AIRBORNE CAMERA EXPERIMENTS FOR TRAFFIC MONITORING

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ABSTRACT:

Prediction of traffic, dynamic routing, off board navigation and a standardisation of traffic flow parameters are the cornerstones of modern intelligent transport systems. The development of such systems requires intelligent data acquisition from different sensors and platforms. Due to its spatial and temporal flexibility airborne sensors can provide useful information beside existing systems, e.g. induction loops and vehicle probes data etc. DLR is involved in two projects proving the gain of using aerial images for traffic monitoring – LUMOS and “Eye in the sky”.

For LUMOS an infrared camera system was used in combination with an inertial measurement unit (IMU) onboard an airplane. The project “Eye in the sky” provides an opportunity to evaluate the relevance of image data captured by a zeppelin and a helicopter. A high resolution digital camera and an inertial measurement unit mounted on an airborne platform were used to provide images and attitude data. In both projects, images were transmitted to a ground station, georeferenced and processed in order to extract user relevant traffic information. The whole procedure is realized in real time.

Within the projects a variety of different sensors and platforms were used. This allows a validation of several configurations helping DLR in opening up new perspectives for traffic monitoring in future.

1. INTRODUCTION

Prediction of traffic, dynamic routing, off board navigation and a standardisation of traffic flow parameters are the cornerstones of modern intelligent transport systems for individual road traffic and fleet management. For all applications, a very good database is necessary so that the applications can contribute to solving such problems as enhancement of road safety, driver assistance, emission reduction, or advance of infrastructure capacity.

The German Aerospace Center (DLR) with its institutes of Transportation Research, Communication and Navigation, and the department of Optical Information Systems is addressing these problems with research on wide area traffic data collection, processing and evaluation. Using innovative technologies and sensors on terrestrial, airborne and space borne platforms, DLR will contribute to opening up new perspectives for traffic monitoring in future (Runge et al 2003, Ruhé et al 2003, Kühne et al 2002).

2. PROJECTS

Two projects mainly influenced the development of airborne traffic monitoring at DLR – “Eye in the sky” and LUMOS. Both projects are introduced shortly.

2.1 Eye in the sky

"Eye in the Sky" is a research project funded by the European Commission that contributes to the development of a European intelligent transport infrastructure. The project aims to develop a number of services based on the synergy of surveillance, communications and digital mapping technologies. The project's main objective is to provide commercially viable integrated solutions addressing issues of traffic monitoring, fleet management, customized mobility information and emergency services support for the better organization of large scale events. The test area of the proposed services is the sky and land area of Athens, which will host the 2004 Olympic Games.

"Eye in the Sky" is a project carried out by an interdisciplinary partnership of companies, agencies and research institutions (Eye in the sky 2004).

The first set of services addresses traffic monitoring, fleet management and customized mobility information issues. In concept, vehicle probes data are collected and transmitted via terrestrial mobile communication networks to a central processing centre. In parallel, high-resolution digital imagery collected from a camera onboard an airborne platform complements the traffic data.

Integration of optical and vehicle probes provides traffic information of superior quality. This approach forms the base on which fleet management services and mobility information services are developed.

The second set of services addresses emergency services support issues.

Both sets of services are geared towards the 2004 Olympic Games in Athens, and the key objective is the formation of a service provider company in time for this large scale event.

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2.2 LUMOS

LUMOS is a cooperation project funded by German Ministry of Education and Research.

On the basis of innovative sensor technology which is now available, a system for the air-supported recording of the traffic situation was designed, realized, and demonstrated within the framework of the project (LUMOS 2004).

The whole chain of the system extends from the sensor technology - including a stabilized platform and image processing, via the data transmission to the ground - to a traffic center for the further processing of images in which the information will be refined with prognosis tools. An open interface ensures a multi-facetted utilization of the information by multiple user groups.

The central technological challenges were located in the software area, i.e. in the development of suitable image processing procedures and the already above mentioned traffic simulation and prognosis tools. The prognosis plays a key role and serves the bridging of inevitably occurring time-gaps in the recording by the airplane. It thus contributes considerably to added value and the acceptance of air-supported monitoring.

3. TECHNICAL CONFIGURATION

3.1 Airborne Platforms

Within the two above mentioned projects different airborne platforms were applied. Their advantages and disadvantages, the environmental conditions and the user specified traffic parameters define a compliance matrix.

3.1.1 Zeppelin

From all available airborne platforms a Zeppelin (ZLT Friedrichshafen / Germany, Figure 1) was chosen for the project “Eye in the sky” firstly. The main advantages of the airship in comparison to helicopters or airplanes are:

- large payloads possible
- highly manoeuvrable
- hovering for several hours
- low flying platform
- low vibrations

Disadvantages of the Zeppelin, including the special ground based infrastructure needed and expensive flight hours, were deemed insignificant in light of the overall goals of the project.

Figure 1. Zeppelin on a mobile anchor mast

3.1.2 Airplane

Airplanes are available almost everywhere and allow a quick access in order to perform test campaigns. DLR used a Grand Commander 608 for its test flights. For scanning tasks (e.g. road survey) airplanes are well suited.

3.1.3 Helicopter

Helicopters have almost the same positive properties concerning traffic monitoring as Zeppelins, but the operating time is significantly lower. For our test campaigns a Bell 206 was applied.

3.2 Camera systems

DLR used its competence on the field of opto-electronic systems and applied a number of different camera systems in order to evaluate their parameters and to define configurations being able to satisfy user specified tasks. A combination of different sensors seems to be very promising.

3.2.1 Visible Camera

Traffic monitoring requires high quality images. Therefore, a set of camera parameters was defined in order to fulfil these requirements.

One of the most important features is the radiometric dynamics describing the number of bits per pixel per channel. As an example, an 8 bit camera is able to distinguish between 256 grey values, while a 12 bit sensor can create 4096 different grey values. The importance of these parameters becomes clear from looking at aerial photos. Especially in urban areas, very bright and very dark regions occur within one image due to totally different reflection properties of the surface (e.g. specular reflection from windows, drop shadows). An additional automatic exposure time control is necessary.

The frame rate has to be determined according to the application. For traffic density, a low frame rate (about 0.2 Hz) velocity was found to be sufficient, while for car velocity measurements frame rates in the order of 5 Hz have to be realized (effectual by common car velocities in cities).

The number of pixels is a compromise between a number of parameters, e.g. ground resolution, expected movement of the platform (above all roll and pitch) and provided data transfer rate.

Several scientific and commercial camera systems were applied and tested (e.g. Kührt 2001). After defining traffic density as the main parameter, a commercial camera system was chosen. Table 1 shows a set of parameters of a typical camera configuration.

Parameter	**Value**
Detector	CCD
Number of pixels	1980 × 1079
Field of view	50°
Radiometric dynamics	12 Bit
Frame rate	0.2 Hz
Ground sampling distance, flight height 1000ft	0.3 m
Swath width	594 m

Table 1. Parameters of a typical visible camera configuration

In dependence on the platform, the cameras were mounted directly on a ground plate (Zeppelin), on shock mounts (helicopter, Figure 2) or on a stabilizing platform (airplane). Two main demands had to be fulfilled: firstly, the target area had to be observed reliably and secondly, the remaining vibrations must not influence the image quality even for long exposure times (blurring).

Figure 2. Integration of the equipment (IMU, VIS-Camera and Camera-Laptop) in a helicopter

The influence of image compression was partly investigated for the projects up to now. This topic remains to be considered if data transfer rate limits image acquisition. So for the project LUMOS an image compression with fixed factor of 2 was applied without significant influence of the quality of image processing.

Parameters describing pixel positions on the focal plane (so-called interior orientation) are necessary for georeferencing of the image data. They were determined during a calibration process in optical laboratories at DLR.

3.2.2 Infrared camera

Cameras working in the infrared range of the electromagnetic spectrum have the advantage to be applicable even at night. In most cases the spectral texture in the infrared allows an easier image data interpretation as with visible cameras. The main disadvantages of infrared cameras are the small number of pixels (so the swath or the ground resolution has to be reduced) and high costs. Table 2 shows the parameters of the used thermal IR camera.

Parameter	**Value**
Detector Type	MCT, cooled at 77°KIR 18 MK III, Barr & Stroud ltd.
Number of pixels	768 × 500
Field of view	15,28° x 10,20°
Radiometric dynamics Spectrum	8 Bit 8 – 14 µm
Frame rate	25 Hz
Ground sampling distance, flight height 3500ft	0.5 m
Swath width	380 m

Table 2. Parameters of a typical IR camera configuration

3.3 Inertial measurement unit

Onboard or real-time georeferencing requires the exact knowledge of all six parameters of the so-called exterior orientation (three translations *x*, *y*, *z*, three rotations Φ, Θ, Ψ) of the camera for each snapshot. Depending on the desired accuracy of data products, these parameters have to be determined with an accuracy in the range of one ground pixel distance and one instantaneous field of view (field of view for one pixel).

A typical technical solution for direct and precise measurements of the exterior orientation parameters of the camera during imaging is to use an integrated GPS/Inertial system, which combines efficiently inertial sensors technology and GPS technology. DLR owns such a system (POS-AV 410 of Applanix Corp.), which fulfils the required specifications (Lithopoulos 1999, Scholten et al 2001). The system consists of an Inertial Measurement Unit (IMU) LN200 and a control unit with integrated GPS receiver. The IMU sensor head was mounted close to the camera. The IMU realizes measurements of accelerations and angular velocities and records movements of the camera/IMU. The time synchronized IMU and GPS data are processed in a control unit within an inertial navigation algorithm. The system provides real time output of position and orientation with a rate up to 200 Hz. In combination with a differential GPS correction, an absolute accuracy for position of 0.5 to 2 meters and for attitude of 0.015 to 0.05 deg can be obtained.

Image and attitude data have to be recorded synchronously. Therefore, Applanix' trigger pulses were monitored and used for commanding the image acquisition process.

3.4 Data Transmission

Onboard captured images and related orientation data are sent to the ground station via radio transmission. The data transmission channel consists of the transmitter and antenna onboard and receiving station on ground. The data transmission rate is the most limiting factor for the specification of the real time airborne monitoring system. It defines the maximum image acquisition rate. The transmission rate values were 2 and 4 Mbps for LUMOS and Eye in the Sky configurations respectively.

3.5 Ground Station

Image data received on the ground station are transmitted to the traffic computer for image processing. Within the LUMOS project a special network of three ground stations with a distance of about 25 km was developed and installed to ensure the coverage of whole Berlin-City with surrounding area. Directional radio link lead the data from each station to the server, where the best of the three data packages is selected and provided to the image processing. For the project "Eye in the Sky" another technical realisation was applied. It is based on a digital transmission system with a mobile GPS antenna placed on the roof of the building for tracking.

4. DATA PROCESSING

4.1 Direct georeferencing

The real time orientation data stored in a control PC describe the actual position of the camera. This position is given by longitude, latitude and ellipsoid height with respect to the geodetic datum WGS84 and the rotation angles of IMU measurement axes given by roll, pitch, and heading with respect to the local tangential coordinate system.

The misalignment between the IMU and camera axes (bore sight angles) has to be estimated offline once per system installation in the airborne platform using the traditional aero triangulation method.

During the measurement flights, real time orientation data, misalignment angles and camera parameters (interior orientation) define a transformation from image space to object space and vice versa. Assuming a medium terrain height, the position of the vehicles can be estimated. Consequently, for each pixel of interest a (*x*,*y*)-tuple can be determined and each real world object corresponds to an equivalent pixel in the image.

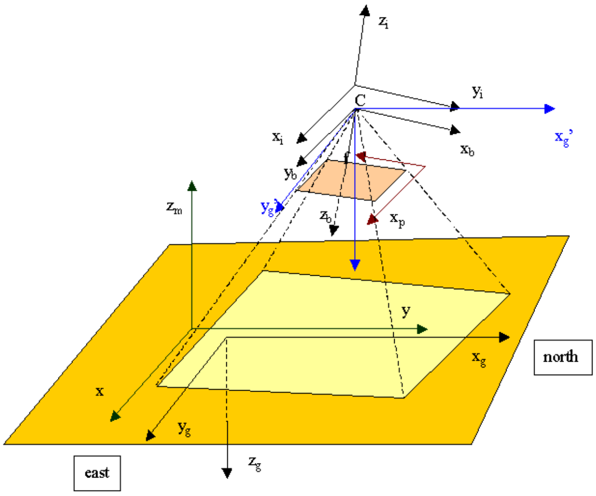

Figure 3. Illustration of projection geometry with directions of used coordinate frames

Thereafter, parameters of interior and exterior orientation of the camera are known. Assuming a known interior camera geometry, for an observed point P the following equation describes the relation between image space and object space (Figure 3):

$$P^m = C^m + (P - C)^m = C^m + a \cdot dp^m \tag{1}$$

$$dp^m = C_g^m C_b^g(\Phi, \Theta, \Psi) C_c^b C_i^c \begin{bmatrix} x_P \\ y_P \\ -f_P \end{bmatrix}^i ,$$

where

- x_P , y_P are coordinates of P in image frame (i)
- f means focal length of the camera,
- C is the camera projection centre,
- Φ, Θ, Ψ (Roll, Pitch, Heading) are Euler angles for the transformation from navigation frame (b) to geographic frame (g).
- C_k^l describes an appropriate rotation for transformation from frame (k) to frame (l).

Thus it is possible to project an image to the digital map frame (m) in a world coordinate system and vice versa (Figure 4 and 5).

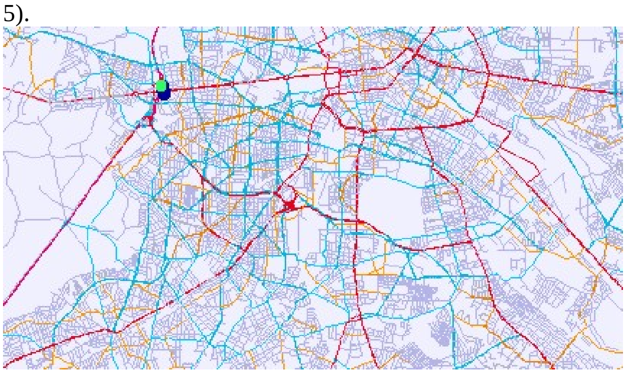

Figure 4. Georeference of the recorded image within the digital map

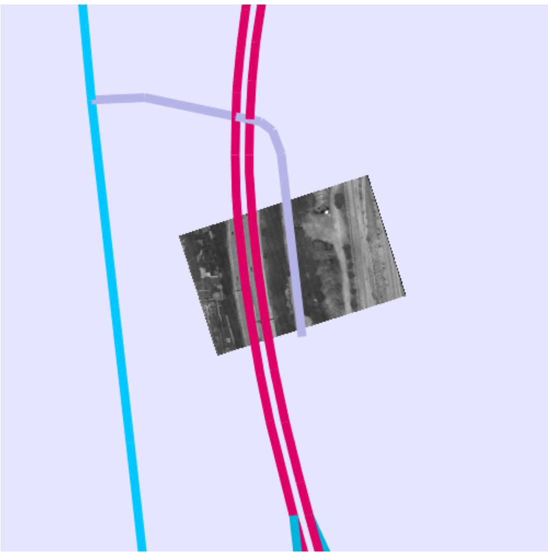

Figure 5. Projection of the recorded image within the graphical representation of the digital map

4.2 Image processing

After deriving the relations between object space and image space, relevant traffic objects have to be detected in the image data. Thematic image processing is the most demanding part of the project. Different algorithms were developed and tested (e.g. Hetzheim et al 2003).

The preferred approach (Ernst et al 2003) deals with a digital road map (produced by Navtech) of the relevant area. Using the a priori knowledge about roads and their parameters (width, lanes, and directions), images can be masked considering a margin depending on the accuracy of different data (etc. attitude data, maps). The roads are now the only image sections to be investigated. Histogram based estimators can additionally limit the car search region. In this manner search area and calculation time per image can be reduced significantly (Figure 6).

Figure 6. The expected road area based on the digital map information is masked out on the image

To get accurate knowledge about the mapped roads all street segments of a sufficient area around the recorded region have to be tested regarding their intersection with the image. This information enables the aggregation of vehicle data from image sequences later on.

The vehicle detection is done on the reduced image area from the previous phase. The pixel sizes of the expected vehicle classes are dynamically adapted to the current navigation data values (height over ground, attitude of the aircraft). The vehicle recognition of LUMOS and “Eye in the Sky” works on single images. Approaches based on difference images or estimated background images do not work reliably for test flights with airplanes due to their fast speed over ground.

The vehicles have a variety of appearances in the captured images depending on sensor type, object properties and environmental conditions (e.g. weather, temperature). But most of the traffic objects can be recognized as coarse rectangular shapes which contrast more or less with the background. Therefore the algorithm searches for characteristic contours (of suitable sizes) in edge images.

If a higher pixel resolution is available (visible camera), further properties of vehicles such as the existence of special cross edges can be included in the search process. Pixel values themselves from the original images give additional information for consolidation or rejection of vehicle hypotheses or indications of the probable driving direction (Figure 7). Evaluating the number of vehicles per scene gives a measure for traffic density that can be provided to a central processing computer.

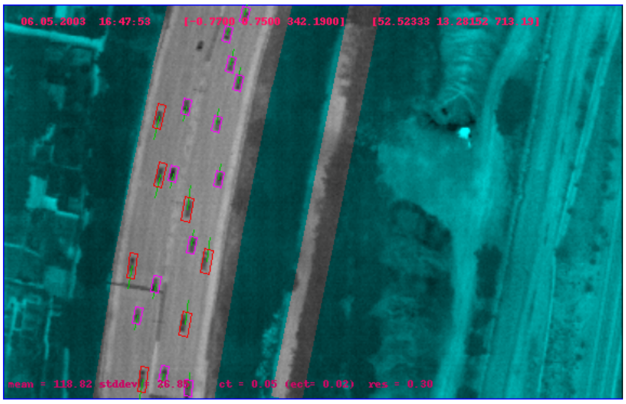

Figure 7. Vehicle hypotheses of different size classes

High frame rates allow the determination of velocities. The frame based information is now processed for successive images in combination to determine vehicle velocities.

Virtual car positions are obtained from real car position data from one image and navigation data from the following image. Velocity vectors can be extracted by comparison of these virtual car positions and real position data from the second image. The repeated recognition of a car in the following image emphasizes the correctness of the car hypothesis.

Assuming a time difference of 1/5 s between two images and a pixel resolution of 0.5 m, velocities of 9 km/h can be detected. On the other hand, a small car moving with 80 km/h does not change its position from image to image by a value of its length.

The vehicle recognition algorithm delivers a coarse size estimation so that accepted car hypotheses can be divided into a number of length classes. Using three classes has proven to be very practical; a larger number reduces the exactness of the classification. Thus essential shapes of cars, vans and long vehicles can be estimated.

The traffic data extraction within the airborne traffic monitoring projects is done per image and road segment first. Densities and/or velocities are calculated for each vehicle class from the obtained vehicle numbers and positions. The extracted data for single images are combined for completely observed road segments using size and position of the overflown streets. The calculated average velocities and densities per road segment of the digital map and per timestamp can used now as input data for simulation and prognosis tools.

5. VALIDATION OF THE SYSTEM

During the last years, several test flight campaigns within the projects LUMOS and “Eye in the Sky” took place to validate the quality and reliability of the system and especially of the real time image processing part. The applied sensors and auxiliary equipment can be integrated within two hours. Different scenarios were flown (hovering vs. moving, visible camera vs. infrared camera, different flight heights, different illumination conditions).

The evaluation of georeferencing quality using photogrammetric methods for calibration flights gives accuracies in the range of one meter which is sufficient for the requested applications.

The comparison of automatic vehicle identification within LUMOS vs. manually counted in the images is shown in the Figure 9. The image sequence with rate of 12.5 frame/sec was captured on May 6, 2003 over Berlin-City Highway from the flight attitude of 600 m (Figure 8). The images showing at least 60 % of segment of the road of 90 m length were taken into account.

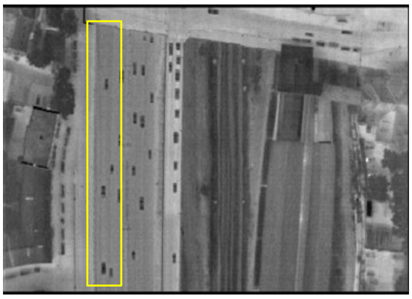

Figure 8. LUMOS-image of the Berlin City Highway southbound (left part of the figure)

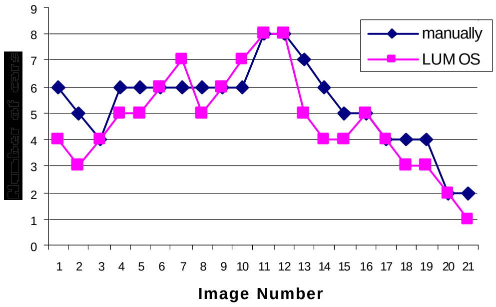

Figure 9. Vehicle counting automatically with LUMOS vs. manually per image

On average, the number of automatically counted vehicles is 11.5 % below the manually generated value. From the averaged detection rates and the length of the observed road section, vehicle number densities of 59.3 vehicles/km from manual counts and of 52.7 vehicles/km from automatic counts are obtained.

To verify a quality of algorithm for velocity determination a special test car of DLR have been overflown for some test flight while driving. The velocity measured on board of a test car with 0.1 km/h accuracy have been compared in off line with a velocity value automatically obtained from the respectively image sequence for three LUMOS flight campaigns (Table 3).

Flight	Velocity on board (km/h)	Velocity LUMOS (km/h)	Differenc e (km/h)	Relative Error (%)
06.05.2003	27.1	25.6	1.5	5.5
03.11.2003	24.4	20.	4.4	18.2
16.12.2003_A	25.3	19.5	5.8	22.9
16.12.2003_B	23.	19.8	3.2	13.9

Table 3. Velocity determination automatically from LUMOS imagery

The overage relative error of velocity determination for one test car within the image sequence of ~1 sec length is about 15 %. This error depends inversely proportional of absolute value of velocity and also of the geometric resolution and radiometric conditions of images.

6. RESULTS

Within the two projects “Eye in the Sky” and LUMOS a system for online and real-time georeferencing was build up. This system is usable for different tasks using frame cameras on air borne platforms.

Based on this system real-time thematic image processing software is developed. For generating traffic flow parameters the detection of vehicles and the classification of them were done.

In this way at last a new kind of sensors for traffic data collection was planed, developed and as a demonstrator tested.

1. A new technology for the wide area airborne traffic measurements based on real time image processing of infrared or visible optical sensors become a reality.
2. The main part of system, real time thematic image processing to the traffic parameters developed by DLR, is optimized for aggregations of measured traffic data to the average parameters for a specific road segment related to the interface to existing traditional traffic simulation and prognosis tools.
3. Experience of operational work with the developed system shows advantage of helicopter as a airborne platform for the traffic monitoring in the Cities because of possibility to follow any flight route up to get caught over traffic “hot spots”. The aircraft has advantage for the monitoring of inter cities traffic flow.

7. OUTLOOK

After successful final demonstrations, sensor and processing concepts should be extended. The image data of several camera systems with different spectral, radiometric and geometric properties should be fused in order to derive user relevant products in new and traditional fields of applications.

DLR pursues also other new approaches of “wide area traffic data acquisition”. One of them is the air borne traffic measurements using Spectral Aperture Radar (SAR) technology. In April 2004 DLR with its institutes of Radar-System-Technologies and Remote Sensing Technology made a first experimental flight for air borne traffic data collection using SAR-sensors. DLR’s goal is to develop smart, (semi-) autarchic airborne platforms being able to deliver reliable traffic information in real-time.

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DLR Institutes of Transportation research and of Communication and Navigation, DLR department of Optical Information Systems, ND SatCom AG, GEOTOPOS S.A., Technical University of Crete, Geosynthesis S.A. New Technologies Applications, Joint Research Centre of the European Commission, gedas Deutschland GmbH, FhG IPK, Robert Bosch S.A., Blaupunkt GmbH

Partners in the project LUMOS:

DLR Institute of Transportation Research, IQ-Wireless, ScanDat, Teltec Telematik, BLIC, Fraunhofer FIRST Institute of Computer Architecture and Software Technology and „Forschungs- and Anwendungsverbund Verkehrssystemtechnik Berlin (FAV).