NEW APPROACHES FOR REAL TIME TRAFFIC DATA ACQUISITION WITH AIRBORNE SYSTEMS

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ABSTRACT:

The topic of the paper is the adaptation of airborne remote sensing techniques and methodology in transportation. All traffic relevant applications require real-time derivation of traffic flow describing parameters. This paper illustrates approaches in hard and software for fulfilling these demands. Two systems for traffic data collection for different operations will be explained and detailed information for online georeferencing, real-time pattern recognition, speed measurement and car classification will be given. The results will be shown and discussed. As a short outlook necessary enhancements and possible sensor extensions will be presented.

1. INTRODUCTION

Intelligent transport systems require a new kind of data acquisition methods to fulfil the demands of today's traffic management. Prediction of traffic, dynamic routing, off board navigation, and standardisation of traffic flow parameters are the challenges we are faced with. Airborne systems are well suited to fit these demands. The advantages of airborne data are spatial availability, the broad variety of extractable parameters and the speed of collection. Beside of these advantages, however, there is a time gap between collecting and processing the data. The highly dynamical system of transport is extremely time dependent.

The broad variety of fields of interest requires different types of operational systems. We focus on two different primary scenarios of airborne traffic data collection. One we call "traffic parameter measurement" for supporting traffic flow modelling, simulation, and prediction allowing many applications in transport. For this a fast data collection over a large area is needed as well as the availability at all weather conditions and the traffic flow description including data aggregation. The most suitable configuration consists of an airplane, a thermal infrared camera and a non tracking downlink system. A network of receiving stations covered the whole Berlin city area and surrounding regions.

The second approach is "traffic monitoring" as a tool to provide integrated solutions addressing issues of traffic monitoring, fleet management, and emergency services support, e.g. for the organization of large scale events. Its main feature is the coverage of a certain area of interest for a longer time. For this, a flexible airborne platform, a high resolution camera in the visible spectral range and a precise navigation system are needed. Additionally to the traffic flow, single car characteristics have to be described too. These requirements lead to a system using a helicopter or an airship with a camera and a moving receiving station at the ground.

The most demanding challenge for both approaches is the software, i.e. the development of suitable fast and robust image processing procedures.

2. SYSTEM DESCRIPTION

2.1 Cameras

Several scientific and commercial camera systems in the visible range of the electromagnetic spectrum were applied and tested (e.g. Kührt 2001).

For the traffic parameter measurement system we selected cameras working in the infrared range (IR). They have the advantage to be applicable even under difficult illumination conditions. In most cases the spectral texture in the infrared allows an easier image data interpretation as with visible cameras. The main disadvantage of infrared cameras is the small number of pixels (320 x 240) - so either the swath or the ground resolution has to be reduced. Besides, IR cameras are still very expensive. Due to its low number of pixels a high frame rate can be expected (up to 25 Hz) despite the limited downlink data rates.

For the traffic monitoring systems cameras in the visual range have been chosen. They allow a high resolution which is necessary for car identification. A camera with a medium number of pixels (1k x 1k, 2k x 1k) guarantees a sufficient ground resolution and is able to cover reliably the area to be observed.

The frame rate of the cameras has to be determined according to the application. For traffic monitoring a low frame rate (about 0.2 Hz) was found to be sufficient, while for traffic flow measurements frame rates in the order of 5 Hz have to be realized depending of the velocities of the car and the airborne platform.

The ground resolution is a compromise between certain parameters, e.g. detector technology, expected movement of the platform and provided data transfer rate.

2.2 Data transmission

The data transmission rate is one of the most limiting factors for real time airborne systems. It defines the maximum possible image acquisition rate. Focusing on freely accessible radio frequencies commercially downlink systems were chosen. They deliver data rates up to 5 Mbps.

For the traffic parameter measurement a system of three ground stations with a distance of about 25 km between them is used. Directional radio links lead the data from each station to the server with a data rate of 2 Mbit/s, where the best of the three data packages is selected and provided to the image processing.

The downlink for the traffic monitoring system is based on a digital transmission. A GPS-supported transportable antenna with mechanical beam steering allows two channel communications. Its data rate amounts up to 5 Mbit/s, The system has a range of about 10-15 km. Image and attitude data received on the ground station are transmitted to the traffic computer for image processing.

2.3 Inertial measurement unit

For both approaches a real-time onboard georeferencing is required. This implies that all six parameters of the so-called exterior orientation (three translations, three rotations) of the camera for each snapshot have to be determined. Depending on the desired accuracy of data products, these parameters have to be measured with an accuracy in the order of one ground pixel distance and one instantaneous field of view.

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 D-GPS receiver. 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 degree can be obtained.

2.4 System integration

Depending on the platform, the cameras were mounted directly on shock mounts (helicopter) 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).

The IMU sensor head was mounted close to the camera in all configurations. Image and attitude data have to be recorded synchronously. Therefore, Applanix' trigger pulses were monitored and used for commanding the image acquisition process.
Camera and IMU require computing units for controlling and data pre-processing.

3. DATA PROCESSING

3.1 Direct georeferencing

The real time orientation data stored in a control computer describes 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 the camera axes (bore sight angles) has to be estimated offline once per system installation (using the aero triangulation method).

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

During the measurement flights, real time orientation data, misalignment angles and 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 1 illustrates the projection geometry with directions of used coordinate frames.

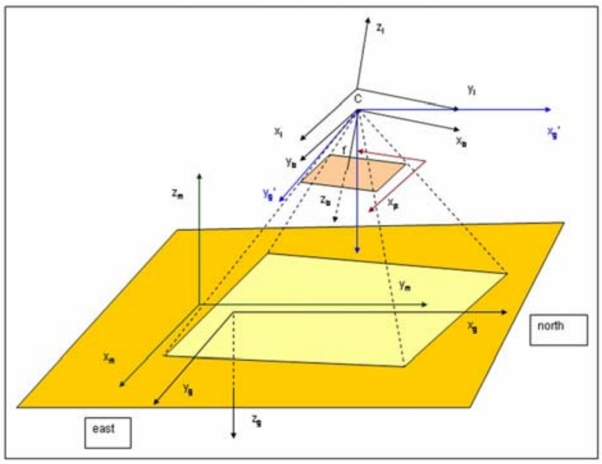

Figure 1. Illustration of projection geometry with directions of used coordinate frames

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

$$P^m = C^m + (P - C)^m = C^m + \alpha \cdot dp^m \quad (1)$$

$$dp^m = C_g^m C_b^g(\Phi,\Theta,\Psi) C_c^b C_i^c \begin{bmatrix} x_P \\ y_P \\ -f_P \end{bmatrix}^i, \quad (2)$$

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 (i) to the digital map frame (m) in a world coordinate system and vice versa.

3.2 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) bases on a digital road map (Navteq). Using the a priori knowledge about roads (e.g. nodes, directions) and manually acquired parameters (e.g. bus or restricted lanes, parking lots), images can be masked considering a margin depending on the accuracy of different data (etc. GPS/IMU data quality, 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. 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 masked image from the previous step. The sizes of the expected vehicle in the image space are dynamically adapted to the current navigation data values (height over ground, attitude of the aircraft). The vehicle recognition 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.

The vehicles have a variety of appearances in the captured images depending on sensor type, object properties and environmental conditions (e.g. illumination, temperature). Most of the traffic objects can only be recognized as coarse rectangular shapes to be more or less in contrast to the background. Therefore the algorithm searches for characteristic contours (of suitable sizes) in edge images retrieved by applying edge detection operators, e.g. Sobel.

If a higher pixel resolution is available (VIS 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. Evaluating the number of vehicles per scene gives a measure for traffic density that can be provided to a central processing computer.

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 can be detected with a discrete step width of 9km/h. On the other hand, a small car moving with 80 km/h changes its position from image to image in the range of its length, which makes an object matching difficult.

The vehicle recognition algorithm delivers rough 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 detected.

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 scanned streets. The calculated average velocities and densities per road segment of the digital map and per timestamp can be used now as input data for simulation and prognosis tools.

4. RESULTS AND DISCUSSION

Real time airborne traffic data acquisition systems and their validation have been demonstrated.
During one year we performed several flights for testing and improving the technical equipment as well as image processing procedures for both systems. This results in a final technical configuration with satisfying performance and a shortening of processing time.

4.1 Software system implementation

Different software packages were developed and tested for the image processing and the real time extraction of the relevant traffic information. Figure 2 gives an example of a typical scene during processing.

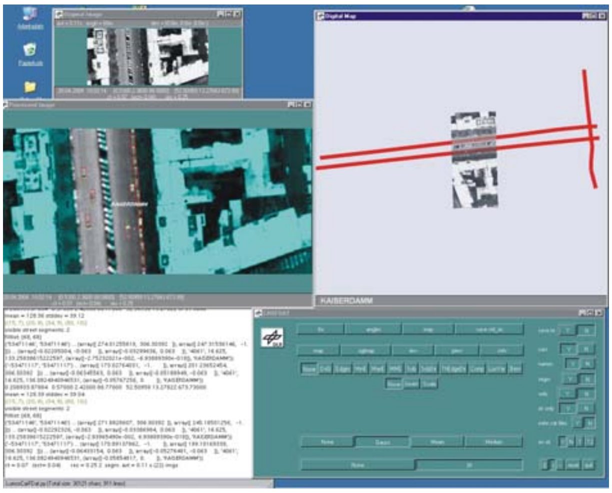

Figure 2. Image capture of data processing

For better understanding and orientation in the image the street names were blended in the images and in parallel a small map region with the image projection is displayed. Both information came from the digital street map offered by the company Navteq.

For the system which collects traffic parameters the average processing time is 0.16 s per image what corresponds to a frame rate of 6 Hz. For the traffic monitoring system with a lower frame rate of 0.5 Hz the mean processing time is 1.0 s. The size of the frames is also different: the IR-Camera frame – chosen for the traffic parameter measurement – gives just a small picture. The Camera for monitoring applications has a wider field of view. Both values meet the criterion of real time processing. During a typical flight time of 90 min the time gap between transmission to the ground and input of extracted traffic data into the data bases never exceeded 30 s.
Before starting comparison of derived results to other traffic data sensors we first focussed on the algorithm validation on a single image basis to prove the correctness of the approach. An additional software tool for the comparison of manually counted cars to the automatically detected ones in every single image has been developed. We analysed images in numerous sequences with various traffic situations under different weather conditions.
Figure 3 shows an image of the comparison tool. Blue squares indicate automatically detected, red squares show the manually detected cars, and green circles mark the matched ones.

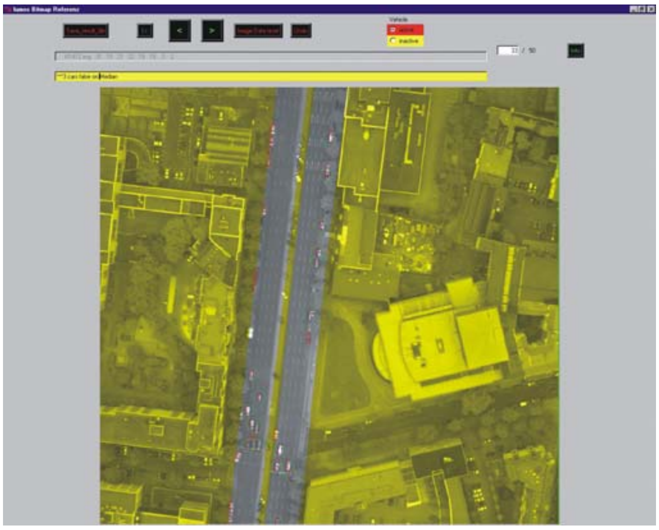

Figure 3. Comparison of auto and manually detected cars

4.2 Results of test campaigns

For the helicopter system we found as a preliminary result for arterial city roads that 61 % of all cars were detected correctly by the automatic detection system. Only 20% were falsely counted cars, i.e. cars that not do exist. Similar results have been obtained for the airplane system.
Moving cars can easier be identified than parking cars. If we exclude parking cars, the automatic detection rate increases to about 75% for the traffic parameter measurements. For this case exclusion of parking car is tolerable because they do not contribute to the traffic flow. Only 8 % falsely counted cars are then found for arterial roads.
In every image sequence the number of automatically found cars is smaller than manually seen.
The derived average velocities per car class are in good agreement with long term experiences of urban traffic observation. They never exceed the speed limitations. The evaluation of averaged velocity estimation from observed images is impossible so is has to be done on a single car basis, to be discussed beneath.

4.3 Discussion and improvement

Since we wanted to achieve the real time feasibility first, also the recognition rate is not too poor. However, there are still several opportunities to tune the algorithm. As already mentioned excluding parking cars increases the recognition rate significantly. The discrimination between parking cars and vehicles only standing in right lane will be one challenge for the next future. Another reason for not finding all cars correctly is that the distances between cars standing at a light signal are some small that they might be below the pixel resolution of the camera. New versions of the algorithm will account for that.
The quality of detection strongly depends on the quality of the digital map. The algorithm accounts for street information like number of lanes or directions of polygons to create the best possible extraction of the streets in the images. Any inconsistency in the map information leads to systematic errors in calculation of the traffic parameters. Especially the increasing numbers of lanes around crossroads leads to a decrease of detected vehicles. Implementing this crossroad information will improve the detection, too.
Finally, an exact determination of the detection error and of its dependence on road type and other influence would allow a better conclusion on the real traffic densities.

4.4 Validation and comparison to other traffic sensors

The airborne systems measure the number of cars (i.e. the traffic density) and their speeds. From these values, the traffic flow (vehicles per time unit) can be derived. This would allow a comparison with data from other sources, e.g. stationary sensors. We compared the data with stationary induction loop detector data from the Traffic Management Centre Berlin (VMZ) as well as with measurements from a video detection system (Autoscope SOLO). Both data match very well (see Fig. 4).

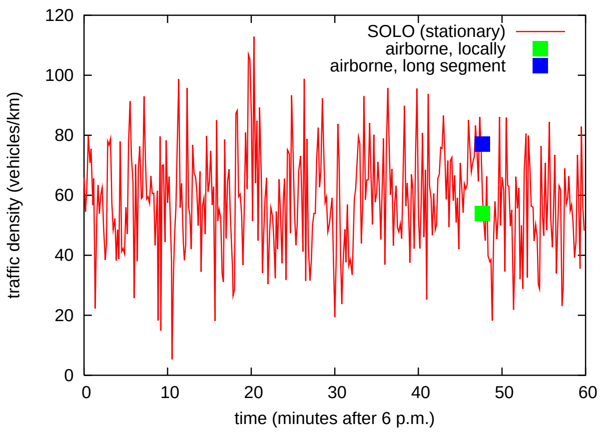

Figure 4. Comparison of traffic densities gained from a stationary sensor (SOLO video system; red curve) with airborne measurements from a 90m long road segment (green) and averaged over a 440 m long road section (blue).

Each stationary detector, however, measures only at one location (as function of time); airplane based methods measure only during a few moments of time (as function of position). Thus, direct comparisons only are possible at the location of the detector and for the time of the flight (see Fig. 4).
For checking the accuracy of the velocity measurements it is necessary to compare the airborne results with data from other sources. For this purpose, we used a test car which was identified in the airborne images, due to its special reflection behavi-

our. The speeds measured on board the car and from the airborne systems have been compared (see table 1).

Flight	Velocity on board (km/h)	Velocity from airplane (km/h)	Difference (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	23.0	19.8	3.2	13.9

Table 1. Velocity determination automatically from airplane imagery

The average relative error of velocity determination for one test car within the image sequence of ~1 sec length is about 15 %. This error is inverse proportional to the absolute value of velocity. It also depends on the geometric resolution and the radiometric conditions of images. Despite the small number of measures the calculation algorithms demonstrate its validity well.
Because densities and speeds are quantities varying not only with time but also with position, the airborne systems are able to provide information which cannot be obtained by stationary sources.

5. SUMMARY AND OUTLOOK

Both technical configurations are suitable to collect traffic relevant airborne data and therefore fit the requirements for real time data processing. From the technical point of view a combination of VIS and IR cameras and the fusion of their image data promise a high potential. High geometric and radiometric resolution is required. High frame rates are needed for velocity estimations. In order to overcome the bottle neck resulting from data downlink, onboard processing could be considered.
The improvement of the basic map information becomes of great importance. Implementation of map and a priori knowledge in a Geoinformation System will led to better results.
For disaster management, the digital street map has to be more flexible. Up to now it is possible to reduce the network automatically depending on the current traffic situation (e.g. accidents or road works). There are a lot of scientific papers dealing with the idea to create a digital roadmap by using remote sensing. These approaches should be extended to create a network of optional streets in the cause of catastrophes. Therefore it is also necessary to simulate the traffic flow depending on social data like e.g. number of households, number of persons, or number of cars in one area.
For a higher disposal of such an airborne system for traffic data collection RADAR or SAR-Sensors should be used.

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