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Retrospective Analysis of Surveillance Data: A Case Study for Road Tunnels

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Abstract

The surveillance of a particular infrastructure is a multi-faceted activity. In addition to tasks which must be performed in real-time, a retrospective analysis of surveillance data is of equal importance for ensuring the quality and plausibility of surveillance activities as well as for drawing conclusions. Based on insights gained from the design of AlVis, a system for the surveillance of road tunnels, the main contribution of this paper is a problem characterization of retrospective analysis tasks in the context of spatio-temporal surveillance data. We also describe concepts for supporting a retrospective analysis in AlVis and we report feedback from a field study.

1. Introduction

Advances in video and sensor technology have enabled a ubiquitous surveillance of many types of infrastructure. The motivation of this work is the application domain of road tunnel surveillance. In this domain, the surveillance is based on videos acquired from a few dozen cameras and from events which are automatically extracted from this video data (e.g., wrong-driving vehicles, lost cargo). Prior work described a design study of AlVis [PBB12] (which stands for “Alert Visualization”), a system designed to overcome limitations of current Supervisory Control And Data Acquisition (SCADA) systems [Kru06]. The key aspects of AlVis are to convey a sense of the spatio-temporal development of a scenario, to enable a situation-sensitive pre-processing and prioritization of information, and to provide an efficient access to live and historic video material (see Fig. 1).

The focus of that prior design study was on aspects ensuring situation awareness [End95] during real-time surveillance. However, activities like an in-depth analysis and detailed reporting are not possible while dealing with emergency situations in real-time. In general, surveillance activities comprise both real-time and retrospective tasks which depend on each other. Real-time tasks must ensure the availability of adequate information for performing retrospective tasks. Conversely, one goal of retrospective tasks is to identify potential problems and improvements of the real-time surveillance process. Based on experiences in our domain, designing a Visual Analytics system for video-based surveillance requires to address both real-time and retrospective tasks and to provide mechanisms ensuring a seamless interplay between both. This paper thus contributes:

- A characterization of tasks for supporting and conducting a retrospective analysis of spatio-temporal surveillance data which is based on insights from three years of collaboration with tunnel experts.
- A description of extensions to the system AlVis as a case study for supporting retrospective tasks.
- A summary of qualitative feedback from a field study where AlVis has been deployed for six months.

2. Related Work

Recent literature has emphasized the value of a problem characterization and an abstraction into tasks and data for problem-driven visualization research [Mun09, SMM12]. Several taxonomies have been classifying domain-independent tasks in context of interactive visualization [AS04, YKSJ07]. However, problem-driven research also requires a characterization of what Munzner calls high-level and lower-level domain tasks [Mun09].

Visualization literature related to surveillance comprises techniques for summarizing videos [DC03] and for addressing specific issues in video-based surveillance. Examples include a multi-resolution analysis of collections of video recordings [KDR07], highlighting detected actions with continuous abstract illustrations [BBS*08], superimposing extracted trajectory data on video sequences [HHWH11], activity analysis of overhead videos [RSSA08], and tracking persons in office buildings based on motion sensor data [IWSK07]. In the scope of designing contextualized

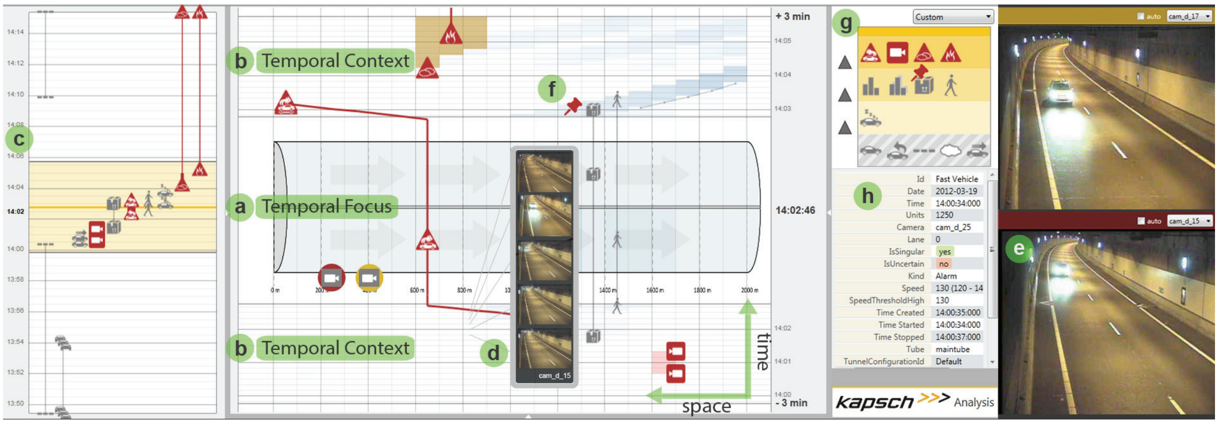

Figure 1: *The AlVis client during retrospective analysis of tunnel surveillance data (offline mode): The Spatio-Temporal View as the main element consists of (a) a tunnel sketch at a Temporal Focus (TF) and (b) the spatio-temporal development around the TF called Temporal Context (TC). (c) TF and TC can be modified within the Temporal Overview. (d) A video cursor provides access to video material for any point in time and space. It may show developments in place as a filmstrip metaphor or (e) assign videos to additional players. (f) Annotated incidents are indicated by a pin icon. (g) An interactive legend enables a prioritization of incident types and annotations. (h) Details are provided on demand for selected incidents and annotations.*

video interfaces, Wang et al. [WKCB07] describe tasks in the surveillance of buildings where the authors identified maintaining security records as a retrospective task. However, none of this work has identified lower-level domain tasks and little attention has been paid to the interplay between real-time monitoring and retrospective analysis. Legg et al. [LCP*12] described a glyph-based system for sports performance analysis. Connecting events to video data addresses both real-time and retrospective tasks. However, their focus is on the visual design rather than the task characterization and techniques supporting retrospective tasks. Moreover, tunnel surveillance as target domain enables a compact visual encoding of space and time [PBB12, AMM*08, AA05, AAD*10].

3. Retrospective Analysis in Tunnel Surveillance

This section characterizes tasks related to an analysis of data from the surveillance of road tunnels. The focus is on retrospective analysis, not mentioning tasks which solely address traffic monitoring as such (respective tasks are listed in prior work [PBB12]). The task characterization is based on experiences from three years of tight collaboration with experts of Kapsch TrafficCom AG (KTC), a company providing equipment for traffic surveillance. The task characterization has been validated in scope of a test installation in a real tunnel (see Sec. 5). The tasks can roughly be distinguished as being carried out in real-time in parallel to traffic monitoring (called *online tasks*), and being performed in subsequent to traffic monitoring (called *offline tasks*).

3.1. Online Tasks

On a high-level, the overall goal of online tasks is to ensure the availability of appropriate information for offline tasks. A key lower-level domain task is to enrich surveillance data by meta-information. Such meta-information may refer to points in time, points in time and space, and optionally to automatically generated events. Potential addressees include operators themselves, the management, or the provider of the surveillance equipment. Typical use cases include:

- Identifying relevant moments for an efficient retrieval during a retrospective analysis. Examples include incidents causing accidents (e.g., a detection of lost cargo) and other critical moments of a "story". A related goal is to denote multiple incidents as belonging to one coherent scenario.
- Indicating errors in the video-based incident detection for a potential re-calibration, i.e., denoting wrong positives, or indicating missing detections as wrong negatives.
- Preventing the deletion of surveillance video. While normal video material is erased after several hours for technical and legal reasons, operators can manually mark video material as relevant for permanent storage.

3.2. Offline Tasks

One can distinguish two broad classes of high-level offline tasks: First, reports need to be created for archiving specific incidents and as a basis for lawsuits (e.g., related to accidents). Second, an analysis of the data is conducted to determine various traffic statistics and to identify potential improvements regarding constructoral measures of the tunnel, traffic control, operator assessment, and automated incident detection. We have identified the subsequent list of lower-level domain tasks:

- **Initialization** by retrieving specific historic data.
- **Detailed inspection** of the development of a scenario.
- **Retrieval of video material** of a camera for a specified time interval. This also requires having an overview about the availability of video material.

- **Navigation** through the incident history and respective video material by shifting the focus of attention.
- **Annotation** of surveillance data for information enrichment as described for online tasks.
- **Compilation of reports** of scenarios. Reports typically include a textual description, details of relevant incidents, still images, and relevant video material.
- **Preparation of traffic statistics** including traffic densities, the frequencies of particular alarms, etc.
- **Analysis** of automatically generated incidents. Of particular interest are repetitive patterns of wrong detections (e.g., fog being mistaken for smoke) and differences in detection characteristics across cameras.

4. Case Study: Extensions of the System AlVis

This section describes concepts to address the aforementioned tasks. Being extensions to the system AlVis, these concepts build upon its visual encoding of spatio-temporal tunnel data which is detailed in previous work [PBB12].

4.1. Initialization and Temporal Navigation

AlVis distinguishes an online mode for real-time monitoring and an offline mode for retrospective analysis. In the online mode, event data is constantly streamed from the video-based incident detection. Conversely, the offline mode displays historic data within a user-defined time span. For a growing number of recorded scenarios, facilitating a scenario-specific selection of that time span is important. AlVis offers guidance based on annotations used to distinguish coherent scenarios (annotation is discussed below).

After initialization, a key difference between the online and offline modes is the concept of time. The online mode supports a distinction between the present, the past, and the future by dedicated areas of the Spatio-Temporal View as the main part of AlVis. The present is shown as a 2D representation of the tunnel, while the past and the history encode the position along the tunnel by the X axis and time by the Y axis. In the offline mode, a key idea is to re-interpret this subdivision in a focus+context manner (see Fig. 1). An interval of three seconds called Temporal Focus (TF) is shown corresponding to the present in the online mode. An interval around the TF (typically several minutes) called Temporal Context (TC) is shown above and below the TF, corresponding to the past and the future in the online mode. In contrast to the online mode, the entire TC displays historic data and no predictions are shown in the offline mode.

Additionally, the Temporal Overview (Fig. 1c) displays a significantly longer period of time by sacrificing spatial information. In the offline mode, a key interaction is to navigate time by altering the TF. We distinguish two independent levels for such temporal navigation: 1) absolute vs. relative and 2) time-based vs. event-based:

- **Absolute time-based navigation** provides quick access to an arbitrary point of time as well as a continuous navigation by dragging the representation of the TF in the Temporal Overview.

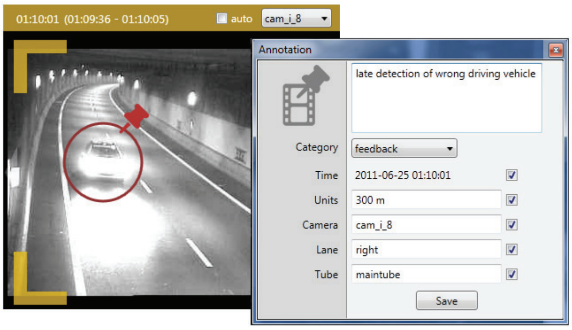

Figure 2: *Annotation of videos and specification of details.*

- **Absolute event-based navigation** enables to precisely set the TF to a specific event by clicking on it.
- **Relative time-based navigation** increments or decrements the TF by a user-defined period (e.g., one minute). Repetitive application supports browsing the data in a well-defined time raster.
- **Relative event-based navigation** sets the TF to the next (or previous) event having a specific type or priority, enabling efficient tracing of key moments of a scenario.

4.2. Annotation

Annotation is a key interaction for insight externalization [CBY10]. In our context, annotation is used to enrich surveillance data by meta-information as a basis for retrieval, navigation, reporting, and analysis. AlVis offers annotation functionality in the online and offline mode. The idea is to utilize the visual encoding of AlVis for specifying reference information with a single click. This reference information always contains a point in time and it may optionally contain a point in tunnel space, a particular event, and a position in image space of a specific surveillance video.

AlVis offers a dedicated Annotation Cursor which is applicable to multiple visual components: Inside the Spatio-Temporal View, a click specifies a point in time and tunnel space. The TC specifies only the position along the tunnel while the TF additionally defines a particular lane. Clicking on an icon adds a reference to the respective incident. Inside the Temporal Overview, a click only provides a temporal reference. Inside a video player, a click specifies a point in time, a point in tunnel space (i.e., the camera position), and a position in image space which is surrounded by a circle having a user-defined radius (see Fig. 2). In addition to this reference information, each annotation also contains a screen shot of AlVis. For specifying the semantics of the annotation, users may enter text and tag the annotation using pre-defined categories (e.g., “critical incident”, “misclassification”, “note”). In our experience, tag-based annotation has proven to be fast enough to be applicable even during stress situations. Moreover, consistent categories largely facilitate automated processing (e.g., characterizing misclassifications).

After creation, annotations are visualized in multi-

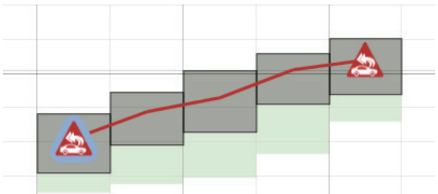

Figure 3: *Video export of an incident spanning multiple cameras (the trajectory of a vehicle). Green indicates available material and gray denotes exported intervals.*

ple ways. The Spatio-Temporal View and the Temporal Overview display icons similar to incidents (Fig. 1f). Annotation icons can also be prioritized or hidden (Fig. 1g) and clicking on annotation icons shows details on demand (Fig. 1h). During video play back, annotations are indicated by circles around the specified position in image space. An optional list view provides a textual overview of annotations and enables filtering and ordering.

4.3. Export

The compilation of reports is a frequent and tedious task of operators. AlVis facilitates the preparation of basis material of reports for subsequent processing in external tools:

- **Compilations of surveillance videos.** A key advantage of the Spatio-Temporal View is to enable the specification of spatio-temporal intervals by intuitive 2D interactions. In particular, the export of video material affecting multiple adjacent cameras can be specified by a 2D rubber-band selection which corresponds to an interval in time for a region in space. Alternatively, exporting the spatio-temporal neighborhood of selected incidents supports an intuitive specification of arbitrarily shaped yet semantically meaningful regions (see Fig. 3). In this context, visualizing the availability of video is crucial information.
- **Still images of surveillance videos.** Video players enable an export of single still images or groups of still images (e.g., every 10 seconds) in standard bitmap formats.
- **Spatio-temporal overviews of scenarios.** Operators have found the Spatio-Temporal View to efficiently summarize the development of scenarios. The Temporal Context can thus be exported as a bitmap image which optionally shows annotations as labels.
- **Annotated event data.** Annotations can be exported as viewable HTML files including screen shots, as XML-based log files, and via SQL queries.
- **Statistical summaries.** Server-side extensions for retrospective analysis concern the computations of aggregated time series. Specifically, aggregations refer to types of events and a temporal unit (e.g., "average speed per hour and camera" or "count of occupied breakdown bay events per week"). Such data is the basis for traffic statistics and multivariate analysis in external tools.

5. Feedback

For evaluation, AlVis was deployed for six months in 2012 in the traffic control center of Munich / Germany, where it was in daily use by operators for surveillance of a highly frequented city tunnel. Before using AlVis, monitoring and retrospective analysis were solely based on the capabilities of classical SCADA systems. In addition to a positive overall feedback of AlVis as detailed in previous work [PBB12], the operators stressed the importance of the extensions for retrospective analysis. As a key message, these extensions have been described as effective for improving the quality of the overall surveillance process (e.g., by supporting the identification of wrong detections) and for reducing the effort of routine tasks like creating reports.

Specifically, the operators emphasized the benefits of the extended version of AlVis for a context-sensitive export of surveillance videos as compared to their previous tools. An identification of relevant and available video material is straightforward in AlVis (see Fig. 3). This has previously been cumbersome especially for incidents spanning multiple cameras based on the video functionality of SCADA systems. The tight integration of the annotation functionality in the spatio-temporal visualization and the video players has also been mentioned as very helpful for the preparation of reports, the archival storage of scenarios, and the validation of the incident detection, e.g., revealing a detection of smoke close to the portal as caused by the angle of the sun. Reinterpreting the layout of the Spatio-Temporal View in a focus+context way in the offline mode has been found intuitive and effective even for long scenarios. As the most relevant aspect for future work, the operators mentioned a simultaneous surveillance of multiple tunnels due to a trend towards centralization in traffic surveillance.

6. Conclusions

This paper focused on a characterization of tasks related to a retrospective analysis of surveillance data in the application domain of video-based road tunnel surveillance. We identified high-level and lower-level domain tasks and distinguished between tasks which are carried out in parallel and in subsequent to traffic monitoring. The paper also described concepts regarding temporal navigation, annotation, and export for supporting these tasks in a system for tunnel surveillance. Feedback from a field study in a real tunnel emphasized the importance of retrospective tasks and confirmed the effectiveness of the respective extensions. An interesting aspect of future work will be to compare in how far this task classification and key concepts like integrated annotation are applicable to different domains of real-time surveillance. Our observation is that real-time and retrospective tasks depend on each other for surveillance activities. We thus see a general need for interfaces combining both aspects as an implication of our work.

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