LOOK2: A video-centric system for real-time notification and presentation of relevant traffic situations in Austria

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Abstract This paper presents a novel traffic information system for publishing fast and highly accurate traffic information about *level of service* (LOS) and *weather-related road conditions* (WRRC) on motorways in Austria. The proposed system periodically fuses low-level measurement data of a number of simple, common road-side sensors with high-level traffic information gained by so-called smart sensors. Smart sensors perform live video stream analysis in real-time, either in the compressed domain as added value to simple, common surveillance cameras or in the uncompressed domain on smart cameras. The gained traffic information is finally published via an extended, DATEX II compliant service to a traffic desk application providing notifications for traffic editors and operators about new, relevant situations on the roads. Geographic maps and recorded or live camera streams are also presented to the users, thus enabling them to visually validate the published messages and even correct them if necessary. Evaluations of the system have shown considerable benefits compared to existing systems, both in terms of reporting and verifying relevant traffic situations.

Keywords: Smart sensors, video analysis, real-time event detection, sensor data fusion, traffic desk application, video-based traffic situation verification, self-organizing system

1 Introduction

Getting relevant traffic information from a road network in real-time is a very important issue for road network operators and radio traffic channels. Usually, a high number of traffic data of various types (e.g., sensor data, floating car data, and road toll-based travel times) is available. Commercial traffic information systems access these data in order to determine the current traffic state, the prevailing road conditions, or to get notice about possible threats on the roads (e.g., accidents, lost goods, or ghost drivers). These traffic information systems work usually well for their main purposes, but there is still a high potential for improving the whole process of detecting relevant traffic situations faster, more accurate, and better integrated. Our observations are mainly based on the traffic information system of the Austrian motorway operator (ASFINAG), nevertheless, other countries and road operators cope with very similar problems. We identified the following five main issues the users (such as traffic operators[1]) and also the developers of traffic information systems are confronted with:

- **Isolation of applications:** Usually, different applications are in use for each different type of traffic information; sometimes there are even several data sources for one type. Typically, there are several applications to query and present the current traffic state, to determine the road and environmental conditions, as well as to get noticed about possible threats on the roads. All these applications work often isolated, have different data sources, and do not interact with each other. Regarding the traffic information type *traffic state*, this separation is probably the worst. Frequently, there is one application to present the traffic state computed from mounted traffic sensors on the roads. Another application determines the traffic state from floating car data, and a third application utilizes road toll-based travel times of heavy good vehicles (as, e.g., GO-SMART [20] in Austria). It is up to the operator/editor, to figure out the most reliable application for a given situation.
- **Low accuracy of information:** The accuracy of the provided traffic information heavily depends on the density and accuracy of the available traffic data sources. First, the more accurate the measurements are, the more accurate the extracted traffic information is. For example, the more precise the measurements of traffic speed and traffic density are available, the more accurate the derived traffic state is. Second, the denser a sensor network is, the more precise is the information about the geographic extension of a traffic situation. Existing traffic information systems often do not handle traffic data sources with low measurement accuracies adequately. Traffic information systems which involve a non-equally distributed sensor infrastructure have problems in providing reliable traffic information in road areas with sparse sensor populations. Microscopic models like in [14, 15] for measuring the individual quality of traffic information have approved this accuracy lack.
- **Difficult real-time validation:** The validation of generated or claimed traffic information by traffic operators/editors is difficult to accomplish in real-time. Validations are typically based on reviews of the source traffic data or manual look-ups of corresponding surveillance camera images/videos in other applications. Only little work has been done on automatic association of sensor data with image/video data from available surveillance cameras. An attempt of video-based traffic message verification in real-time was done in [10]. The results have clearly shown that the visual verification process should be applied on the early sensor data level, and not on the traffic message level.

[1] A traffic operator is a human who controls the traffic flow from a control center.

- **Proprietary services:** The majority of commercial traffic information systems still utilize proprietary and non-extensible protocols for exchanging traffic information, sensor data, and multimedia data between services and client applications. For traffic data exchange between traffic system components very often arbitrary structured comma-separated-value exports are used. Standards like DATEX [1] or its successor DATEX II [13] are rarely used. The situation is similar in exchanging traffic-related multimedia data. While the encoding and communication of multimedia data in most systems follows well-known standards like MPEG4 [2], H.264 [19], and RTP [5], the control protocols are still proprietary. An example for such a control protocol for the traffic domain is MoRIS [3]. These circumstances make the development of open, multimedia-enhanced traffic information services costly, both on the traffic data producer and especially on the consumer side. Instead of proprietary protocols for traffic information exchange, standards like DATEX II should be rather preferred. DATEX II provides three levels of extension and hence also enables for a standard-compliant integration of multimedia data in the traffic information exchange.
- **Lack of self-organization:** Self-organization principles and design paradigms as proposed in [18] have found application in the traffic domain in the area of wireless inter-vehicle communication. Self-organizing traffic information systems, like SOTIS [16, 17], are completely decentralized and do not need any sensor infrastructure along the highways. This approach promises high traffic information accuracy and low communication delay, but is far away from being applicable and especially combinable with pre-installed sensor infrastructures, which are still dominant today. In current infrastructure-based traffic information systems, self-organization principles are not considered in large part. However, some principles like emergent behavior and adaptability with respect to changes in the environment (e.g., by taking into account feedback of traffic editors/operators) are well applicable.

In this paper, we present a traffic information system entitled *LOOK2*, which addresses these problems and suggests several solutions. LOOK2 is a video-centric system for real-time notification and presentation of relevant traffic situations on Austria’s motorways. LOOK2 is named after its predecessor, the LOOK system [10], which enables for video-related traffic message verification in real-time, with certain limitations. LOOK2 served also as a traffic domain-related case study in a substantial research project dealing with self-organizing multimedia architectures (the “SOMA” project). LOOK2 does not operate only on the level of traffic messages; much rather, it directly operates on sensor and video data available from the sensor and video surveillance camera network. LOOK2 introduces two different kinds of smart sensors: (1) Smart cameras, containing sufficient CPU power and memory to implement video analysis directly on board and (2) Server-side software extensions to common, simple cameras (a large number of them available on the Austrian motorways). All available sensor data are fused to determine traffic situations of type *level of service (LOS)* (i.e., traffic state) and *weather-related road conditions (WRRC)* with focus on snow on the road. The derived traffic situation information is finally published via a DATEX II compliant Web service, together with proof video recordings from smart sensors as well as references to corresponding camera live streams. Finally, the LOOK2 systems comes up with an interactive Web-based traffic desk application, which periodically fetches actual traffic information from the DATEX II service and presents this information to traffic editors and operators for further decision taking. Therefore, an integrated visualization of traffic information utilizing standard-compliant geographic maps, video summaries utilizing SMIL technology [21], and live stream access to the camera network is provided. The traffic editors and operators can easily verify the proposed relevant traffic situations and give feedback to the system, if a proposition is not correct. The feedback to the system is also communicated in terms of DATEX II messages and internally taken into account by the fusion service in future sensor data fusion steps. The whole LOOK2 system is built upon Open Source technology, which has been extended in several parts for our purposes.

Evaluations of the system on dedicated test tracks on Austrian motorways have shown a very high LOS classification precision (about 95%) of our smart sensors [26]. The traffic situations generated by the fusion and DATEX II traffic information services have also shown a high reliability. The system was evaluated by ASFINAG's traffic operators for several weeks. The main feedback was that the system considerably improves the notification process about relevant happenings on the roads. It also provides a comprehensive multimedia-based view on the reported events.

The remainder of this work is organized as follows. Section 2 gives a brief presentation of the overall LOOK2 system architecture. In section 3, the two types of LOOK2 smart visual sensors are described, including smart sensors for fixed surveillance cameras and smart cameras. Section 4 gives some insights into the fusion process. The output of the fusion service is transformed to standard compliant DATEX II traffic information descriptions. This service is discussed in section 5. The interactive LOOK2 traffic desk application for traffic editors and operators is topic of section 6. Section 7 presents our main system evaluation results. And finally, section 8 concludes this contribution with some perspectives about our future work.

2 System architecture

Figure 1 gives an overview of the LOOK2 server system architecture. It consists of 10 main central services, 2 web applications, and an arbitrary number of smart sensors. The system complexity is divided into six layers. The bottom layer (layer 0) is not specific to LOOK2 and provides sensor and video data of the road network operator. From the designs point of view, the set of covered sensors includes (i) infrastructural sensors like environmental sensors (measuring parameters such as lane state, lane temperature, or precipitation intensity), vehicle classifier and speed sensors, and sensors belonging to the road toll system, and (ii) mobile sensors providing floating car data and high-level traffic information in case of reporting drivers. Regarding video surveillance data, the set of covered cameras includes fixed and PTZ (pan/tilt/zoom) cameras. Mobile sensors and PTZ cameras are currently not implemented, but planned to be supported in the near future (see dashed boxes).
The *external data access layer* (layer 1) is the first LOOK2 specific layer which is responsible for periodically importing and receiving measurement data and traffic information from external sensors. This includes measurement data from environmental conditions sensors, vehicle classifiers, road-toll systems, and floating cars, as well as traffic information (LOS, WRRC) from reporting drivers. It also provides a camera gateway and stream relay service for accessing and controlling MPEG4/RTP-based live streams from the available surveillance cameras. For accessing camera live streams in the ASFINAG video system, the MoRIS XML control protocol is used. The mobile sensor data input service is planned to be implemented in the near future (see dashed box).
The second LOOK2 specific layer (layer 2) is the *smart sensor layer*. It includes smart detectors on a number of smart cameras, as well as for an arbitrary number of fixed surveillance cameras. Smart sensors generate LOS and WRRC estimations as result of uncompressed and/or compressed domain video analysis. Smart sensors also operate a feedback service for the above layer (data fusion) to get informed about the quality of the provided LOS and WRRC estimations.
The *data fusion layer* (layer 3) is the core system layer. It periodically receives and stores all kinds of sensor data from the external, mobile, and smart sensors. Smart sensors provide high-level traffic situation information in terms of LOS and WRRC estimations obtained from video analysis. In case the observed LOS or WRRC state changes, these sensors also provide short proof recordings to the *fusion input service*. The main service of this layer is the *fusion service*, which periodically transforms incoming sensor and feedback data to new LOS and WRRC snapshots of the observed tracks.

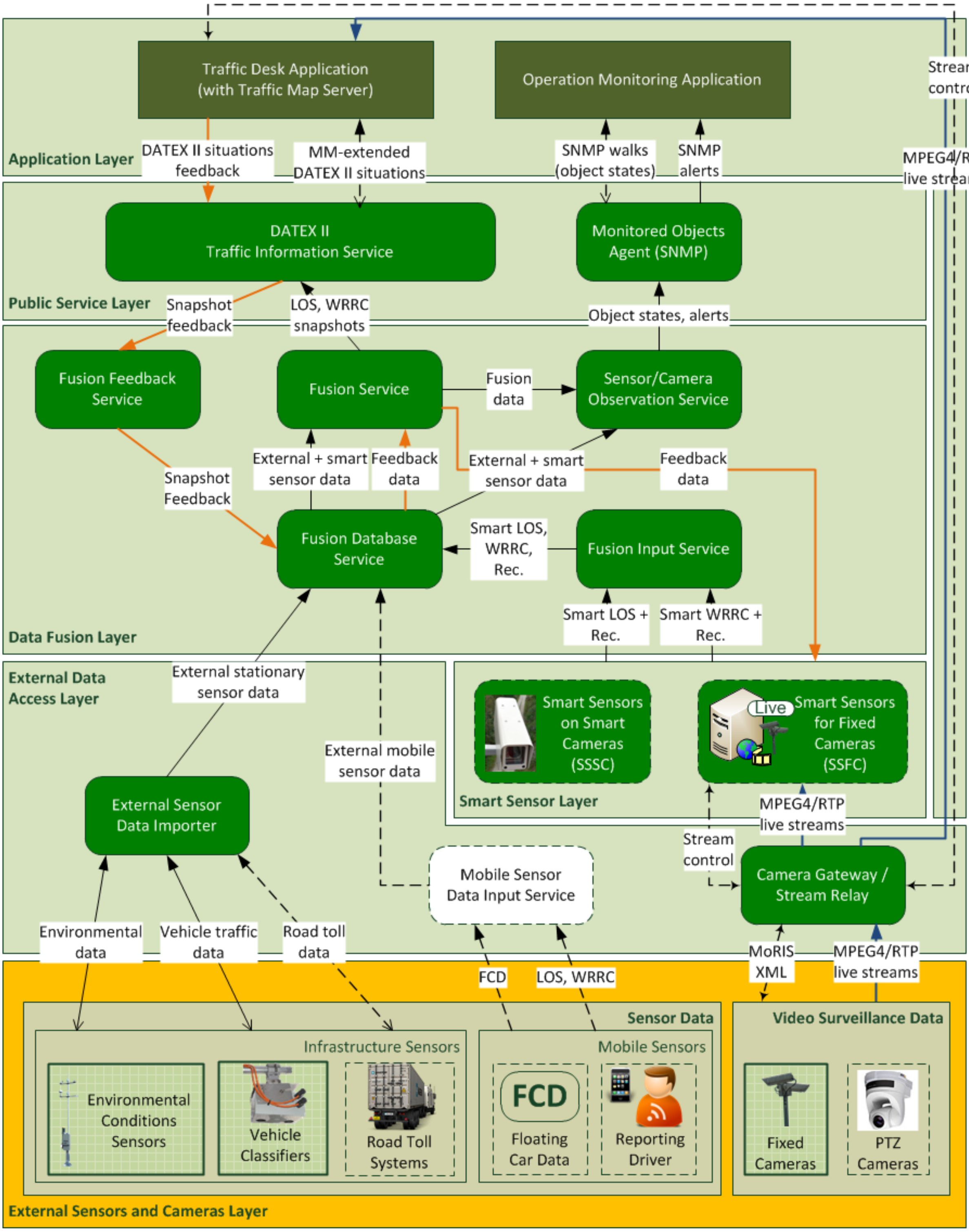


Figure 1 – LOOK2 server system architecture overview

This is accomplished by a grid-based spatio-temporal data fusion approach, taking into account spatial and temporal distances of measurements to corresponding spatio-temporal fusion points. Sensors detected to not have correlated measurement values with other sensors within a grid cell are reported to the *sensor/camera observation service*. This service is responsible for monitoring the measurement series of each sensor and, in case of smart sensors for fixed cameras, the working state of each used surveillance camera. Sensor and camera object states, as well as detected malfunctioning of them are published to the upper layer. Finally, the *fusion feedback service* is responsible for taking over corrections from the traffic editors and operators, and storing them for later use of the fusion service (see the orange feedback flow arrows).

The fourth LOOK2 specific layer is the *public service layer*. The services in this layer implement LOOK2 interfaces which are open to registered users of the LOOK2 system. The *DATEX II traffic information service* receives the LOS and WRRC snapshots from the fusion service, transforms them to DATEX II situations by applying spatio-temporal situation reasoning, and implements a DATEX II compliant web service. Here, level B extensions are applied to the DATEX II standard to include user authentication and the integration of multimedia stream references into situation descriptions. The *monitored objects agent* enables for querying the current states of all covered sensors and cameras via SNMP walks, as well as pushing alerts about malfunctioning sensors/cameras via SNMP traps.

Finally, the fifth LOOK2 specific layer is the user-level *application layer* which includes the two web applications *traffic desk application (TDA)* and *operation monitoring application (OMA)*. The TDA periodically fetches active situations on the monitored tracks from the DATEX II traffic information service and presents these situations in a geographic map, and corresponding video recordings from the smart sensors in a synchronized summary. Traffic editors and traffic operators can verify the published LOS and WRRC situations, and correct them, if necessary. Corrections are sent back to the DATEX II service via a feedback channel. The OMA is a non LOOK2 specific SNMP manager application, which allows querying the sensor/camera states from the SNMP agent, as well as getting informed about malfunctioning of them via SNMP traps.

The following sections describe some aspects of the most important services in more detail.

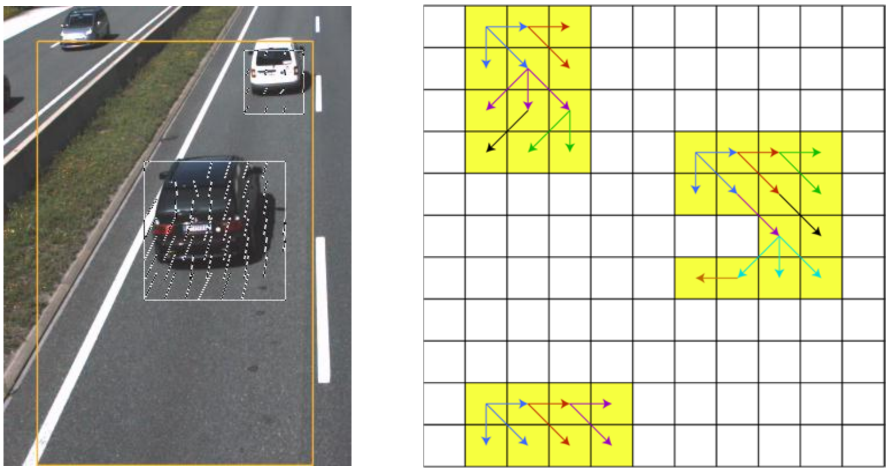
3 Smart sensors

Smart sensors are sensors which determine LOS and WRRC information themselves by analyzing live video data. In contrary to the other road-side sensors, smart sensors are providing high-level traffic information to the fusion service, and not plain measurement properties like traffic speed or density. Two kinds of smart visual sensors have been defined: (i) server-side sensors for common, simple surveillance cameras and (ii) sensors as additionally mounted smart cameras.

3.1 Smart sensors for fixed surveillance cameras

This type of sensors performs LOS estimations completely in the compressed MPEG4 video domain. Based on a set of only four statistical features of selected motion vectors within a defined region of interest (ROI), a method utilizing a Gaussian radial basis function network (GRBFN) is used to estimate the LOS. Tests on a comprehensive data set have shown an average estimation accuracy of more than 86% for four LOS levels [22, 23]. Being able to analyze hundreds of camera streams in parallel on a standard server computer also approved the usability of this method. Figure 2 illustrates the region growing method used to cluster motion vectors within the ROI.

WRRC estimations are done in the uncompressed domain by selectively decoding I frames. WRRC estimations include the detection of risky driving conditions like snow on the road and aquaplaning. The estimations are basically done on statistical color features.

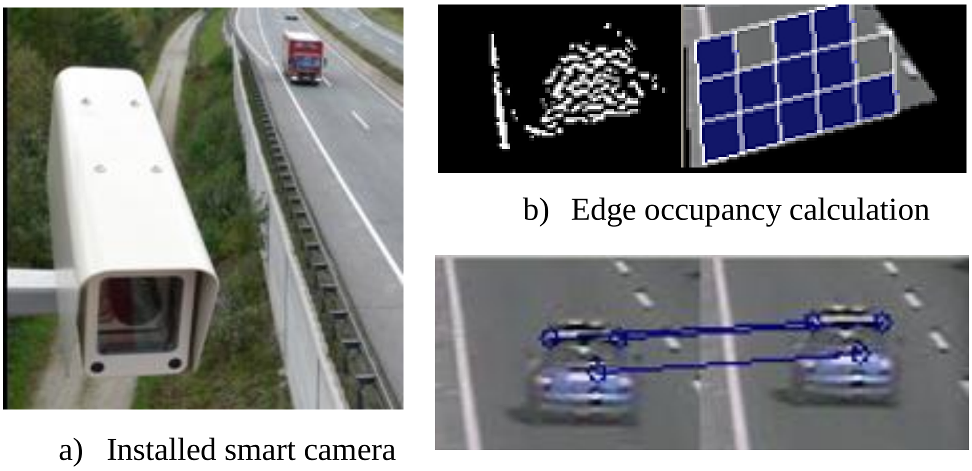


a) ROI with motion clusters b) Region growing method

Figure 2 – Motion vector clustering with region-based growing

3.2 Smart cameras as smart sensors

Smart cameras perform the video analysis in the uncompressed domain by directly processing the RGB frames from the camera sensor on board. Two LOS detection methods have been implemented: (i) a learning-based statistical method and (ii) a measurement-based statistical method. In (i), a set of statistical features of computed motion vectors is used to feed a GRBFN for training and classifying the LOS. This method can be applied to uncalibrated cameras and achieves an average classification accuracy of more than 86% [11, 12]. In (ii), vehicle speed and density are computed directly from KLT motion vector and binary edge statistics. LOS is then computed from these measures via the national LOS computation guide MARZ [27]. This method achieves a precision of more than 95% for detecting stationary and free-flow traffic [26]. However, the cameras require a preceding calibration.



a) Installed smart camera

b) Edge occupancy calculation

c) KLT feature tracking

Figure 3 – Smart camera with edge occupancy calculation and KLT vector matching

Figure 3 depicts an installed smart camera (subfigure a)), the block-based edge occupancy calculation for the density feature (subfigure b)), as well as the KLT feature tracking [24] (subfigure c)) to compute the motion vectors.

4 Fusion service

For all monitored test tracks, the fusion service transforms all incoming sensor data (i.e., environment and vehicle-related measurements, as well as LOS and WRRC measurements from the smart sensors) to LOS and WRRC snapshots. An example LOS snapshot is given in Figure 4. It is composed of a series of LOS regions, whereas each region is composed of a series of fusion results with equal LOS level. A LOS fusion result is computed for each fusion point, whereas the number of fusion points depends on a configurable fusion cell size. In this example, region 1 covers the fusion result *stationary traffic* for the fusion points at km 0.5, 1, 1.5, and 2. Since at km 2.5 the fusion result has level *queuing*, it starts a new region. The data fusion algorithm takes into account all relevant measurements within the enclosing fusion cell. Thereby, spatial and temporal distances of each measurement, as well as confidences in the source sensors are considered to estimate the final LOS level.

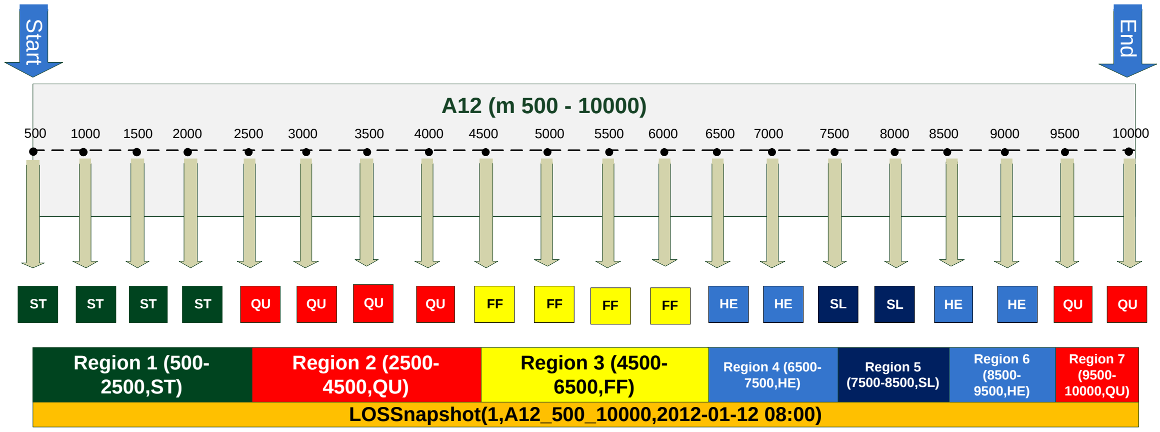


Figure 4 – An example LOS snapshot

5 DATEX II traffic information service

The DATEX II traffic information service (D2TIS) is the main reasoning service about abnormal traffic and weather-related road condition situations according to the DATEX II standard. As illustrated in Figure 5, it is located between the fusion service and the TDA, and consists of the input and output web services, as well as a database service.

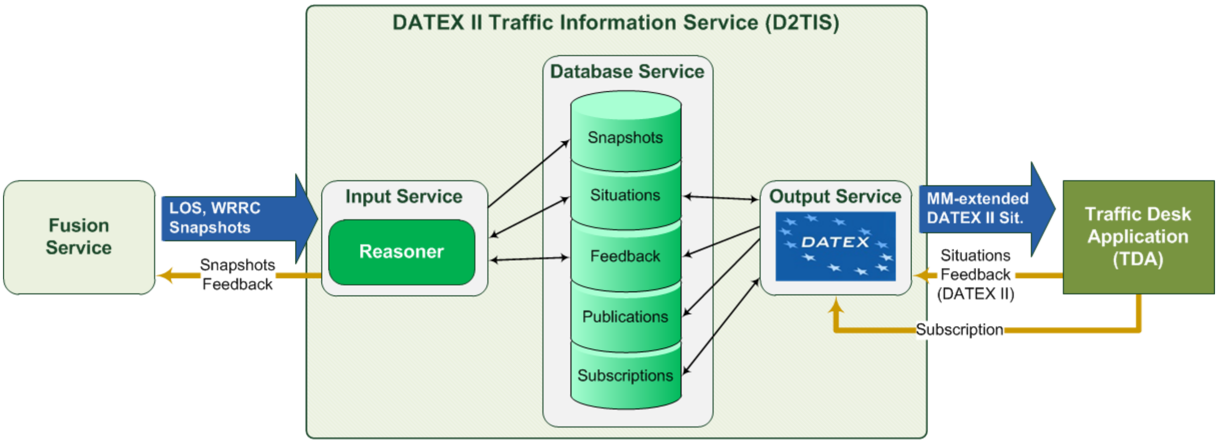


Figure 5 – Internal components of the D2TIS

Receiving LOS and WRRC snapshots from the fusion service, the input web service' reasoner component performs a spatio-temporal analysis of these snapshots and computes new LOS and WRRC situations (or versions) based on the set of current active situations. With the versioning of situations, this service is also able to track the whole evolution of situations. With the help of the reasoning engine, spatial relations between LOS and WRRC situations are inferred. It can determine, e.g., that a heavy traffic situation is related to impeded driving conditions caused by snow. The input service also translates received DATEX II feedback from the traffic editors/operators to snapshots feedback, and sends it back to the fusion service.

On the output side, the output service publishes actual traffic situations and their relations to the traffic desk application on demand. It also provides means to subscribe to the service, as well as to receive feedback about the published situations, again encoded in DATEX II messages.

6 Traffic desk application

The traffic desk application (TDA) is the main web-based user frontend application of the LOOK2 system. It enables traffic operators and editors to get notified about relevant LOS and WRRC situations on the observed tracks, as well as to make corrections to these situations and give feedback to the system. It does this by (i) periodically querying the DATEX II traffic information service for the current active situations, (2) generating geometries for these situations with the help of an internal traffic map server (TMS), and (3) showing the situations with reference to the earth surface and relation to the recorded as well as available camera live streams.

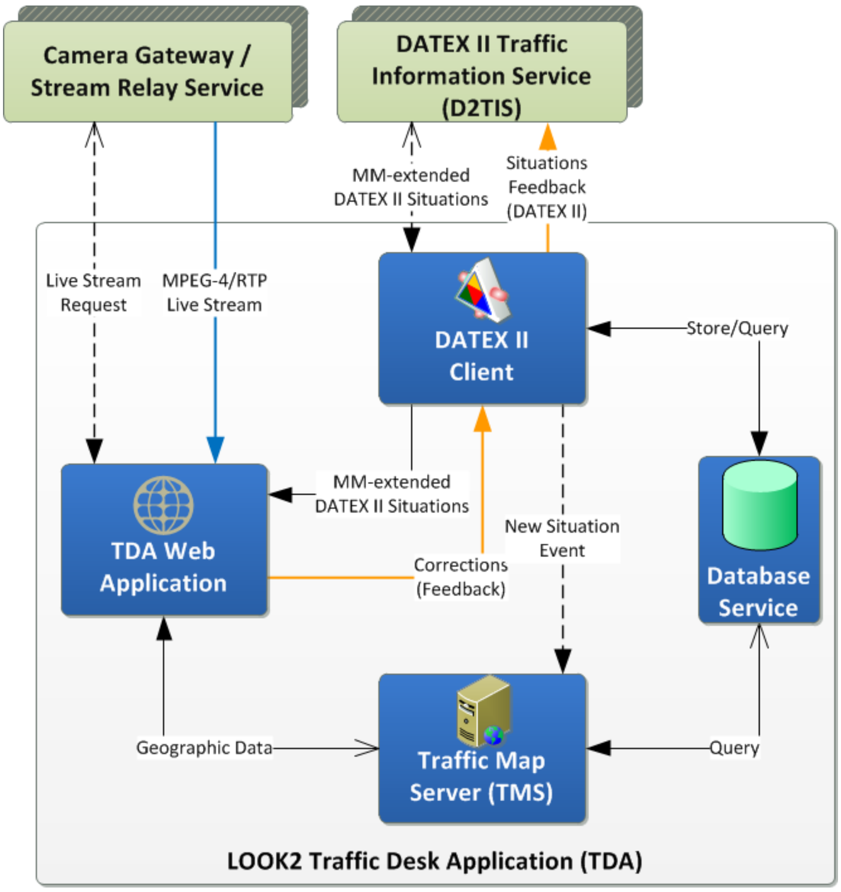
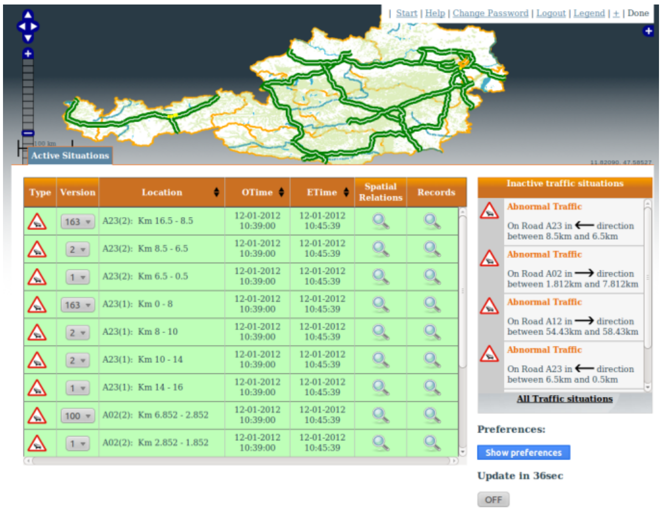
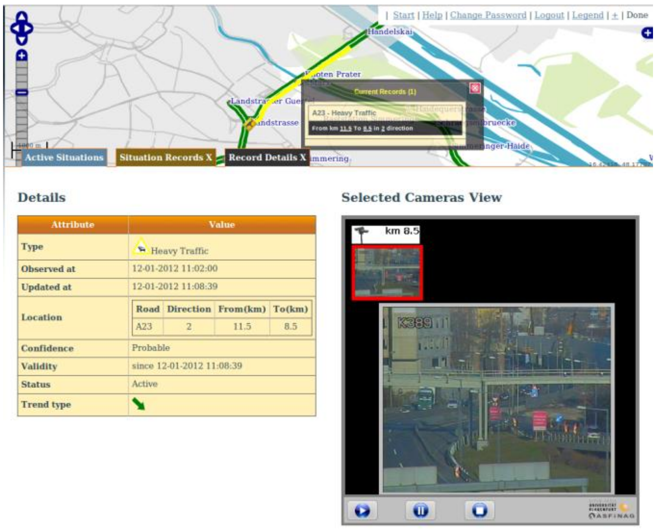


Figure 6 – Internal components of the TDA

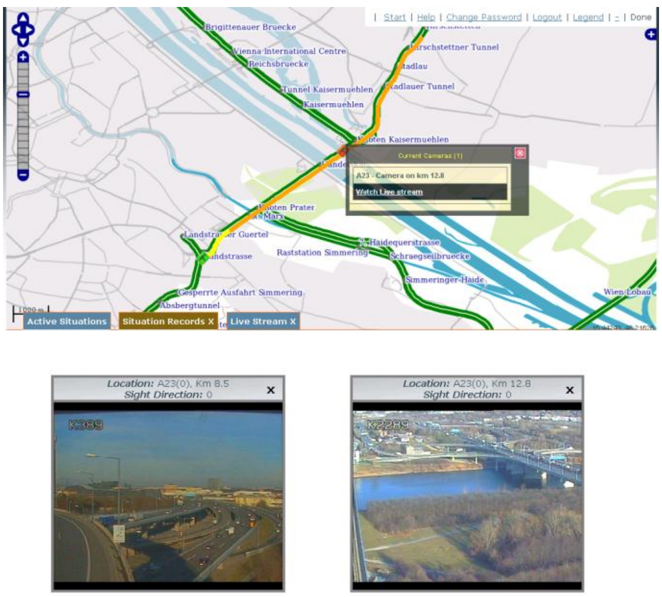
Figure 6 illustrates the internal components of the traffic desk application to accomplish these tasks. The TMS is based on the Open Source GeoServer system [8], which implements standard compliant OGC web map and web feature services. As database system for storing and retrieving the geographic data a PostgreSQL instance with PostGIS extension [7] is used. For map rendering in the TDA web application the OpenLayers library [9] is used. Users can then spatially and thematically validate a proposed situation by utilizing the interactive map, provided stream recordings of the smart sensors, as well as by connecting live streams of cameras in the situation's geographic area.



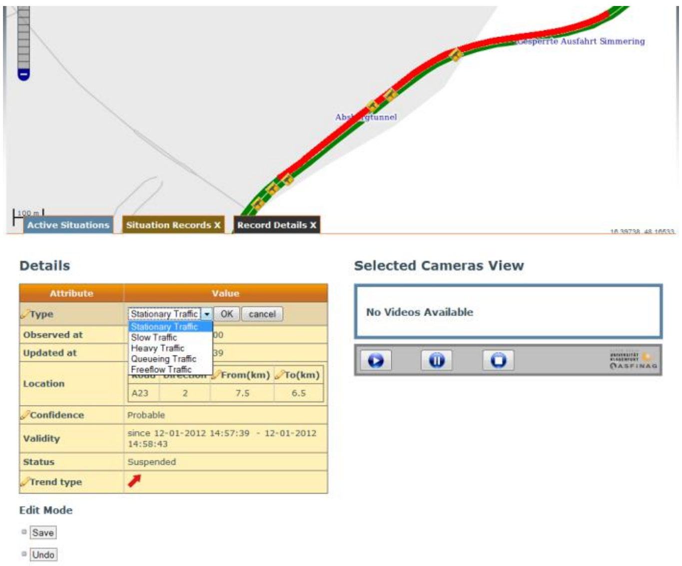
a) **Overview of active situations**



b) **Details of a heavy traffic record**



c) **Connecting live streams via the map**



d) **Giving feedback about wrong LOS level**

Figure 7 – Impressions of the traffic desk application

Figure 7 gives some impressions about the usage of the TDA. Subfigure a) shows the top-level view on current active LOS situations (left side). The map on the top shows the motorway network of whole Austria and also displays the active situations on this network. The details of a heavy traffic record within a LOS situation are shown in subfigure b). Here also a visual summary from smart sensor recordings is provided (integrated as SMIL [21] presentation by using the Ambulant player browser plugin [25]). Subfigure c) illustrates the validation step by utilizing camera live streams. Here the user connected two camera live streams via the map to make sure a LOS situation with queuing (orange) and heavy (yellow) traffic records is correct. Finally, subfigure d) depicts the process of changing the level of a LOS situation record and giving correction feedback to the system.

7 System evaluation

The LOOK2 system was evaluated by traffic operators of ASFINAG in January and February 2012. Aside the high LOS detection precision of the smart sensors for the uncompressed and compressed video domain (described in [26] and [22], respectively), the traffic situations generated by the LOOK2 fusion service have shown a high accuracy during the evaluation period. The generated traffic information quality was able to compete with that of the reference system GoSmart [15], which is based on road-toll data. However, there where three main advantages of LOOK2 reported by the operators: (i) the time needed to generate the same traffic information quality was much less; (ii) LOOK2 enables for an automatic notification of relevant traffic situations, as e.g. the building-up of a stationary traffic; and (iii), the integrated provisioning of camera live streams enables for a much faster traffic situation verification.

8 Conclusion

This paper has presented a novel traffic information system for generating fast and accurate traffic information, in particular *level of service* (LOS) and *weather-related road conditions* (WRRC) on motorways in Austria. The system is composed of a large number of services and components to gather various low-level data and generate high-level traffic information, by utilizing video stream analysis and sensor data fusion. Smart sensors for common, simple surveillance cameras of the road network operator ASFINAG, as well as smart cameras perform feature-based video analysis in the compressed and uncompressed video domain, respectively. The obtained prevailing LOS and WRRC estimations are fused with the low-level traffic data to generate accurate traffic situation snapshots. A subsequent reasoning of LOS and WRRC situations enables for a publication of highly accurate information about abnormal traffic and WRRC situations using the upcoming DATEX II standard. The published DATEX II traffic messages are extended by references to proof video recordings and live streams of surveillance cameras within the corresponding geographic locations. Finally, traffic editors and operators consume the published messages via an interactive web-based traffic desk application. This application allows them to easily verify the spatial and thematic accuracy of the messages by using geographic situation maps, as well as corresponding recorded and live video data. The editors/operators can also correct the proposed situations and provide feedback to the system. Evaluations of the smart sensors have shown high classification accuracies for LOS of more than 95% in the uncompressed video domain. Evaluations of the overall LOOK2 system have shown considerable benefits compared to existing systems, both in terms of notifying and verifying relevant traffic situations.

9 Acknowledgements

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