to infer future actions. The second key point is to monitor or even to predict changes in the environment by exploring dynamic data sources.

Finally, we outlined some of the features of a prototype application to monitor a fleet of delivery trucks. In particular, the prototype uses Twitter as a viable dynamic data source to detect changes in the current road conditions, as well as to register future, planned changes that may affect the traffic in certain roads.

We plan to improve the prototype application in several directions. In particular, we intend to explore a supervised strategy to address the problem of classifying facts extracted from tweets. We also plan to explore RSS feeds as a dynamic data source (Chen et al, 2007) and to automatically analyze Web site containing news and weather reports as a viable source of dynamic information.

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