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SYNERGETIC TELECOMMUNICATION AND EARTH OBSERVATION DATA FUSION FOR ROAD TRAFFIC MONITORING

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Abstract

Public and market-oriented services in the field of traffic telematics require the provision of reliable and up-to-date traffic data. The presented innovative traffic observation concept *TrafficEye* is based on synergetic usage of satellite-based telecommunications and Earth observation resources by using data fusion techniques. In this way, it supplements existing, solely terrestrial systems. The backbone of the observation system is based on primary data generated by a certain set of co-operative vehicles that send their data (*FCD - Floating Car Data*) in real-time via a radio link to a telecommunications satellite. These messages are collected by the satellite payload continuously and originate directly from the actual traffic situations. The observation process is supported by synchronous complementary image data gained by either optical or microwave payloads. In the ground segment, this raw traffic data is fused and aggregated with other terrestrial traffic raw data to obtain best possible traffic information for commercial services.
This paper reports on the differences to terrestrial FCD-based systems which are currently under development, as well as to the potential of information enhancement through complementary image data. First results on relevant enabling (key) technologies in the area of image processing (small object detection by processing of sub-pixel information, real-time algorithms for the on-board data classification, data reduction, data compression, data fusion) are presented as well as techno-economical life cycle figures.
The presented results are based on relevant studies on satellite constellations (university satellite *TrafficEye*) and on first results of an on-going ESA Project (RTMS – Road Traffic Monitoring via Satellite), the world-wide first FCD implementation using a direct satellite communication link (ESA's PRODAT system).

Introduction

Traffic Telematics – Information Networking

Public and market-oriented services in the fields of traffic telematics, including traffic management and traffic data gathering, will play an ever increasing economic role in the next decade. According to recent estimates they will reach a monetary value of 40 to 50 billion Euro in the next decade. [BMV97].

Inherently, the quantitative largest potential lies in the area of road traffic (individual traffic). Besides this, equivalent technology solutions can also be used for similar observation targets as railways or waterways. The demand for customer-oriented and therefore directly marketable traffic information services can be reduced to two key qualities of traffic information: high *reliability* and high *actuality*. Unfortunately, traffic situations inherently have adverse properties in their local distribution and time variance.

The concrete implementation of solutions for the problem area of traffic telematics can be derived from actual developing tendencies in the field of information networking. There, the following generic tasks can be formulated:

I. *Provision* and *acquisition* of information,
II. *Processing* and *generation* of *value-added* services,
III. *Transmission* and *distribution* of information.

The operating efficiency of a traffic telematics concept is largely determined by its ability to solve the basic problems of *information gathering* (I). Only the sufficient ability to observe the traffic process results in an effective assessment and controllability of the overall traffic situation through the subsequent steps of information *processing* (II) and information *distribution* (III) (*'You cannot control what you cannot measure'*).

Actual Systems in Traffic Telematics

Current traffic telematics systems use primarily terrestrial resources, e.g. technologies like road-implemented sensors (induction loops, infrared sensors attached to road bridges); individual communication over the GSM cellular network; global information distribution through TMC and RDS. Today, satellite-based navigation technologies (GPS) are merely used for the acquisition of information (I). This allows a certain degree of observability of tracer vehicles (samples), but the spatial observation of the overall process has to be limited to urban areas and selected main roads for cost reasons.

Satellite-based Systems in Traffic Telmatics

Satellite-based information systems gain their attractiveness mainly from their excellent properties of *global access* and *independence of terrestrial infrastructure*. An excellent example is satellite-based navigation on the basis of the Global Positioning System (GPS), representing the backbone of today's traffic telematics systems. As a next step, it is obvious to perform an analysis of strong and weak points of satellite systems considering benefits and system-specific limitations.

This analysis is necessary to utilise the benefits and potentials in the best possible way to support other tasks in existing and future traffic telematics networks.

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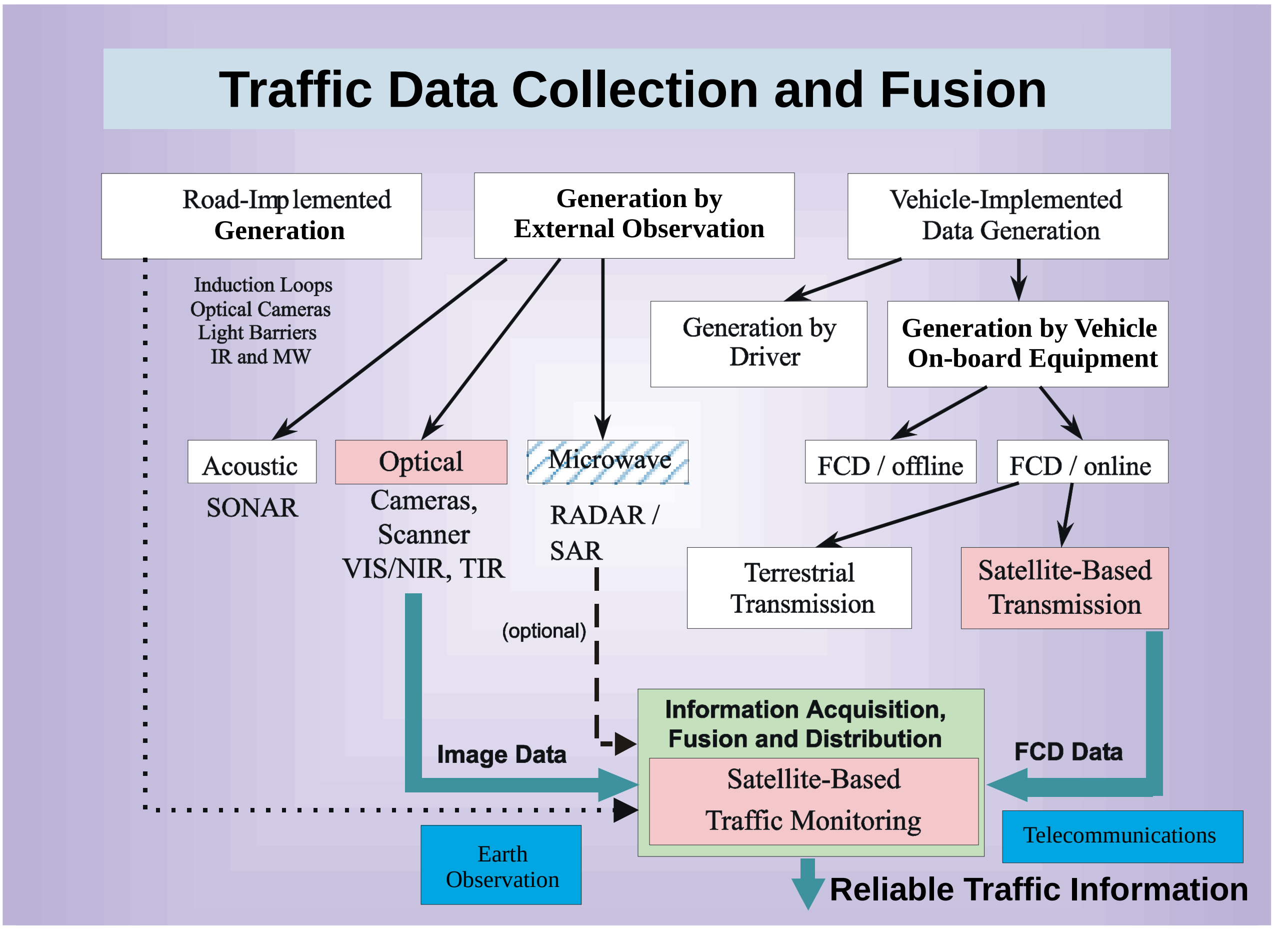

Figure 1: Methods for the generation of traffic data.

Consequently, solutions for the problem areas information gathering, information transmission and information distribution are of particular interest. They are inherently connected to the technology potentials of Earth observation and telecommunications. Considering the complementary character of different technology areas, an actual usage of these cost-intensive resources requires their appropriate functional combination. This allows the application of the synergy principle to generate a qualitative and quantitative added value in traffic information products.

Trends

The significance of the increasing use of satellite-based resources for traffic telematics products becomes transparent considering the on-going discussion about the future European Satellite navigation system *Galileo*. [Galileo99]. The current Galileo market model assumes a road traffic related user share of 77%, corresponding to a turnover of 200 billion Euro for the years 2005 to 2025. In order to meet the demands of this market segment, a functional integration *of complementary telecommunications payloads* onboard the Galileo satellites is planned. This is underlining the special real-time aspects of traffic telematics, which will be met in the best possible way.

TUD Satellite Research Group

In 1997, the Technische Universität Dresden (TUD) has established an interdisciplinary research group representing the faculties of Electrical Engineering, Mechanical Engineering, Geo Sciences, Traffic Sciences and Economics. The main scientific target of this group is research on *innovative system concepts* in *LEO* (Low Earth Orbit) *satellite constellations*. This comprises

the development and provision of selected *key technologies* for the implementation of the suggested system concepts. Traffic telematics, a very newsworthy and market-oriented application field, was selected. This led to the formulation of the project headline "*TrafficEye* – Satellite-based Monitoring of Mobile Objects". This topic is subdivided into a number of smaller projects which are handled consecutively considering technological and economical aspects. This paper presents some of the current results of these research projects.

Traffic Information Systems

There is an extraordinary wide variety of approaches for the solution of present and future traffic problems. However, there is an increasing demand for new, innovative transportation concepts as an alternative to extensive solutions like the construction of new roads and motorways. In those alternative solutions emphasis is laid on the effective and intelligent use of available resources in transport and infrastructure. In particular, traffic telematics includes the components communication and information engineering, location and navigation, automation engineering and computer science. Those element together are expected to contribute to the optimisation, the displacement the reduction, and the avoidance of traffic.

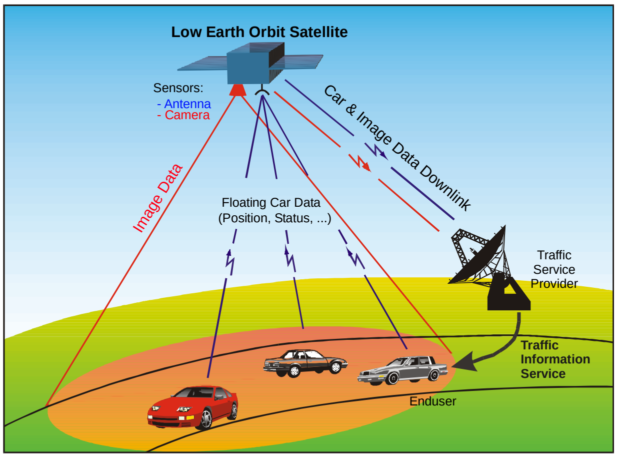

Figure 2: The satellite-based concept *TrafficEye* for traffic data generation

For the element "Traffic Information" of traffic telematics, the utilisation of satellite-based communication systems opens new possibilities for traffic observation, traffic data collection and qualification by means of system-internal integration of multiple data sources.

The economic relevance of the element "Traffic Information" results from a world-wide developing commercial market for traffic information. It is evident today that traffic information is an economically very relevant property.

Traffic information is related to a determined area (in terms of location and time), the corresponding geographic and cartographic information and the following traffic structural components: street, vehicle, and management.

The following considerations refer to the private car traffic. Thereby, information about the traffic situation is the focus of interest. This information has to be processed in a Traffic Information Centre (TIC) which uses multiple data sources. Particularly, dynamical routing systems require wide-area traffic data with high reliability and actuality. There is a considerable deficit in this field on a global scale [Mich98a].

Figure 1 shows an overview of the methods for traffic data generation and the integration of satellite-based traffic data collection by means of FCD (Floating-Car-Data) and image technology.

A Satellite-based Concept for Traffic Observation

Overview

The application of satellite-based resources in addition to the already established GPS-based autonomous localisation function is of primary interest for complementary processes of *information gathering* (ref. chapter 2).

The proposed innovative system concept *TrafficEye* contains the following main functions (Figure 2):

- *Primary data generation by FCD*
  continuous and event-driven *microscopic* road traffic properties of a limited number (samples) of co-operative vehicles are delivered directly out of the current traffic situation (FCD – Floating Car Data) and are collected by a satellite telecommunications payload.
- *Complementary synchronous image data*
  At discrete times, an observation of wide-area traffic scenarios (macroscopic traffic data, e.g. traffic density) is accomplished by optical or microwave (SAR – Synthetic Aperture Radar) payloads. The image data contain co-operative and non co-operative vehicles.
- *Information fusion*
  In the ground segment, FCD and image data will be fused and aggregated at different levels with additional terrestrial traffic data (e.g. from induction loops, bridge sensors). On the basis of macroscopic features and numbers, best possible near real-time traffic information for commercial traffic information services will be provided.

Integration of Image Information

The salient innovative component of the proposed concept lies in the integration of *wide-area image data* into the traffic information chain. Owing to the fact that the traffic process is more or less observable by feeding an apriori anticipated statistical model with near real-time continuous FCD data it is sufficient to update this model with complementary image information at *discrete points in time* and *for spatially limited areas*. This allows to support and calibrate this estimation process by adaptation of the apriori anticipated statistical parameters. This 'update only' characteristic of the image data greatly reduces spatial and temporal observation demands to the Earth observation component.

The following platforms for wide-area observation are suitable for *gathering image data* (in the order of increasing area coverage): Stratospheric balloons, blimps, (stratospheric) planes and satellites. As will be shown in the following chapters, the required image data processing methods are widely independent from the particularly selected platform. Seen from an operator's perspective, satellite EO platforms offer a variety of advantages and obviously determine the technical demands on the design. For this reason, satellite-based observation systems are treated as a reference design baseline.

Analysis of Advantages and Disadvantages of Satellite-based Systems

The directly obvious *benefits* of satellite-based systems lie in their

- *global access* in LEO satellite constellations;
- *wide-area access* when GSO satellites are used;
- widely *independence* of *terrestrial infrastructure*, i.e. they can be used in structurally weak regions

The market-oriented implementation of such systems is already demonstrated successfully in the areas of telecommunications, mobile communications and navigation. Based on estimations for the future, a fast development of technologies in the area of commercial broadband telecommunications (*Internet in the sky*) can be expected. This potential can be also used for future applications in the area of traffic telematics.

The well-known *disadvantages* of satellite-based systems for monitoring purposes manifest in contradictory demands of

- *temporal* resolution
- *spatial* resolution
- *interfering environment* (clouds, night phases)

In the context of traffic telematics, the use of *geostationary satellites* is limited to telecommunications from today's perspective . Advantageous is the wide-area availability and disadvantages exist because of the long link distance (about 36.000 km), resulting in higher efforts in terms of RF power and antennas on the vehicles and high transponder power demands and large directional antennas onboard the satellite.

LEO (Low Earth Orbit) satellites can be used for telecommunications *and* for Earth observation. The advantages like lower RF power and antenna requirements are accompanied by a global availability in satellite constellations. Disadvantages are reflected in the need for a number of satellites in a constellation where reduced technical requirements for the Earth observation payload result in lower orbit heights and thus a larger number of required satellites. Moreover, *passive Earth observation payloads* are susceptible for disturbing environmental conditions like clouds and lighting conditions. These problems can be overcome by using *active* observation systems like SAR (Synthetic Aperture Radar) at the penalty of higher efforts in terms of volume and electrical power.

Perspectives for an Operational Implementation

A careful analysis of the advantage / disadvantage profile of the suggested system concept reveals despite of the prevailing system limits a considerable performance gain potential for traffic telematics systems. Before special implementation options are discussed, an important premise shall be formulated: "*Road traffic monitoring is only one of many similarly conceivable applications*". There are a large number of similar, more or less market-oriented monitoring tasks in the area of traffic monitoring (rail, water, air) as well in environmental applications, geophysics, etc. A future market scenario is expected similarly to the past and present market development in satellite-based navigation. The majority of GPS applications and products was developed after the GPS system was fully deployed and operational, i.e. when the GPS-System was available as a "tool" to everybody. In our present case it is true to focus investment plans primarily on the direct application of "road traffic monitoring", but in the end, secondary applications have to be considered in our discussion as well (i.e. investment of / return on investment for *different* user groups).

Considering the mentioned premise, the following *implementation options* are imaginable:

- ***Usage of existing resources:***
  Similarly as GPS Navigation and GSM cellular communication are a common resource for current traffic telematics applications, existing satellite-based telecommunications and Earth observation systems can be used as function-enabling resources. For *communications*, GSO and LEO systems are equally usable, e.g. PRODAT [Jongejans],[RTMS99], Iridium, Globalstar and possibly future follow-up systems. In principle, also *image data* can be obtained from existing EO satellites in appropriate spatial resolution. In fact, the real bottleneck are the different independent satellite operators which are exclusively and directly accessing their satellites and therefore introduce an unnecessary delay in delivering the data to the user. A fast data distribution of thematically selected data (e.g. via Internet) could introduce considerable observation benefits. Weather and lighting-independent observation data can be included in the planning of future traffic observation systems taking into account planned and arising SAR-EO systems.

- ***System integration – multifunctional satellite systems:***
  Up to today, satellites were solely used for dedicated purposes of telecommunications *or* Earth observation. Combined systems have not been implemented yet. Provided one accepts the fact that already existing LEO comsat constellations are using orbital heights which are equally suitable for Earth observation, the question arises whether these systems can be used as *platform* for *complementary EO payloads*. Following two simple conclusions can be drawn:

  (a) Using a telecommunications platform for secondary or complementary payloads is only a reasonable solution for a satellite system owner if the additional investment will pay off through *additional*, *attractive* and *marketable* products in the future.

  (b) The impact of complementary payloads on the system design for the primary application (i.e. communication) has to be limited such that the EO payload has to be sufficiently '*compact*' (*smart*) concerning mass, volume, electrical power as well as 'robust' against satellite attitude changes. Given the availability of such a *smart EO system*, the traffic telematics market presents an enormous potential in the area of marketable services would be enormous (ref. chapter 2).

  The trend reversal from the special function satellite to the *multifunctional satellite platform* can actually be observed at the European Galileo satellite navigation system [Galileo99]. A complementary telecommunications payload shall be integrated into the Galileo "navigation" satellites for the first time in the framework of commercial spaceflight, to support just the design-driving application of traffic telematics. Therefore, an extension of this new design paradigm to LEO communication satellites for EO tasks is a thoroughly serious option [Jan98].

- ***Dedicated Observation Systems:***
  Provided that the future holds an increasing demand in global, near real-time geo-information through different user groups (commercial, public interest), dedicated Earth observation systems can be anticipated. In this case, further developments and specialisation of multifunctional satellite systems (see above) are conceivable which i.e. contain special monitoring payloads (multi-spectral, limited geographical coverage). The Galileo design paradigm can serve also as a reference for this class of systems.

Key Technologies

Following the discussion in the last section about realisation options, the following specific key technologies can be derived for the *TrafficEye* concept:

- *Optimised FCD Telegrams*
  ... minimal amount of data through intelligent preprocessing onboard the vehicle.

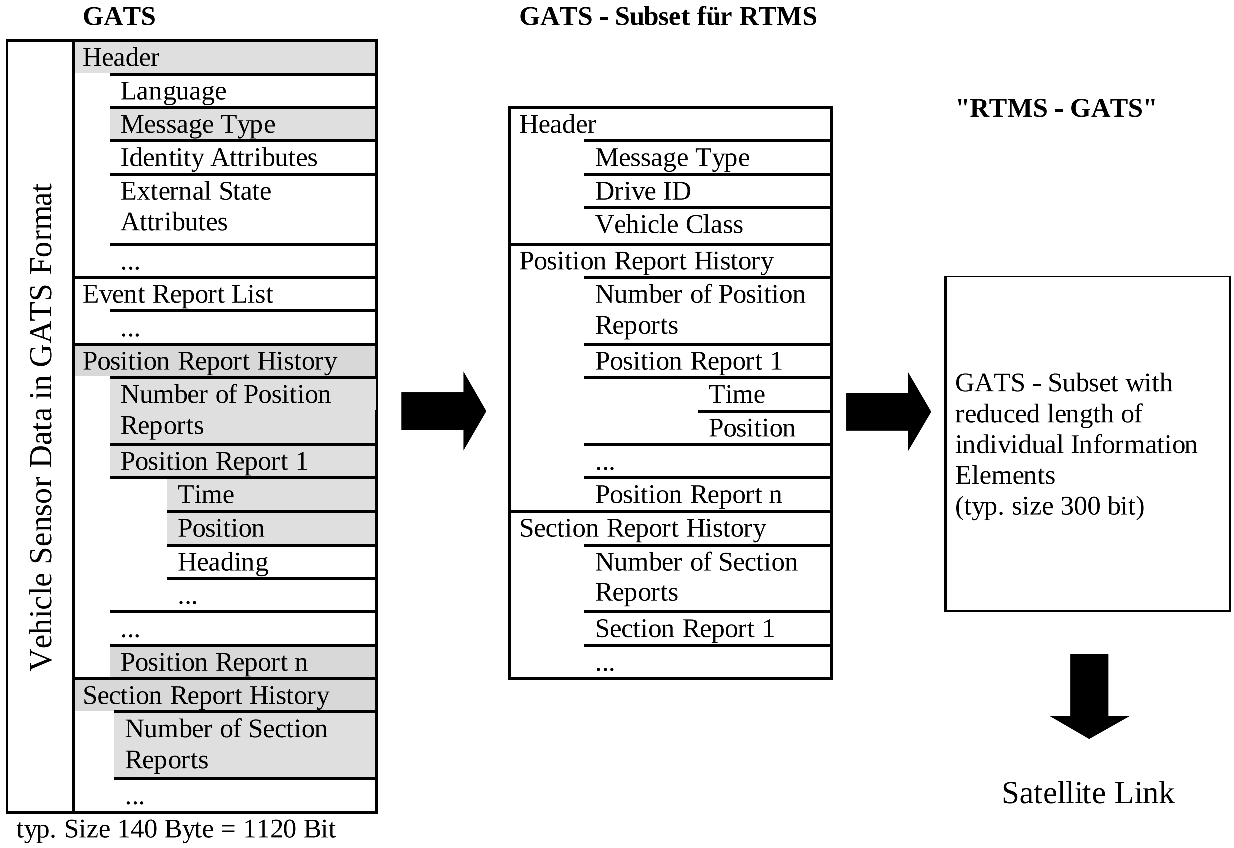

Figure 3: Optimisation strategy for GATS FCD protocols.

- *Optimised RF links*
  ... optimal usage of data channels (e.g. signalling channels), resource effective access, coding and modulation schemes.
- *Thematic Image Data Reduction*
  ... autonomous on-board selection of application-specific image contents owing to minimum downlink capacity.
- *Thematic Image Data Processing*
  ... Extraction of vehicle and traffic density relevant features.
- *Smart EO Imaging Systems*
  ... application-optimised EO imaging systems in the 2 metre ground pixel resolution range.
- *Image Compensation of Satellite Attitude Inaccuracies*
  ... Image correction systems for EO sensors on multi-functional platforms.
- *Real-time Distribution of EO Data Products*
  ... customer-oriented access and distribution mechanisms.
- *Techno-Economical System Design Models*
  ... comprehensive overall system optimisation (selection/combination of different implementation options) under market aspects

All above mentioned research topics are covered within the framework of the TUD satellite research group; some of the results are illustrated in the following chapters.

FCD Technology

For traffic data collection, the FCD principle has been applied for several decades in the form of the ”floating” measuring vehicles. In the terminology of today, this method corresponds to an offline-FCD-technology. For localisation and referencing of traffic data the FCD vehicles are equipped with GPS-based location and navigation equipment [Mich98a],[Mich98b].

The now globally available technologies and services of mobile communication have enabled a further development of the FCD principle to the online-FCD-technology.

In comparison to FCD systems with terrestrial data collection and transmission, satellite-based FCD systems have the benefits of the near-simultaneous observation of wide areas, the variability and flexibility in view of the choice of the transport system and a far-reaching independence from terrestrial telecommunication infrastructure.

In addition to traffic data collection, FCD systems can also realise the collection of supplementary data (meteorological data, visibility etc.) as well as the recording and transmission of breakdown and emergency information.

Generally, a qualification is needed before the data and information from several sources can be fused. This includes the removal of incorrect data as well as the connection of data, the marking, distribution, classification, aggregation and transformation of the collected values, that is, a 'screening'. In this way, the screening process can be carried out on board the vehicle or at a later stage.

For each part of the floating car data it has to be decided if it is to be removed completely, can be transmitted without changes or has to undergo a qualification, so that after a fusion with data from other sources, particularly image data, one can determine traffic flow coefficients (traffic density and volume, spatial gaps etc.) or estimate the traffic pattern.

Aiming at the standardisation of the data exchange between the vehicle traffic telematics equipment and the Traffic Information Centre (TIC) the companies Mannesmann Autocom GmbH and TEGARON Telematics GmbH developed the GATS standard (Global Automotive Telematics Standard) [ENV].

GATS was submitted to the European Committee for Standardisation (CEN) in 1998 and presently has the status of a pre-standard. It is supported by a great number of car manufacturers, terminal manufacturers and service providers. GATS standardises the radio interface between the vehicle telematics equipment and the TIC. GATS is focused on onboard-terminals (including positioning capabilities), but it is not a terminal specification. The standard has a modular structure and offers an open platform for future innovations and extensions.

The following traffic telematics services are currently included in GATS:

- floating car data collection,
- breakdown and emergency services,
- broadcast traffic information services,
- navigation services,
- operator services,
- general information services,
- interactive traffic information services.

GATS is optimised for narrow band communication systems (e.g. GSM / SMS).

The usage of other communication systems (e.g. PRODAT - satellite based system for bi-directional data transfer) requires modifications of the GATS protocol to achieve the optimal system performance.

The optimisation strategy is illustrated in Figure 3 at the example of a message used to transmit floating car data from a vehicle to the TIC within a satellite based traffic monitoring system (RTMS - Road Traffic Monitoring by Satellite).

Earth Observation Approaches

A periodical, synoptic observation of whole road sections with image data from LEO satellite clusters will be a potential step ahead in traffic data gathering, which should be envisaged in the near future. As target features for civilian satellite observation road vehicles are, however, a true challenge. Within the available geometric resolution from space and the resulting 'under-sampling', no satisfying definition of hard features of a mapped vehicle or vehicle cluster can be given, no matter which imaging technology is used. Nevertheless, the present studies of available sensors and in-house task-specific software let us assume, that there is an exploitable information potential in satellite imagery. The applicability of space-borne thermal infrared and panchromatic cameras operating in the visible range of the spectrum have been analysed by theoretical assessments and simulations. Further studies will include Synthetic Aperture Radar (SAR). The following considerations have taken into account, that a future mission will face severe limitations regarding:

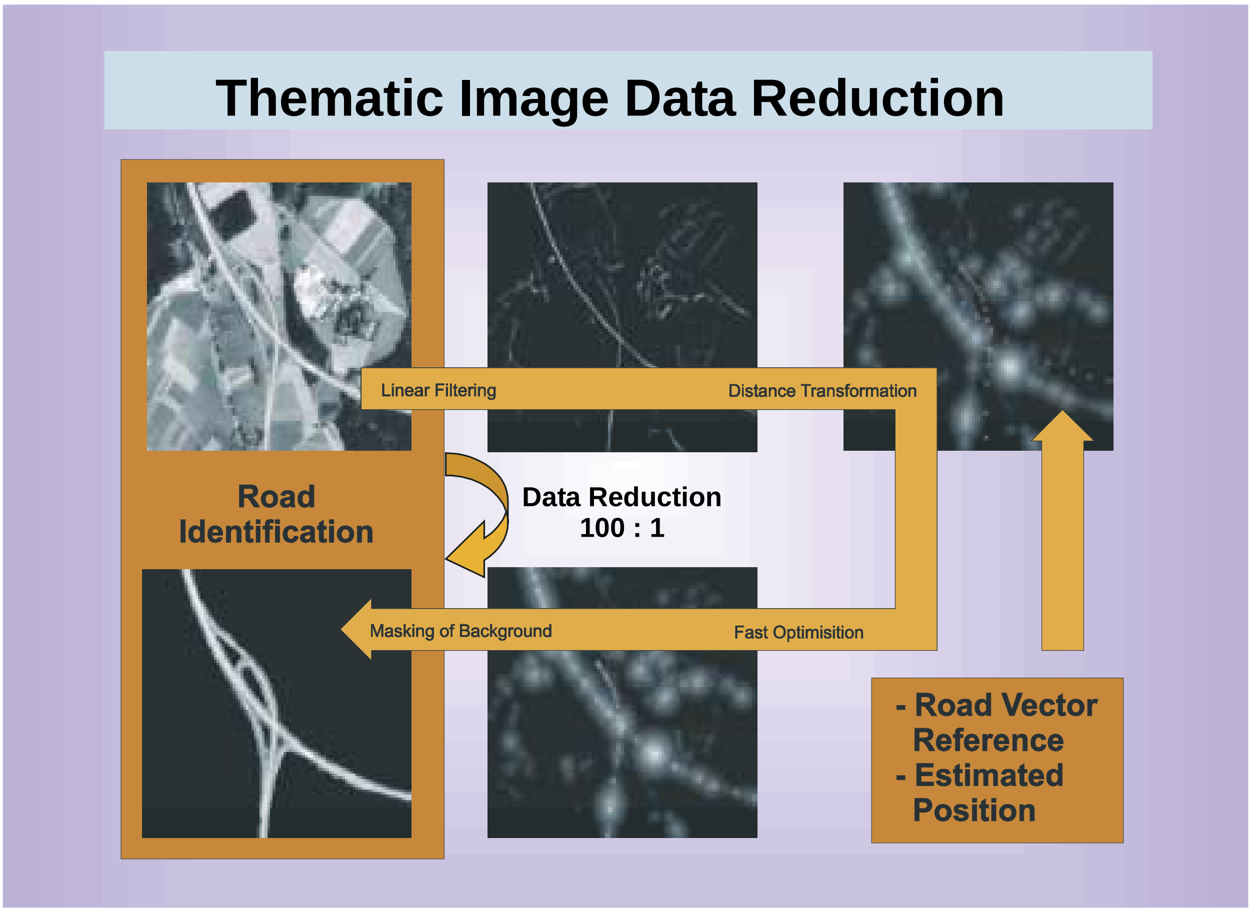

Figure 4: *TrafficEye* on-board image reduction concept

- energy supply,
- downlink capacity, and
- positional information quality.

The core task simply is to separate target pixels (vehicles) from the background (road surface) and, in a further step, to evaluate the target objects statistically (number of vehicles per road section of a defined length). For optimum use in traffic models, the desired vehicle density shall be automatically estimated according to

- travelling direction,
- car and lorry percentage and
- temporal and spatial location.

Moreover, a reliable accuracy measure shall be provided as meta-information. The following assumptions concerning given data have been made in our studies regarding the image processing:

- Availability of vector data of the main road network (navigation systems !),
- local reference data for calibration and validation of extracted parameters.

The Choice of Sensors

For a more detailed treatment the reader might refer to contributions (Buchroithner, Prechtel, Schenkel, Klix 1997) to the Phase A study [TUD98a]. In the task-oriented comparison of semi-operational sensors in thermal-IR and in the optical range, mainly parameters of the planned BIRD mission [Briess97] and the VHRC (Very High Resolution Camera) [Grot97] were used.

The results of the above mentioned reports show that the drawbacks of thermal remote sensing – such as low geometric resolution as result of low radiance compared to the solar spectrum, problematic influence of the atmosphere, and higher mass of the camera - will not be compensated by advantages as e.g. independence of daylight. A ground segment in a realistic dimension of approx. 50m x 50m, 293K surface temperature, and an emissivity near 1 emits approximately 10^{-9} W towards the sensor. For example, the signal of a single vehicle inside the ground segment, only strong enough to match the noise level of the camera, would require a car surface temperature of 50 K above the background temperature. Assuming 10 cars being mapped in the same segment, a minimum difference of 6 K would still be necessary to measure the same signal difference. Close-range measurements of the research group, however, have shown, that the thermal behaviour of car surfaces can hardly be predicted because of different material properties and 'histories' (colour of the vehicle, length of the journey, solar heating of the surface, average speed, etc.). Only in case of a traffic jam or if the car is stationary, the bonnet will typically show a significantly higher surface temperature than the background. In the Phase A study [TUD98a] a discussion of vehicle detectability under different thermal conditions can be found including a simple energy flow model.

Consequently, the optical VHRC camera of DLR-Adlershof [Neukum97] has been selected in the study. This is a CCD frame camera with an array of approximately 7000 x 9000 detector elements. In its spectral range (0.45µm - 0.8µm) the problem of an unpredictable target-background contrast is persistent as in the case of any thermal sensor. Vehicle surfaces appear brighter or darker than a road surface depending on colour and roughness of the surfaces as well as pollution. Only a geometric resolution improvement by a factor of 100 in the thermal domain may lead to a signal modification allowing to detect a single car in the ground segment. An extremely high resolution as a precondition for the task means that the huge image frame cannot be read out and sent to the ground segment in real-time.

Image Processing

The bottleneck of the downlink capacity led to the development of an on-board masking method which uses apriori road geometric information and distinctively contributes to reduce the data flow inside the mission's transmission chain. The second essential image processing step is designed as an on-ground duty. It is performed by a computer program extracting the traffic density numbers directly and in real-time from the image that has been reduced to observed road segments before.

Real-Time Road Detection Using Vector Information

A ground resolution of 2 x 2 metres results in a data flow of 280 Mbit/s. Reducing this data flow to 2 MBit/s, i.e. by a factor of 140, without any degradation of the image signal in the target area (precondition for the later-on processing) can only be achieved if the original image frame can be reduced to the road network. The limit is the total space of major roads inside the frame, which typically is far below 1% of the total area. The proposed solution comprises the following steps [Prechtel98] (Figure 4):

- Enhancement of potential road pixels and, vice-versa, dampening of the potential background,
- Distance transformation of the potential road pixels,
- Matching of existing road reference vertices onto the transformed road pixel image,
- Blanking out the background, preservation of the detected road network.

Potential road pixels are enhanced by linear filtering in four basic directions. The filter design is optimised for line structures, not for simple edges. While looking for road structures, a time-consuming post-processing of edges (edges parallel and in a given mutual distance) can therefore be avoided. The output of the enhancement is a set of bright pixel structures on a dark background. The foreground is indicating line structures within a certain width range and with low curvature in the original image: potential road candidates. Objective of the following process is to improve the relatively inaccurate positional data of the navigation systems by comparing digital vector data of the road network with the potential road network in the enhanced image. An optimum match is achieved, if all road vectors are situated above bright road candidates. Transforming the vectors for an optimum match with the help of an iterative search requires modifying the enhanced image by a distance transformation to provide local steadiness of the signal. If a reliable matching optimum is found during the iteration, the position of the target areas is immediately clarified by the transformed road reference. A masking of non-road areas in the image can take place. After wiping off the background, the new image can be compressed and transmitted to the ground segment. Theoretically, this method is adaptable to any type of target area, whenever vector data for an improvement of the positional information and for masking of the target areas is available. The real-time demand has been tested and the run-time for the whole process does not exceed 2 seconds with special DSPs.

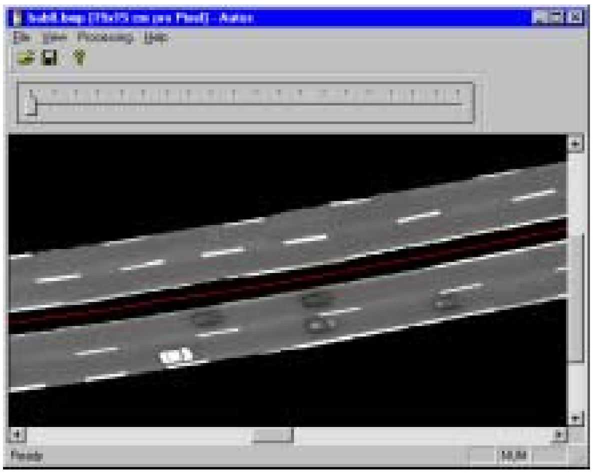

Figure 5: Section of a geo-referenced traffic scenario

Traffic Density Extraction from Image Data Using Ancillary Information

The actual method that is still under development, is based on the following principles:

- Contour- or shape-based detection of vehicles is useless because of the undersampling effect,
- Size distribution of single vehicles (cars and lorries) can be described by external statistical data,
- Road geometry and attributes (number of lanes, width) are given,
- The Images show only road and vehicle surfaces (no additional disturbing objects like temporary markings, worksites, etc.),
- Road surface is predominant compared to the vehicle surfaces in the image projection.

By the sampling size, the cars are mapped as amorphous micro pixel clusters. Therefore, the target-background separation has to rely on a grey-value histogram analysis. Since globally the road surface is the main signal contributor, the grey-value maximum must represent the road signal. Changes in road surface properties can be taken into account by a shift of the field of view in the histogram sampling area. This shifting process stops, if the distribution of the histogram gets uni-modal and the area around the peak shows a large gradient.

Starting from the background grey-value at the maximum of the histogram towards both sides, thresholds will be defined to divide the image into background and target areas. This process works in an iterative way, so that for any threshold position the target clusters can be checked for plausibility of shape and size. Then the road profile is scanned along the given centre line (vector data) in a topological manner. During the scanning process, the potential vehicle pixels are added up along with the position co-ordinates. Using a statistical size distribution of cars and lorries, the target clusters can now be transformed into discrete numbers of vehicles as shown in Figure 6. Finally, the result can be calibrated by using a correction factor, which is empirically derived by a mean number of misclassified objects (e.g. vehicles without contrast to the road).

In the present development stage our research group uses airborn VHRC sample data with a resolution of 0.15m, Figure 5. This original resolution has synthetically been degraded, allowing to find the minimum required image pixel resolution to achieve a certain accuracy. Limits of the panchromatic data for the observation of road traffic can be assumed to be around 2m according to preliminary results.

It should be pointed out, that more sophisticated and robust solutions will certainly be more appropriate with an image resolution below 1m. This resolution represents the threshold where the proposed method falls behind contour-based vehicle detection methods.

Telecommunications

Generally, telecommunication tasks of satellite-based traffic observation can be divided into following areas:

A. Collection of FCD Data (Uplink/Downlink)
   - A.1 Excluding Backhaul Channel (*TrafficEye*)
   - A.2 Including Backhaul Channel (RTMS)

B. Data Transfer of EO Data (Downlink)

Tasks A and B can be implemented on different platforms (ref. chapter 4) to utilise existing resources as best as possible or can be functionally integrated (multifunctional platforms, e.g. demonstration mission *TrafficEye*).

According to telecommunication tasks in category A, GSO satellites or constellations of LEO satellites can be used to maintain a steady contact to the FCD vehicles. In a LEO network the ground station has to be located near the geographic traffic observation area such that the satellite can maintain contact at the same time to both the ground station and the FCD vehicles. Alternatively, the RF link can be established from a ground station any desired observation satellite which is relayed through subsequent RF links between the satellites inside the network (ISL - Inter-Satellite Links).

Important criteria for the ground segment design (FCD vehicles and facilities within the central ground station) are *the satellite visibility* and the required *effective radiated power* (ERP). Geostationary systems require a high ERP and therefore the vehicle antennas have to be omnidirectional with some antenna gain for medium elevation angles. LEO satellites require less ERP owing to less free space attenuation but one has to consider a continuously changing pattern of satellites which can be seen from the mobiles. As a prerequisite, the satellites have to maintain communication to the mobiles at all times and have to transfer the mobile links to other satellites when they leave the mobile's visibility range (handover).

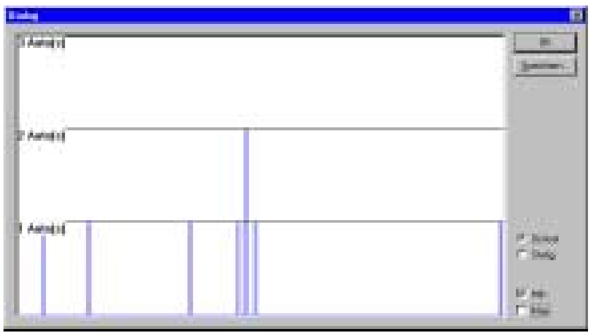

Figure 6: Automatic vehicle number estimation over the observed road section; the minimum number of vehicles is shown.

In a satellite communication system without a backhaul channel an individual FCD vehicle does not know whether his message was received correctly and therefore repeats it several times. Collisions of the data packets with packets originating from other vehicles are the result and only a certain percentage of all data packets reach their destination. Even FCD data packets represent only sample data of the overall traffic situation, the system still makes sense. With a backhaul channel, an individual FCD vehicle knows if the system received its message correctly. It does not have to repeat its message and therefore saves channel capacity. The system has a higher data throughput and allows a "handshake" to the traffic information centre such that FCD vehicles can be addressed directly and groups or alternatively groups of vehicles in certain geographic areas. Also, short text messages can be sent in response to emergency messages. Furthermore, short text messages can be used as elements in value-added services.

Design criteria for task B are governed primarily by the bandwidth of the telecommunication channel. A high resolution Earth observation sensor, for example, delivers data rates of several Mbit/sec which have to be received and processed by the ground segment. Owing to the required ERP considerable efforts are necessary in terms of electrical power and antennas onboard the satellite. This stands in contrast to demands for smaller, better and cheaper satellites in constellations.

Design Options – Examples

RTMS-PRODAT:

RTMS (Road Traffic Monitoring by Satellite) is a Project which is currently issued by ESA and contracted jointly to the Dutch company ARS and Technische Universität Dresden, Germany [RTMS99]. It is centred around the PRODAT-2 communication system which was originally developed for fleet management purposes. The project is aiming at observing a few hundred thousand FCD vehicles; in a field trial lasting from February to May 2000 about 50 FCD vehicles will be equipped in and around Rotterdam with PRODAT communication terminals. Integral part of these activities is a protocol definition that allows FCD data transmission in the GATS format. Some technical data on PRODAT :

- Near real-time message "store-and-forward" system
- Forward link 1500 bits/sec BPSK/TDM
- Return link CDMA/OQPSK 600 bit/sec
- Adaptive block coding with ARQ
- Omnidirectional vehicle antenna, 10 Watts RF power

Demonstration Mission *TrafficEye*:

The Technische Universität Dresden has concluded a phase A study within an interdisciplinary team of researchers. Subject of this study was a *multifunctional demonstration satellite* for traffic observation [TUD98a]. Central element of this satellite is a high-resolution camera (geometric resolution 2 to 2.5 metres) and an FCD data receiver. Its purpose is demonstrating the feasibility of satellite-based traffic observation and has as a major design driver a limited downlink channel capacity of 2Mbit/sec. The camera has an area sensor (about 66 Mio. pixel / image) and during operation, an estimated data stream of 280 Mbit/sec. will be generated. By suitable data processing onboard the satellite, the sensor data stream can be reduced to 1% of its initial value such that it fits within the downlink channel envelope in near real-time. Of course, the satellite also allows the transmission of previously stored image data.

Link	Function	Data Rate	Band
Downlink	Payload Data	2.0 Mbit/sec	S-Band (BPSK)
Uplink	Vehicle Data	250 kbit/sec	L-Band (BPSK/ ALOHA)

Table 1: *TrafficEye* payload communication links

The FCD vehicles send their data randomly in the ALOHA access scheme. This scheme is in its design suitable for a field test population of 40 FCD vehicles but has, if the demand exists, a maximum capacity of several hundred FCD vehicles. Table 1 summarises the telecommunication links of *TrafficEye*.

Information Fusion

The raw traffic data (FCD = microscopic features; image data = macroscopic data), gained from different sources, have to be combined in a subsequent information processing stage to obtain results that are suitable for marketable products. In this case. the interesting features are *macroscopic features of the traffic flow* (e.g. traffic density, traffic volume, traffic flow gaps, mean speed, heavy traffic proportion) and traffic status estimates. These features have to be time referenced and spatially referenced, i.e. they have to be referenced to defined road segments (cluster).

Owing to the different qualities of raw traffic data, different methodical approaches have to be used and combined for the task of information fusion, e.g. numerical, symbolical and semantical fusion methods. First results concerning this research project are documented in [TUD98b].

On-Going and Future Projects

A sequential project model was defined (Project Tree) for a technical demonstration of the proposed traffic telematics concept *TrafficEye*, consisting of several programmatic viewpoints. The individual projects are of increasing complexity, functional representativity, financial volumes and timelines in the order they are presented. The shown project model allows therefore an *early demonstration* of single *key technologies* along with acceptable financial efforts and especially supports the usage of *mixed financing sources*. The objectives of those projects A to E are explained as follows:

Project A – Offline (Posteriori) Observation Using Existing Resources: This project uses recorded (i.e. past) traffic data for demonstrating process algorithms.
Status: In summer 99, an aerial test campaign with a small plane is planned, where video images, and in parallel, GPS data in tracer FCD vehicles are recorded. This data is used for gaining traffic data.

Project B – Real-time Observation Using Existing Resources: Short-dated (i.e. near real-time) traffic data for the demonstration of processing algorithms as well as data distribution are used.
Status: In February 99, ESA awarded the contract *Road Traffic Monitoring by Satellite* to Ars Traffic & Transport Technology (NL) and Technische Universität Dresden (D). A pilot field trial will be conducted in the area of Rotterdam in spring 2000 where actual floating car data (FCD) methods are combined with an existing geostationary satellite mobile communication system (PRODAT). This will be the first time ever that FCD data collection is combined with direct satellite communications [RTMS99].

Project C – Satellite Payload: Special project-relevant technologies for satellite payloads for traffic observation will be demonstrated, e.g. image processing.
Status: In May 99, ESA awarded a contract on an *Optical Correlator for Camera Pointing Recording* (Technische Universität Dresden; Ufa State Aviation University, Russia). This project deals with an on-board system for real-time image correction of optical secondary payloads on telecommunication satellites of medium pointing accuracy [Jan99a],[Jan99b].

Project D – Nanosatellite: A satellite of very small size (30 to 40 kg) that only carries a telecommunications payload *or* a camera payload shall be demonstrated (less complex mission; piggy-back payload).
Status: see project D

Project E – Microsatellite: A microsatellite (about 100kg) for *synchronous* traffic observation including a camera and a telecommunications payload shall be demonstrated.
Status: A phase A study and a detailed system concept study was conducted from April 97 to May 98 [TUD98a], funded by the Saxonian Ministry of Science and Arts (Sächsisches Staatsministerium für Wissenschaft und Kunst). Currently there are on-going co-operation negotiations with relevant national research institutes and SME's as well as with Russian establishments (payloads, launch opportunities).

Summary

The presented innovative traffic observation concept *TrafficEye* uses a telecommunication component for mobile data transmission of continuous Floating car Data (FCD). The observation process is amended by synchronous complementary image data which is gained by a satellite-based optical or microwave (SAR – Synthetic Aperture Radar) payload. In the ground segment, the gained traffic raw data will be fused and aggregated with additional terrestrial traffic data in order to provide best possible near real-time traffic data for commercial traffic information service providers. Besides a conceptual discussion, first results concerning *key technologies* in the fields of *image processing* (object recognition in the sub pixel domain, real-time algorithms for data classification, data reduction and data fusion) as well as first results of the on-going ESA project (RTMS – Road traffic Monitoring by Satellite) are presented.

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