Visual Traffic Monitoring

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Overview

- Introduction in Airport traffic monitoring / A-SMGCS
- Airport surface movement monitoring (A-SMGCS) using optical sensors: The INTERVUSE project
- INTERVUSE project results
- A case study: Prague International Airport
- Introduction in Road traffic monitoring
- Road (tunnel) and airport (parking) traffic visual monitoring: The TRAVIS project
- TRAVIS project results
- Conclusions, Lessons learned and future work

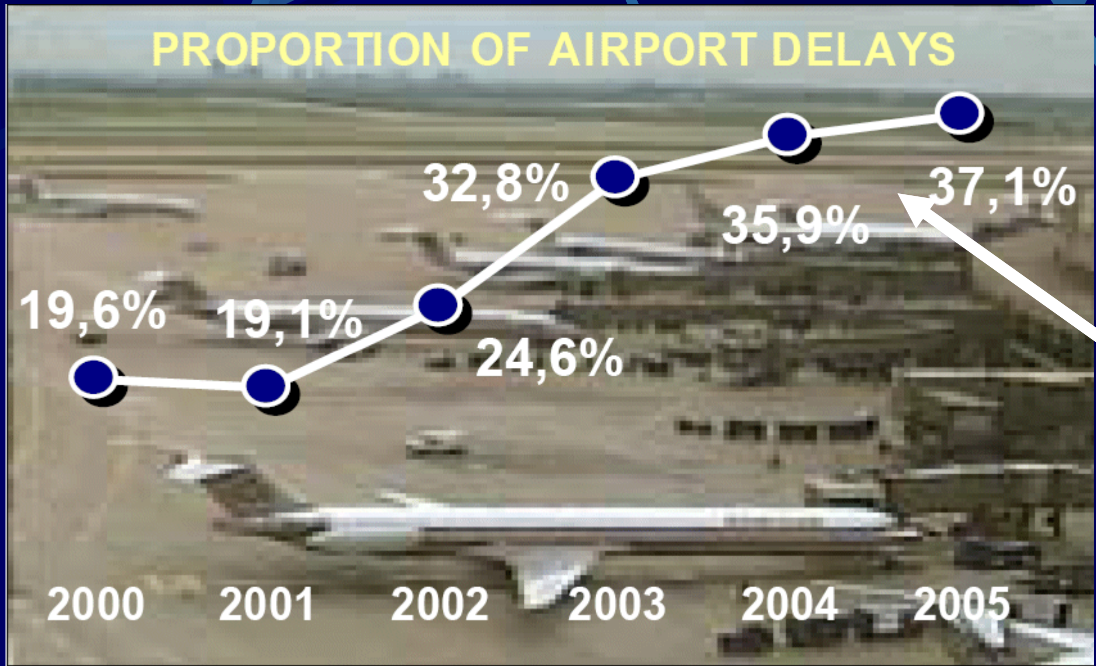
Introduction to Airport (Surface) Traffic Monitoring

- Air traffic management problems
- Introduction to A-SMGCS
- What sensors are used?
- Related Commercial Systems
- Related Research Projects

Air Traffic Management Problems

- Number of flights is constantly rising (traffic is doubled almost every 12 years)
- Limited airspace usage caused by restricted airways and corridors instead of free flight
- Limited traffic on ground caused by insufficient technical support with ground control systems
- Large number of operations (refuel, passenger transportations, etc) are simultaneously performed at the airport surface, even under difficult weather conditions.
- The highest risk for incidents and accidents is when the aircraft is moving on the ground

Airport(-related) Delays



Airports become air traffic management bottlenecks according to EUROCONTROL statistics

Runway Incursions (source: Federal Aviation Administration)

CALENDAR YEAR	OPERATIONAL ERRORS	PILOT DEVIATIONS	VEHICLE/ PEDESTRIAN DEVIATIONS	ACCIDENTS
1994	83	66	51	200
1995	65	125	50	240
1996	69	146	60	275
1997	69	132	87	292
1998	91	183	51	325
1999	78	182	61	321
2000	87	259	85	431

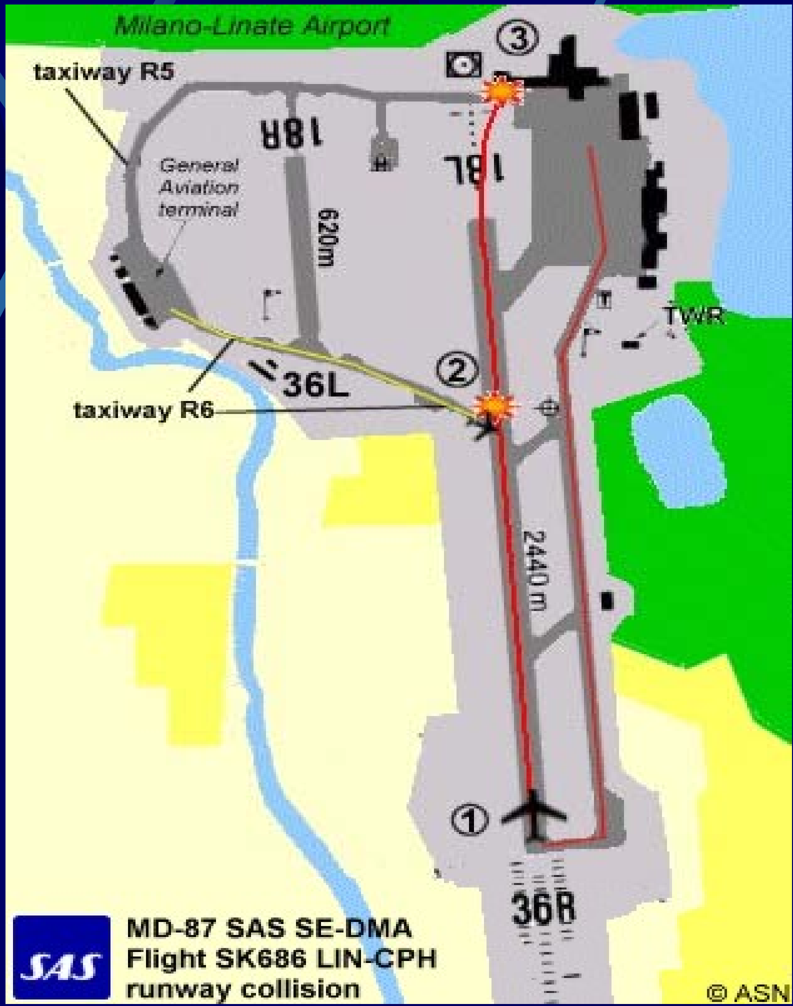
Between 2000-2007 figure remains rather constant but still significant: 320-340

A tragic accident: Linate airport

- Place: Linate airport, Italy
- Date: 8 October 2001
- 114 passengers killed and
- 4 people at the ground lost their lives

Reason:

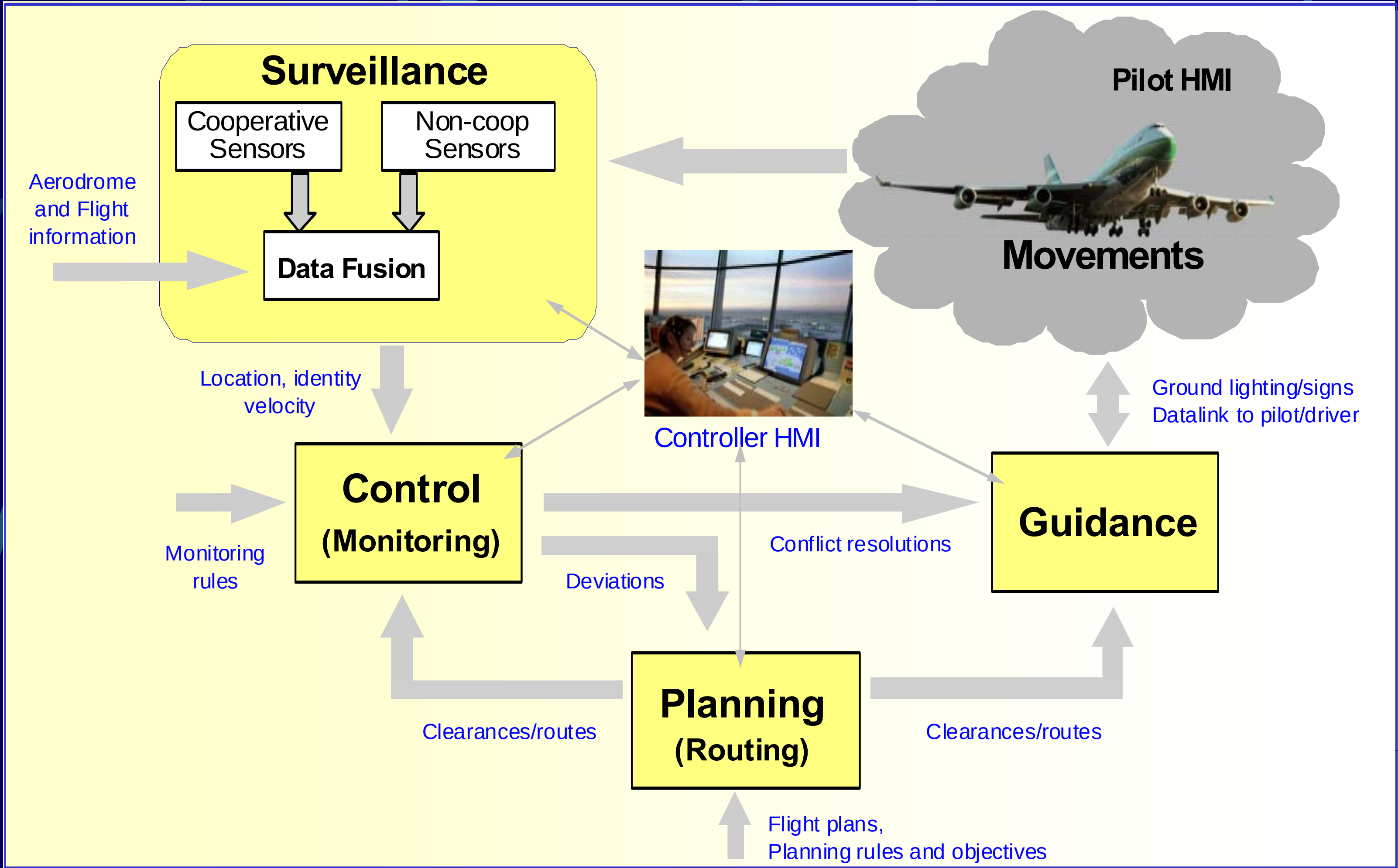
- Limited visibility (225m).
- The airport did not have any means for surface traffic monitoring



Solution: Use of A-SMGCS (Advanced Surface movement Guidance and Control Systems)

- Surveillance
  - Level 1 – basic surveillance
- Monitoring
  - Level 2 – adds automatically generated alarms
- Guidance (and Control)
  - Level 3 - adds automated guidance
- Planning/Routing
  - Level 4 – adds automated planning

A-SMGCS functionalities



(Figure from EMMA IP project)

Features of A-SMGCS Systems

- A-SMGCS provides a valid tool to Air Traffic Controllers that
  - Reduces risks for life-threatening accidents
  - Improves traffic management reducing the delays at airports
  - Is traditionally based on Surface Movement Radars: SMRs(primary radars) and SSRs(secondary radars)
- However, it is usually difficult to reliably cover the entire aerodrome due to
  - Reflections
  - Shadows due to buildings, equipment or other reflecting objects on the airport surface.
- Thus additional sensors ("Gap Fillers") may be needed to cover the blind spots of an A-SMGCS setup.

Present situation: Lack of A-SMGCS Systems

- A survey conducted within ISMAEL project with questionnaires to approximately 500 EU airports showed that:
  - 80% of these airports rely on human visual inspection from the control tower and
  - 40% face problems due to low visibility (visibility<400m) for more than 15days/year.

<u>Result</u>

Increase of Delays

Decrease of security

Sensors used for A-SMGCS: 1.SMR

- Surface Movement Radars (SMR) / Airport Surface Detection Equipment (ADSE)
  - Primary radars for ground surveillance (non-cooperative systems)
  - Range: 5-8km
  - Operation in X-band (8-12 GHz) or Ku-band (12-18 GHz)
  - Automatic target identification/labeling: NOT possible
  - High cost (300-500k Euro) / Integration with ATC/A-SMGCS system
  - May have problems due to:
    - reflections
    - shadowing (blind spots)

2. SSR

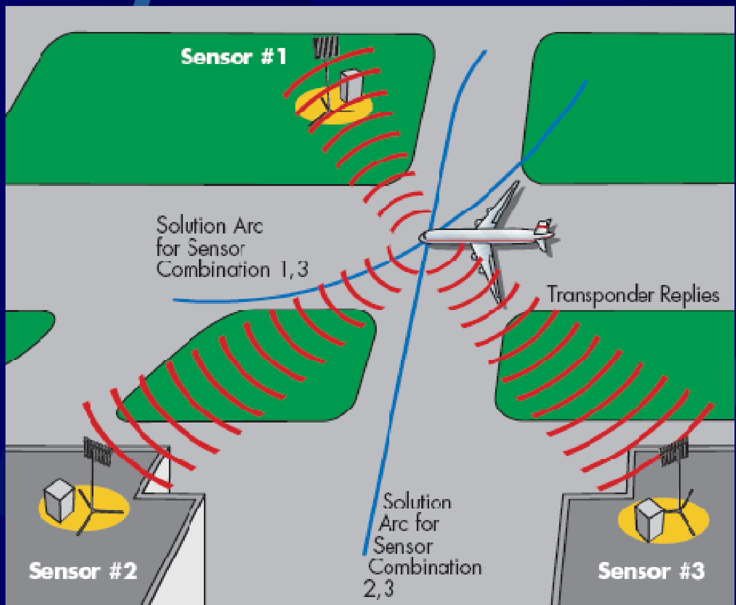
- Secondary Surveillance Radar (SSR) extends the SMR by not only detecting and measuring the position of aircraft but also by requesting additional information from the aircraft such as its ID and altitude. These are provided in Mode-S signal by the aircraft transponder
  - Cooperative system
  - Allows automatic target identification/labeling
  - Similar problems as SMR, i.e.:
    - reflections
    - shadowing (blind spots)
    - if the transponder is switched off or malfunctions

3. Automatic Dependent Surveillance-Broadcast (ADS-B)

- An ADS-B-equipped aircraft determines its own position using a global navigation satellite system (GNSS) and periodically broadcasts this position and other relevant information to potential ground stations and other aircraft with ADS-B-in equipment.
- ADS-B can be used over several different data link technologies (e.g. Mode-S Extended Squitter, VHF data link. etc).
- Cooperative system / requires additional equipment to be installed in the aircraft

4.(Mode-S) Multilateration

- Multilateration systems determine aircraft position by Mode-S signals transmitted by the aircraft transponder.
- Multiple receivers to capture the “squitter” transmitted from the Mode-S transponder. Then, by comparing the time difference, the system calculates the position.



- However:
  - Cooperative system
  - Aircraft transponder has to be ON: in case of a system/ malfunction or if the pilot switches it OFF, the accident risk increases

Commercial A-SMGCS systems

- NOVA9000 (Park Air Systems, Norway/US),
- STREAMS (THALES ATM, France/Italy),
- ASDE-X (SENSIS, US),
- A-SMGCS system (HITT Traffic, NL)
- SurfTrack (NESS, US/Israel)
- A-SMGCS system (Alenia Marconi Systems, IT)

Research A-SMGCS Projects based on novel sensors

- INTERVUSE (FP5 IST) – optical sensors(cameras with embedded processors) of AutoscopeTM, which was very successful for road traffic detection and relatively low-cost,
- ISMAEL (FP6 IST STREP) – novel developments in magnetic sensing technology, low-cost
- AIRNET (FP6 IST STREP), EGNOS/GPS low-cost platform combined with wireless telecommunication systems (CDMA, WiFi, TETRA, VDL-4) for communicating results to control center.
- SAFE-AIRPORT (FP6 IST STREP), rotating directional microphone arrays.
- Design of an A-SMGCS Prototype at Barajas Airport / Airport surface surveillance based on video images: work by EPS Universidad Carlos III de Madrid.
- AVITRACK project (FP6 AERO STREP): Aircraft surroundings, categorised Vehicles & Individuals Tracking for apRon's Activity model interpretation & Check
- EMMA FP6 IP (European airport Movement Management by A-SMGCS)

Comparison of A-SMGCS technologies

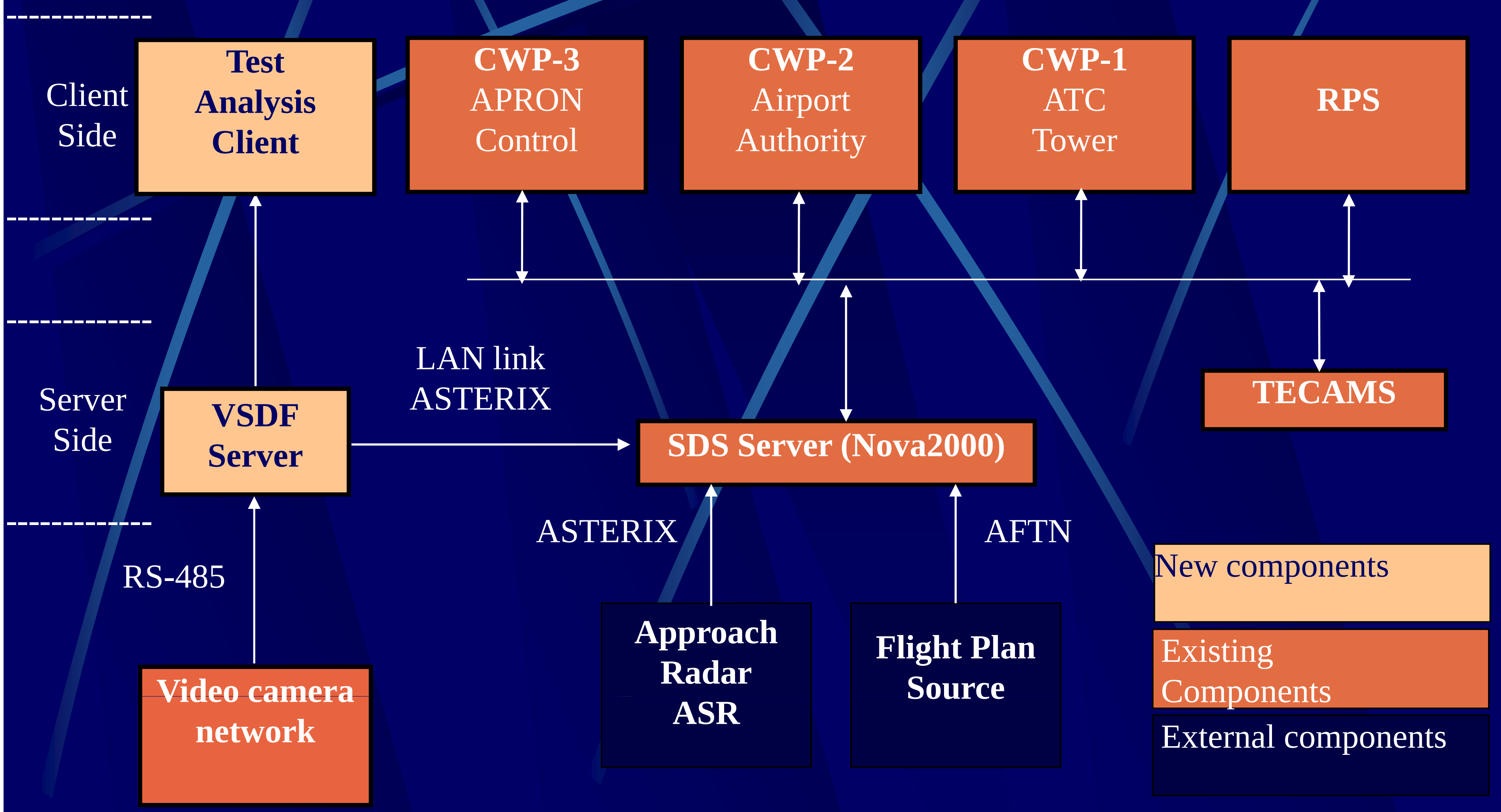
Technologies/Characteristics	Visual	Magnetic	Radar (primary)	GPS	Multilateration
Installation cost	Low	Medium	High	Low	High
Operation cost	Low	Low	Medium	Low	Medium
Ease of installations/ modifications	Easy	Medium	Hard	Easy	Hard
Influence from weather conditions	Yes	Temperature-dependent	No	No	No
Active detection (need for cooperative targets)	No	No	No	Yes	Yes
People detection	Yes	No	No	No	No
Target identification	No (maybe class)	No (maybe class)	No	Yes	Yes

INTERVUSE IST project: Airport surface monitoring using intelligent optical sensors

Objectives:

- Provide a new position sensing technology for A-SMGCS by combination of moving target extraction based on video cameras with ATC radar tracking, flight plan processing.
- Correlate and fuse these data to generate a synthetic ground situation display in an integrated SMGCS-ATC controller working position.
- Develop and test prototype systems at two European airports: Mannheim and Thessaloniki.
- Study of the usability of the system as:
  - a low cost solution for A-SMGCS tasks at smaller airports (Mannheim tests)
  - solutions for limited A-SMGCS tasks (Thessaloniki tests)
  - contributions for larger A-SMGCS solutions at large airports to cover blind spots like hidden yards or taxiways

System Architecture



Autoscope Solo® Wide Area Video Vehicle Detection System

- Autoscope® system uses machine vision technology and an embedded processor to produce highly accurate traffic measurements:
    - speed data
    - estimation of traffic statistics (e.g. volume)
    - vehicle classification
- Detection of incidents in highways.

- Each camera can be individually configured with Virtual Detectors
- Virtual Detectors: "Regions of Interest" that can detect local motion (target presence) using contrast recognition and learned patterns.
- All cameras are addressable by a unique IP address and are linked using serial cables (RS-485 similar to RS-232 but suitable for larger distances up to 1Km)

Demonstration of Camera functionality (Thessaloniki Airport)

- **Camera 1**

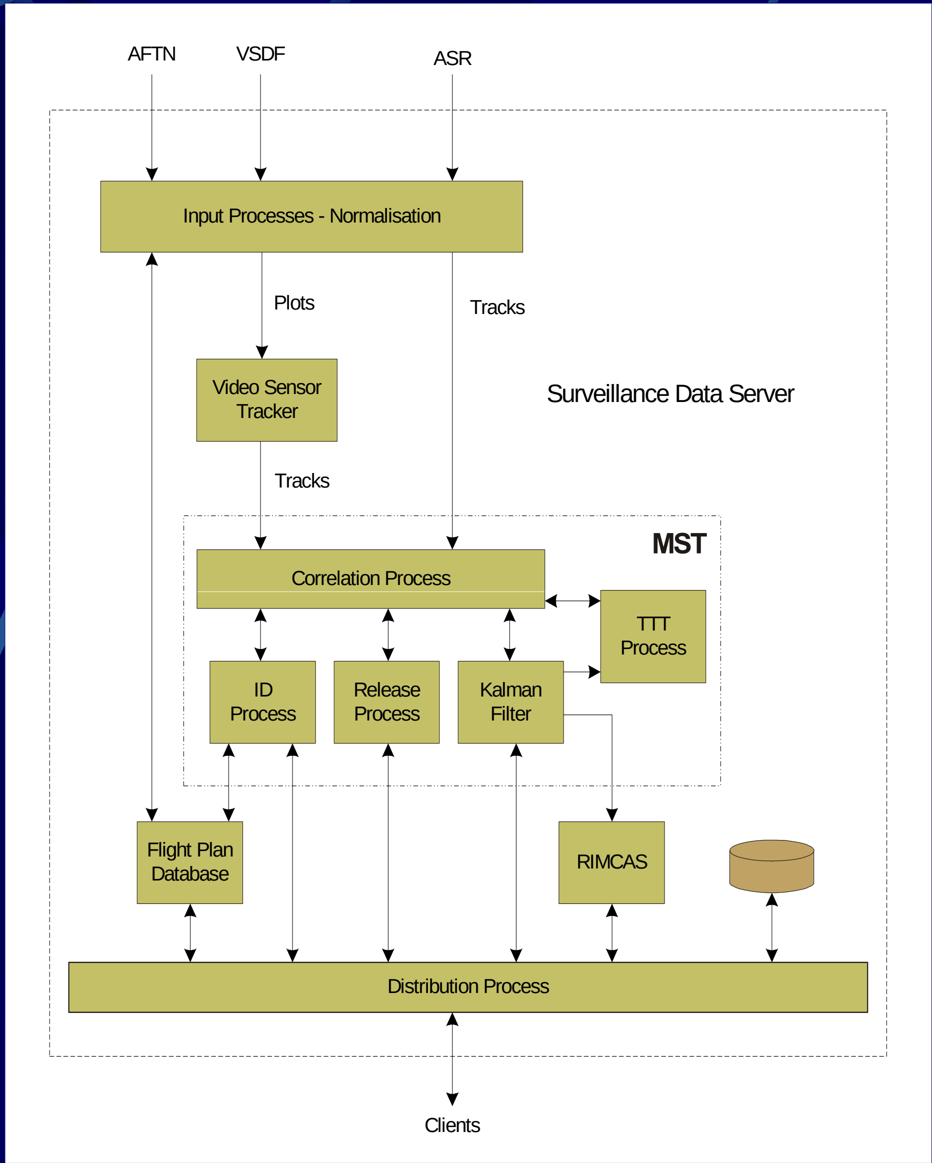
- **Camera 2**

Video Sensor Data Fusion

- Periodically polls the event data (VD states) from the cameras (constant time cycle),
- Processes the data received to detect and avoid possible false alarms
- Forms the observations (plots) that contain:
  - The time of the event
  - The ground position and size of the target (using homography-based calibration)
  - Additional information (e.g. velocity)
- Sends observations to the tracker of the system (SDS) in ASTERIX format (radar data exchange standard)
- Supports an optional visualization window, which shows VDs and observations on an airport map.

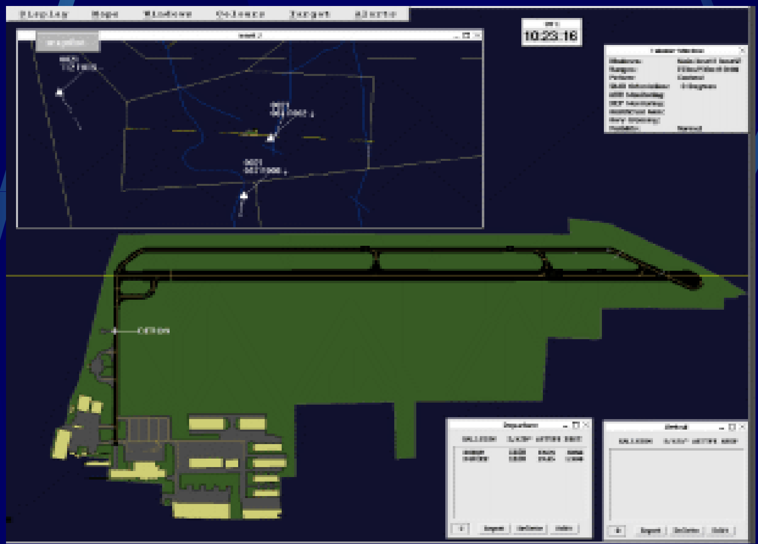
The Surveillance Data Server

- Based on NOVA2000
- Interfaces to VSDF, ASR, and flight plan data sources; Additional interfaces are available for SMR, MLAT, ADS-B
- Performs data fusion, correlation, and multi-sensor target tracking using Kalman filtering
- Distributes data to the controller working positions and other clients



Controller Working Positions

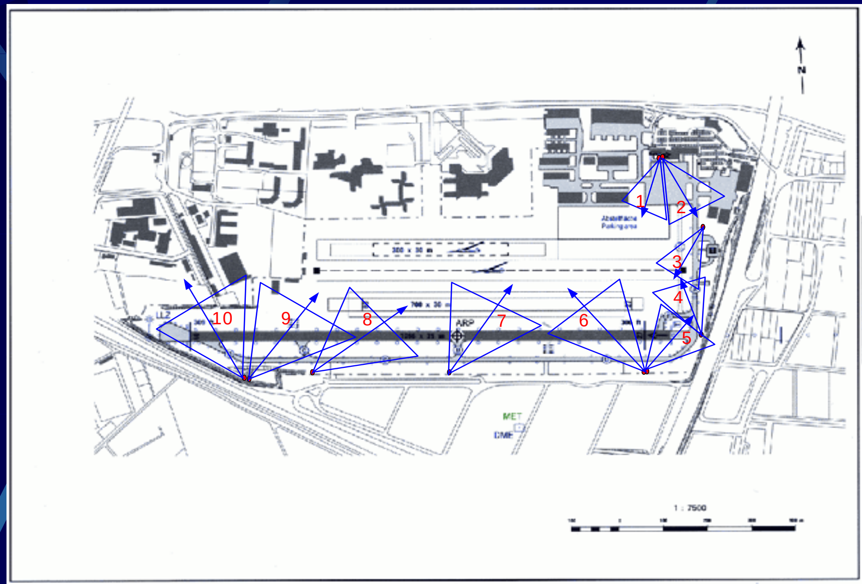
- A main traffic situation display window showing the movement area along with the tracked surface movement targets
- An inset window showing the traffic situation in the air



- Arrival and Departure flight plan lists with manual labelling capability
- A vehicle list with manual labelling capability
- Windows for presentation of alerts and status information

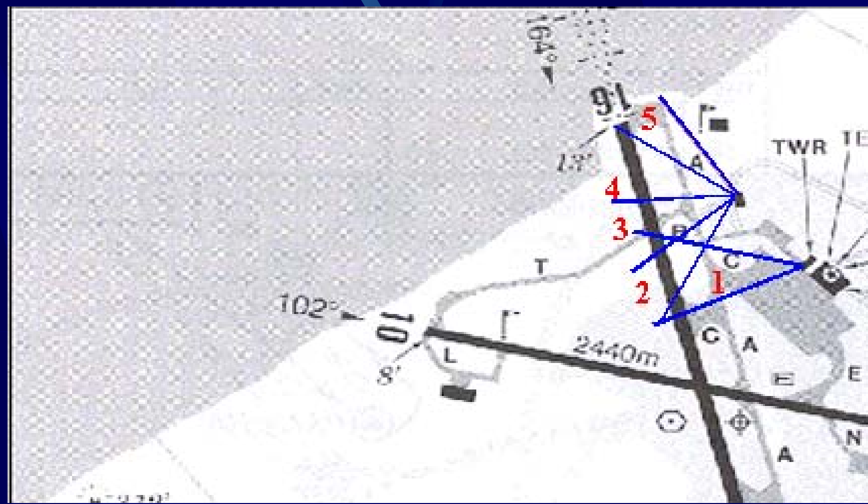
Two Prototype Systems

Site 1: Mannheim Airport



- All the area of the airport was covered
- Ten cameras were installed
- There were gaps between cameras.

Site 2: Thessaloniki Airport



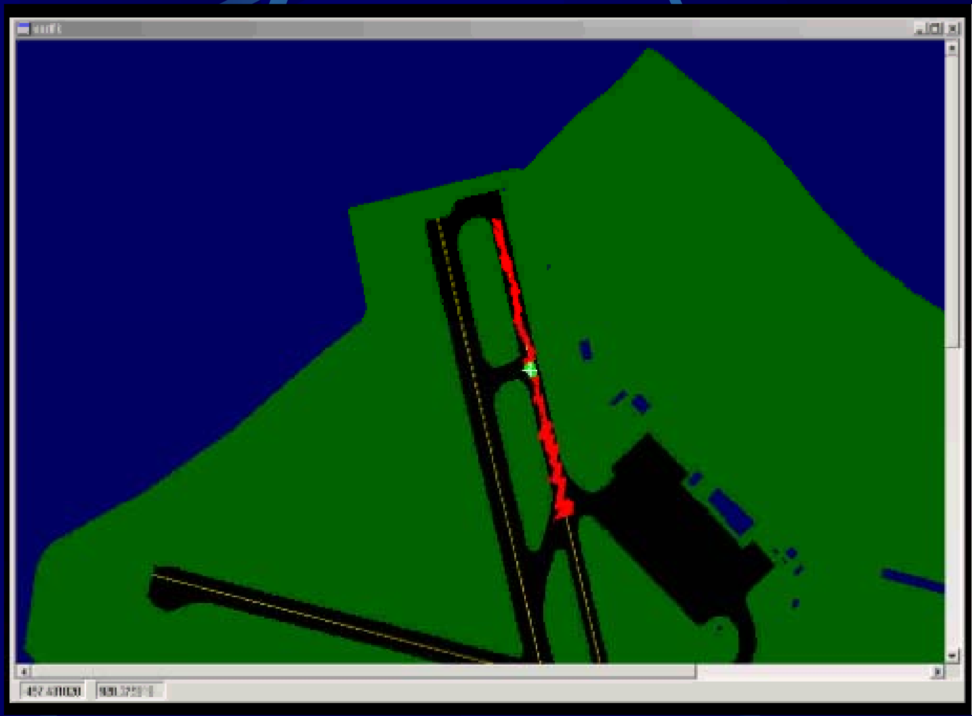
- Only a part of the main taxiway was covered (800m)
- Five cameras were installed
- There were no gaps between cameras.

TEST RESULTS

- False detection error: 1.5%
- Missed detection error: 4%
- Theoretical obtainable accuracy 7.5m
- Possibility to discriminate between targets which are separated by 15m or more
- Good Performance for velocities between 0 and 100km

Demonstration (Mannheim Airport)

Demonstration (Thessaloniki Airport)

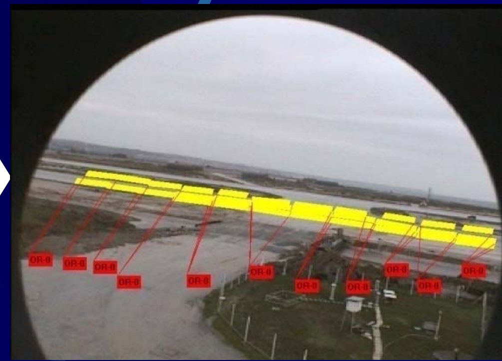


Lessons Learned

- The cameras should be installed as high as possible and close to the area to be surveyed to reduce shadowing and occlusion effects and improve calibration accuracy
- VDs can be placed in multiple parallel (to the road)

rows and combined using OR operations to

increase robustness to false alarms



- One way to avoid occlusions is to place detectors

ONLY at the road closer to the sensor (lower in image)

- The VSDF algorithm used can handle traffic in roads and crossings, but not more complex movements (e.g. in APRON), when target trajectories are not predefined
- Camera movements/oscillations should be minimized/compensated
- The existence of sky in the camera's field of view should be avoided since Autoscope sensors are sensitive to sudden illumination changes.

Lessons Learned (2)

- Optimization of FoVs of the sensors: small overlaps between them, so that
  - efficient use of the cameras is made
  - gaps (blind spots) are minimized.

- Optimization of the VD configuration of each sensor:
  1. Ground length of detectors is determined by the resolution requirement (approximately 15m).
  2. Detectors are non-overlapping and consecutive detectors are adjacent, so that the probability of detection at any time instant is increased.
  3. Adjusting sensitivity of VDs was difficult. Some algorithmic details about Autoscope VDs are still unknown (commercial product).
  4. Local adjustments may be required for some detectors, depending on the camera viewing angle and/or their image content.

Conclusion

The results indicate that the INTERVUSE technology CAN achieve most of the performance requirements of an SMR

Strengths

- Lower cost
- Higher update rate
- No radiation
- Configurable setup
- Passive system
- (Optional) Provision of video image(s)

Weaknesses

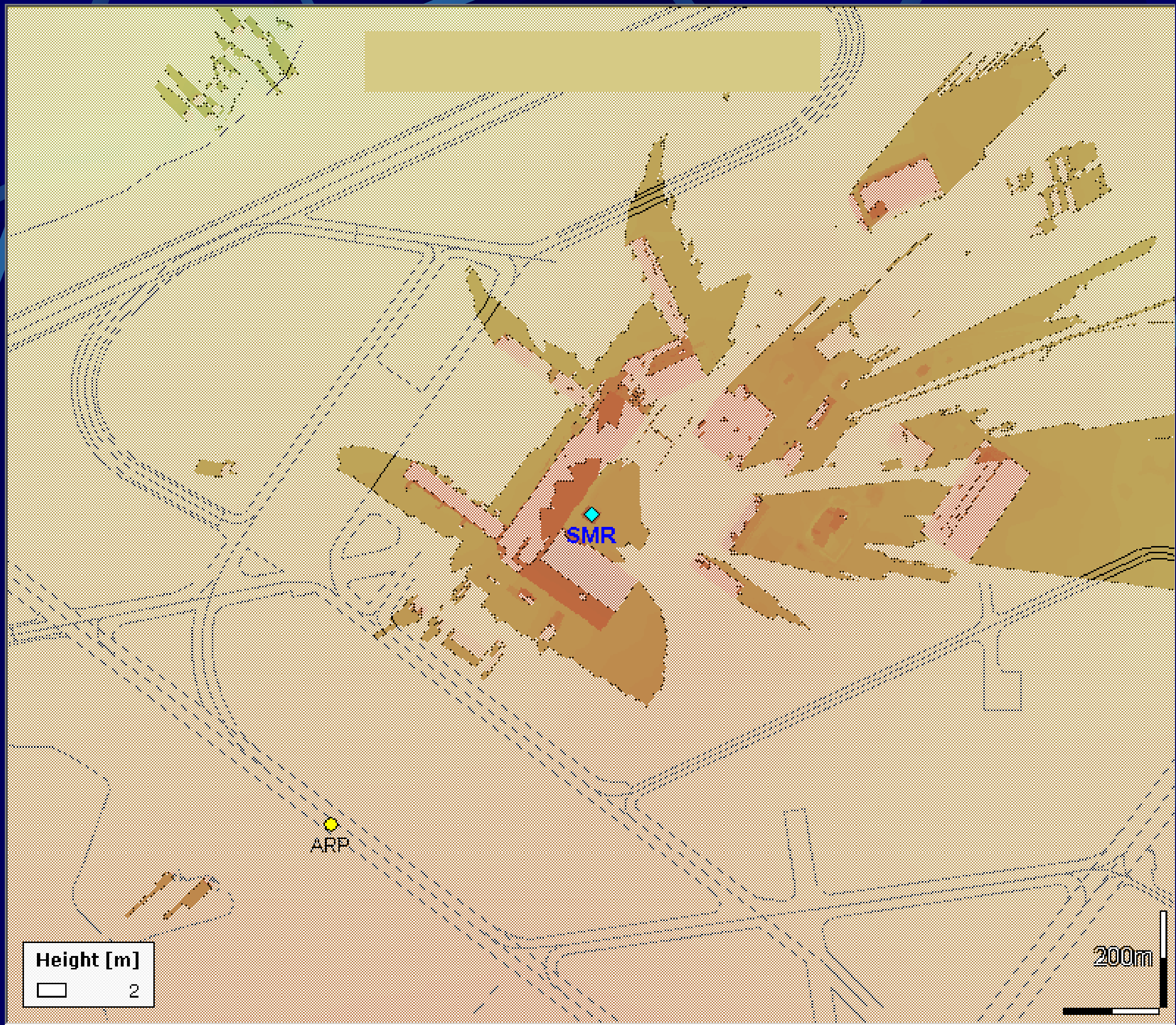
- Limited coverage
- Some detection problems in heavy fog
- Problems/False detections
  - due to occlusions
  - due to sudden illumination changes
  - Targets not moving for a long period (e.g. >2mins)

A Gap-filler scenario (case study): Prague airport

- Test of Gap-filler system at Prague International airport within FP6 EMMA IP project (European airport Movement Management by A-SMGCS, http://www.dlr.de/emma/)

Prague Airport Layout

SMR Shadow Areas

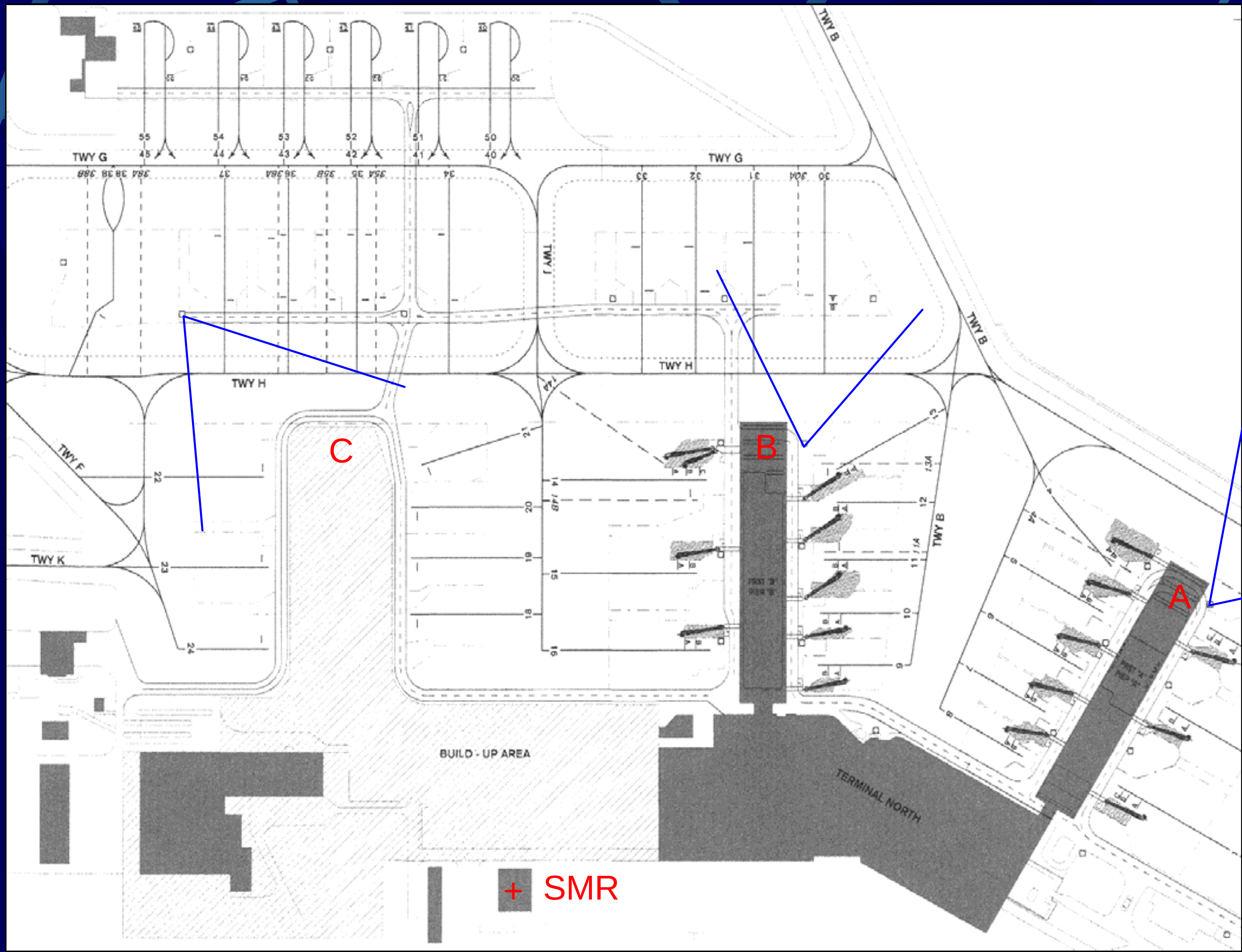


SMR Blind Spots

View North from Tower

Installation Positions for Cameras

Camera Locations amd FOVs



Final VD setup

Final System

Road Traffic Monitoring

- **Laser technology:** A laser or radar pulse is detected after its reflection from the vehicle. Very accurate but expensive and are used mainly for detecting speed violations.
- **Radar/Microwave technology:** Similar principle. Can also be used to detect other violations, e.g. vehicles in bus lanes.
- **Induction loops:** Coils of wire embedded in the road's surface. They detect a change of inductance in a large coil, which forms part of a resonant circuit, caused by the coil's proximity to a conductive (e.g. metal) object. Large installation, maintenance costs (asphalt has to be cut), small region
- **Magnetic sensors:** Detection of the changes of a magnetic field (e.g. the earth magnetic field) through the physical influence of a ferromagnetic object in the vicinity of it.
- **Visual detection:** Optical cameras using image processing and/or computer vision to detect moving objects, low-cost installation, larger area is monitored, different approaches

Research and commercial visual traffic detection systems

- Research systems (traffic data collection and/or scene understanding):
  - Video Surveillance and Monitoring (VSAM, US)
  - SCOCA (Trento, IT) – also capable of accident analysis
  - V. Kastrinaki, M. Zervakis and K. Kalaitzakis, A survey of video processing techniques for traffic applications, Image and Vision Computing, Volume 21, Issue 4, 1 April 2003, Pages 359-381.
  - Inigo, R. M. (1985). Traffic monitoring and control using machine vision: A survey. IEEE Transactions on Industrial Electronics, 32(3), 177– 185.

- Commercial systems:
  - Autoscope(Autoscope),
  - QUIXOTE TRANSPORTATION (UniTrak / VideoTrak Systems), INVIS(ASCOM),
  - MiTAC Integrated Highway Surveillance System,
  - SMART EYE- Smart Traffic Data Sensor by Smart Systems, TRAFICON,
  - CITILOG,
  - EXCEL TECHNOLOGY GROUP

Motivation for a New project

- To use SoA background extraction algorithms instead of the patented and old (70s) Autoscope algorithm
- To create an inexpensive Multiple Target Tracking sensor
- To avoid some of the shortcomings of the INTERVUSE sensor (e.g. track general motion)
- To create an open system suitable for many surveillance/monitoring applications

TRAVIS: An open Traffic Visual Monitoring Architecture

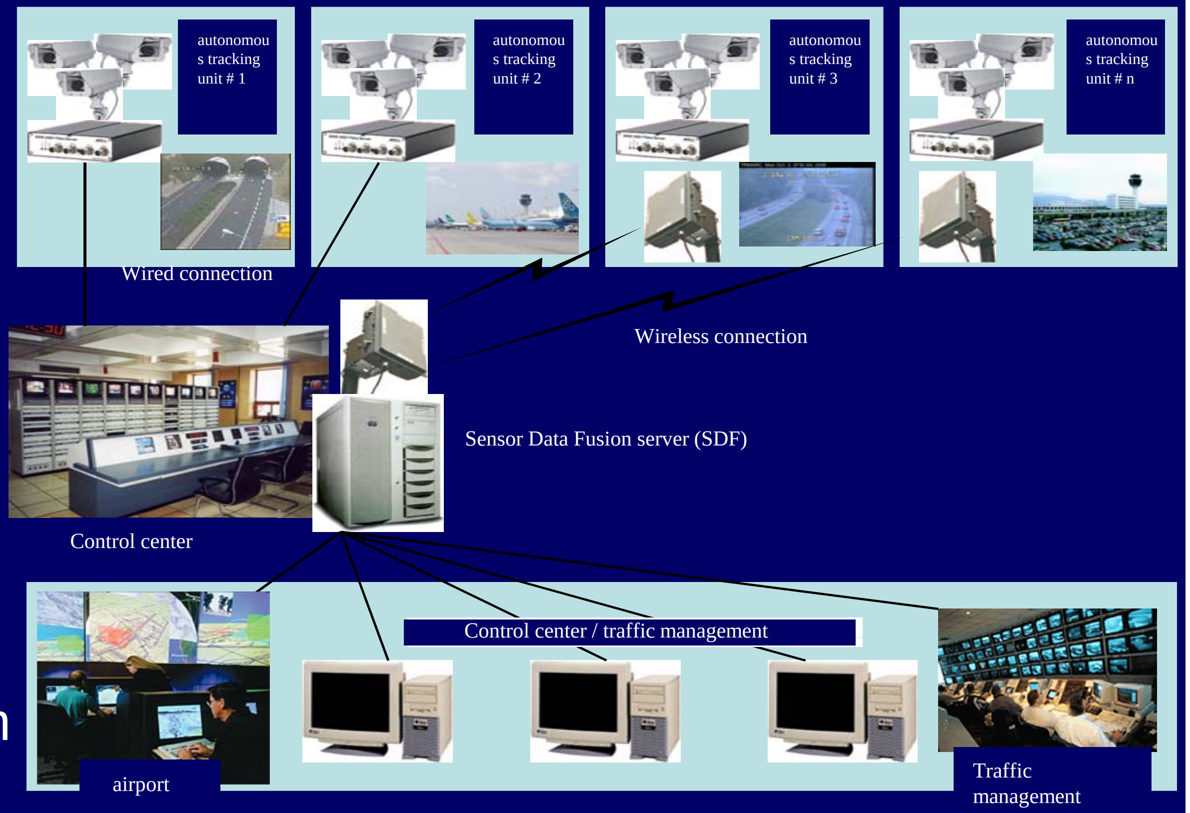
Objectives:

- To design a scalable, parameterized client-server Multiple Target Tracking system, based on a network of cameras.
- To support many applications using an open and extendable architecture and be a testbed for SoA algorithms.
- Two prototypes were delivered:
  - A tunnel monitoring system able to detect accidents and/or events that can lead to accidents. Installed at a tunnel near Piraeus harbor.
  - Monitoring movements occurring at the aircraft parking area (APRON): Installed at Macedonia airport of Thessaloniki, Greece

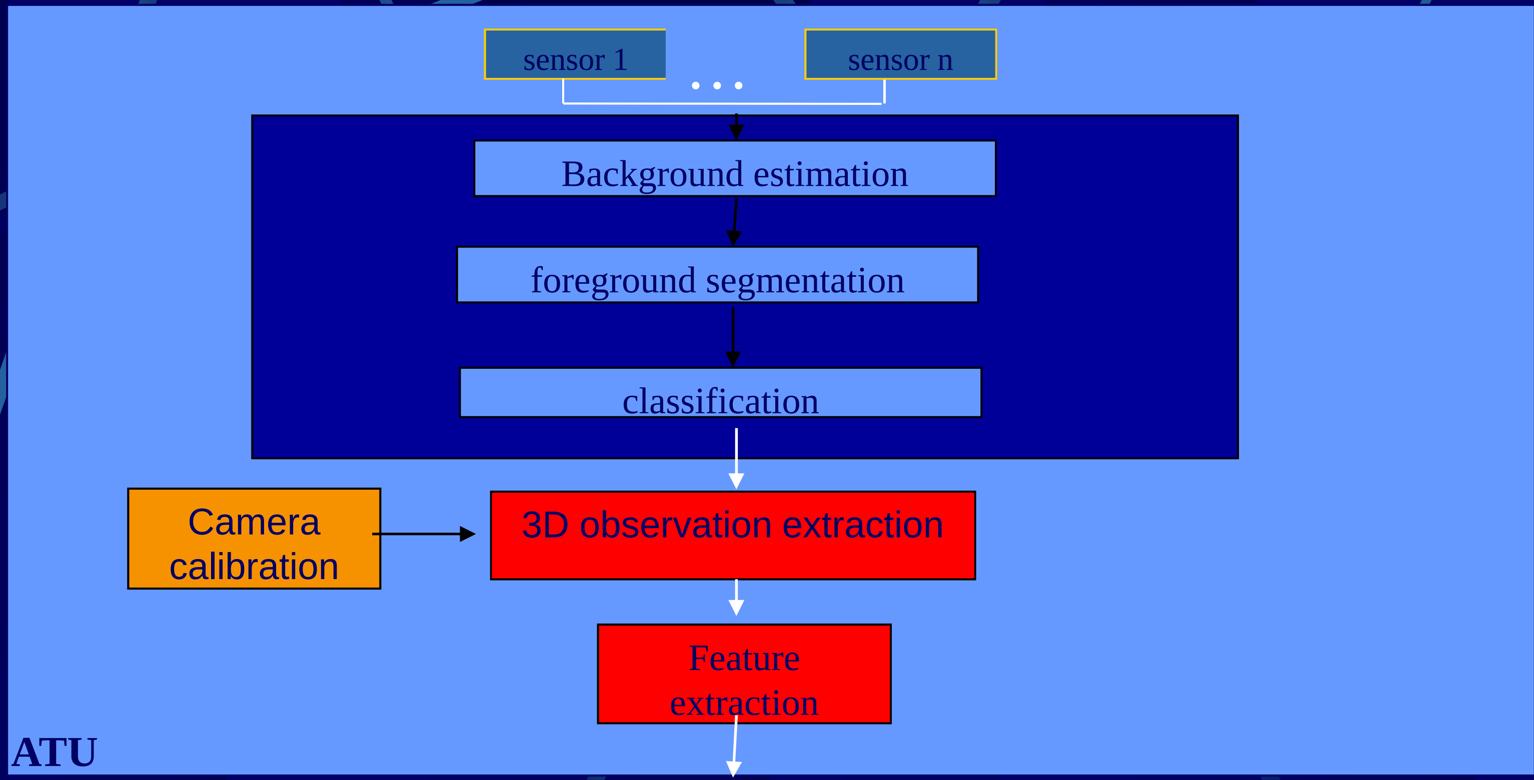
TRAVIS System Architecture

- Network of Autonomous Tracking Units
  - Capture images
  - Detect/classify foreground objects
  - Transmit the results

- Sensor Data Fusion server (SDF)
  - Fuses observations from ATUs
  - Tracks moving objects
  - Visualizes moving objects



Autonomous Tracking Unit

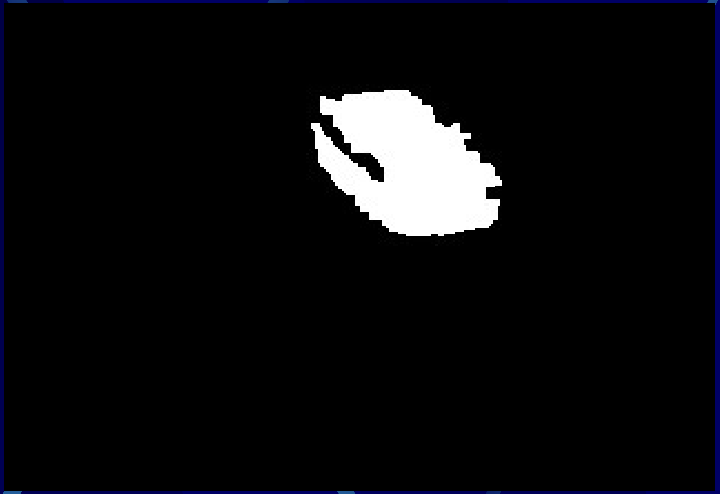


SoA Background extraction

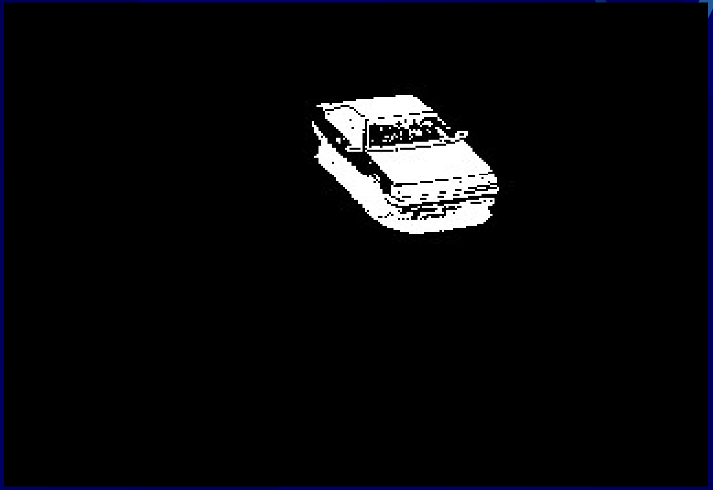
- Four background extraction methods are supported:
  - Bayes Technique (Li et al) – (OpenCV,slowest of the three)
  - Mixture of Gaussians (OpenCV,KaewTraKulPong and Bowden)
  - Reliable background subtraction and update (Lluis-Miralles-Bastidas) (fastest of the three)
  - Non-parametric Model for Background Subtraction (Elgammal et al)
- They were tested against crucial factors, such as complexity, illumination changes, shadows.
- Based on experimental results, the Non-parametric Model for Background Subtraction seems to be the most efficient one.

Background extraction (Road)

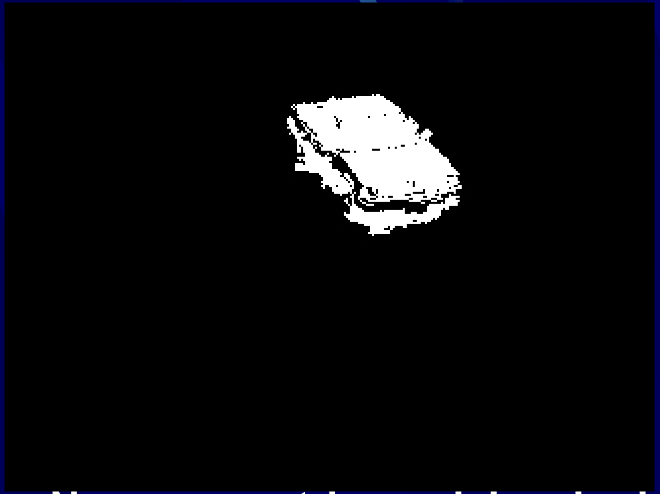
Mixture of Gaussians



Bayes

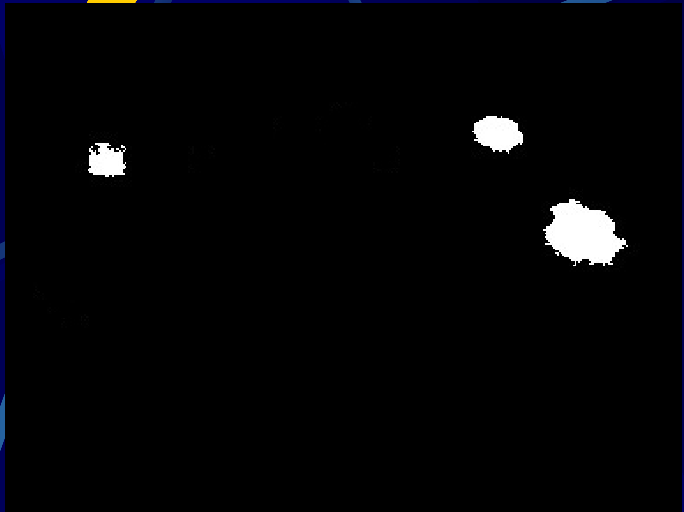


Fast technique (Lluis)



Non parametric model + shadow suppression (Elgammal)

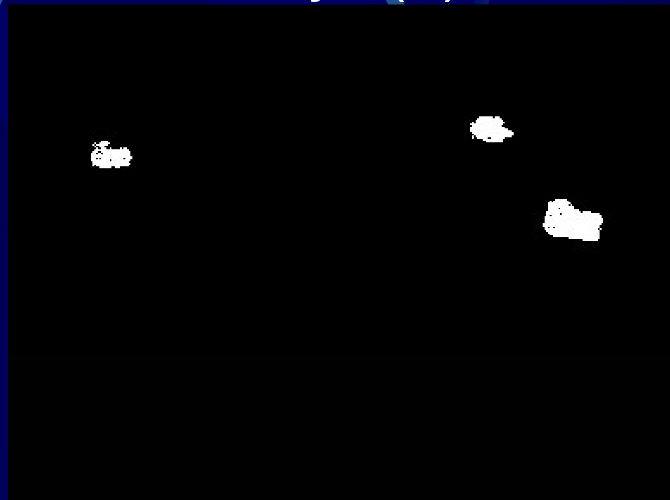
Background extraction (Airport)



Mixture of Gaussians

Bayes (Li)

Fast technique (Lluis)

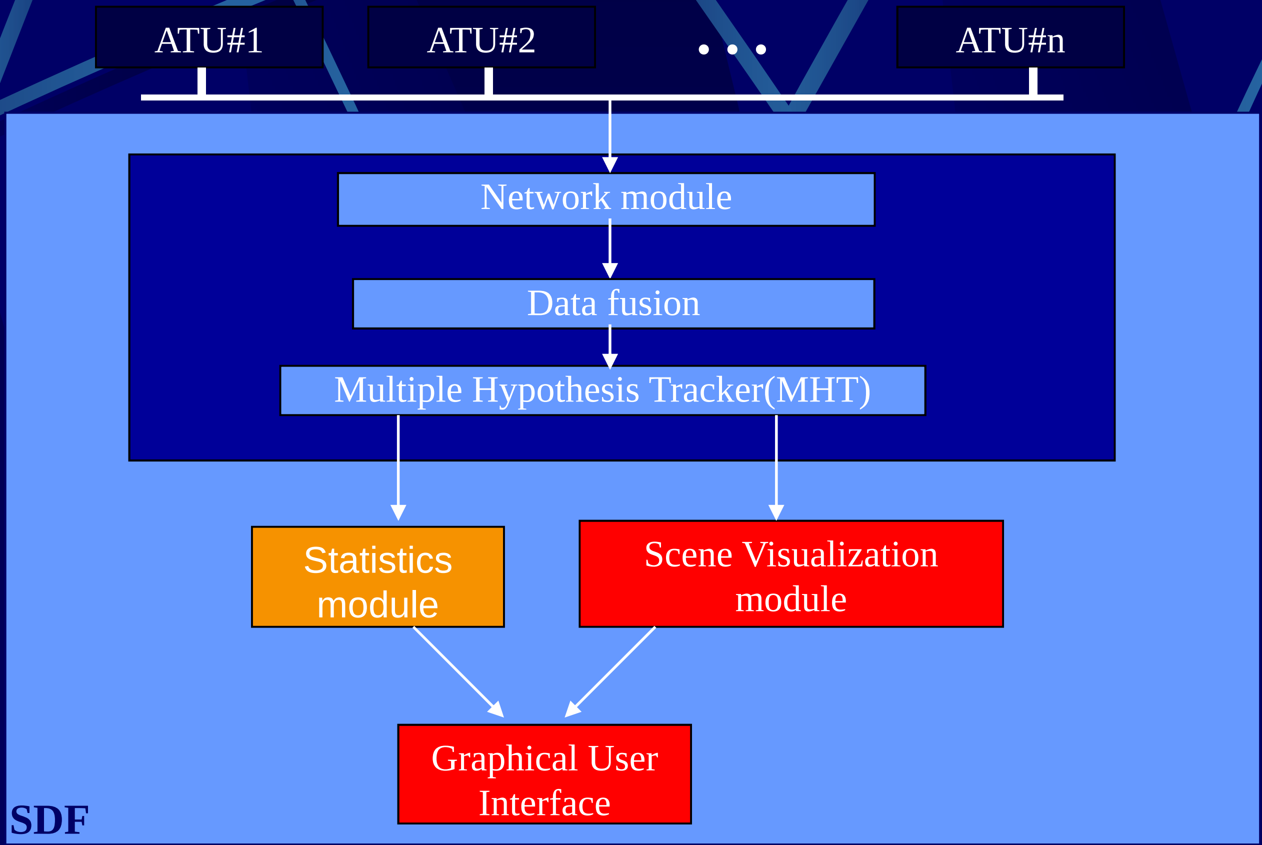


Non parametric model (Elgammal)

Classification

- A Back Propagation Neural Network was used (9 inputs, 100 hidden nodes, 4 outputs). Outputs correspond to four categories :
  - Human
  - Car
  - Large vehicle (track, bus)
  - Airplane (Airport) / Motorcycle (Tunnel)
- Neural network Inputs: Shape features (7 Hu moments of the blob, describing the shape of object, Major/Minor ellipse axis of the bounding ellipse of the observation in ground plane)

Sensor Data Fusion server (SDF)



Sensor Data Fusion server (SDF)

- Collects information from all ATUs during a constant polling cycle
- Observation Fusion: Produces fused estimates of the position and velocity of each moving target
- Tracking: Tracks the moving targets using a multi-target tracking algorithm (Multiple Hypothesis Tracking – MHT)
- Supports a user-friendly Graphical User Interface to:
  - Generate a synthetic ground situation display and provide alerts when specific situations (e.g. accidents) are detected.
  - Present the moving targets in real time
  - Present traffic statistics
  - Show Diagnostics / Modify configuration parameters

SDF server – observation fusion

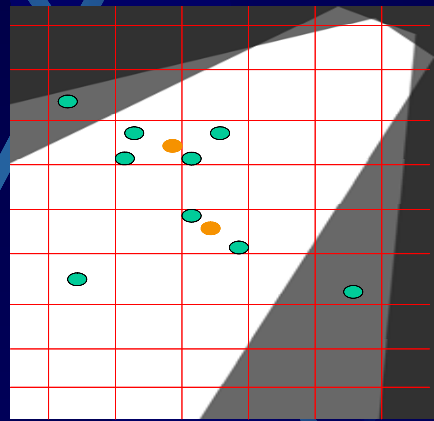
Two fusion techniques (when FOVs overlap):

- Grid-based fusion
  - Divides the overlap area (in world coordinates) in cells
  - Observations belonging to the same cell (or neighboring cells) are grouped together
  - Fused observations are produced be averaging the parameters
- Foreground map fusion
  - Foreground (probability) maps are generated for overlapping regions
  - These maps are transmitted to the SDF, where they are fused together (warped onto the ground plane and multiplied together)
  - Blob extraction from the final “fused” map

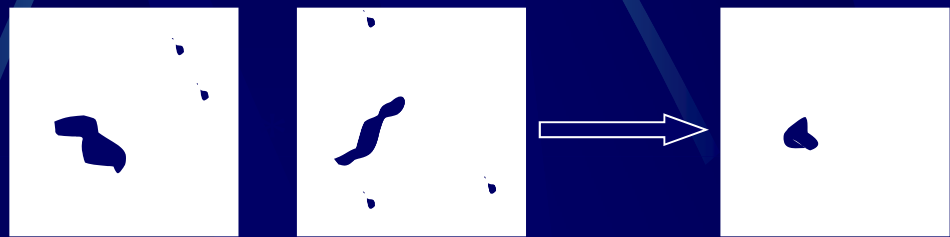
SDF server – observation fusion

Data fusion modes

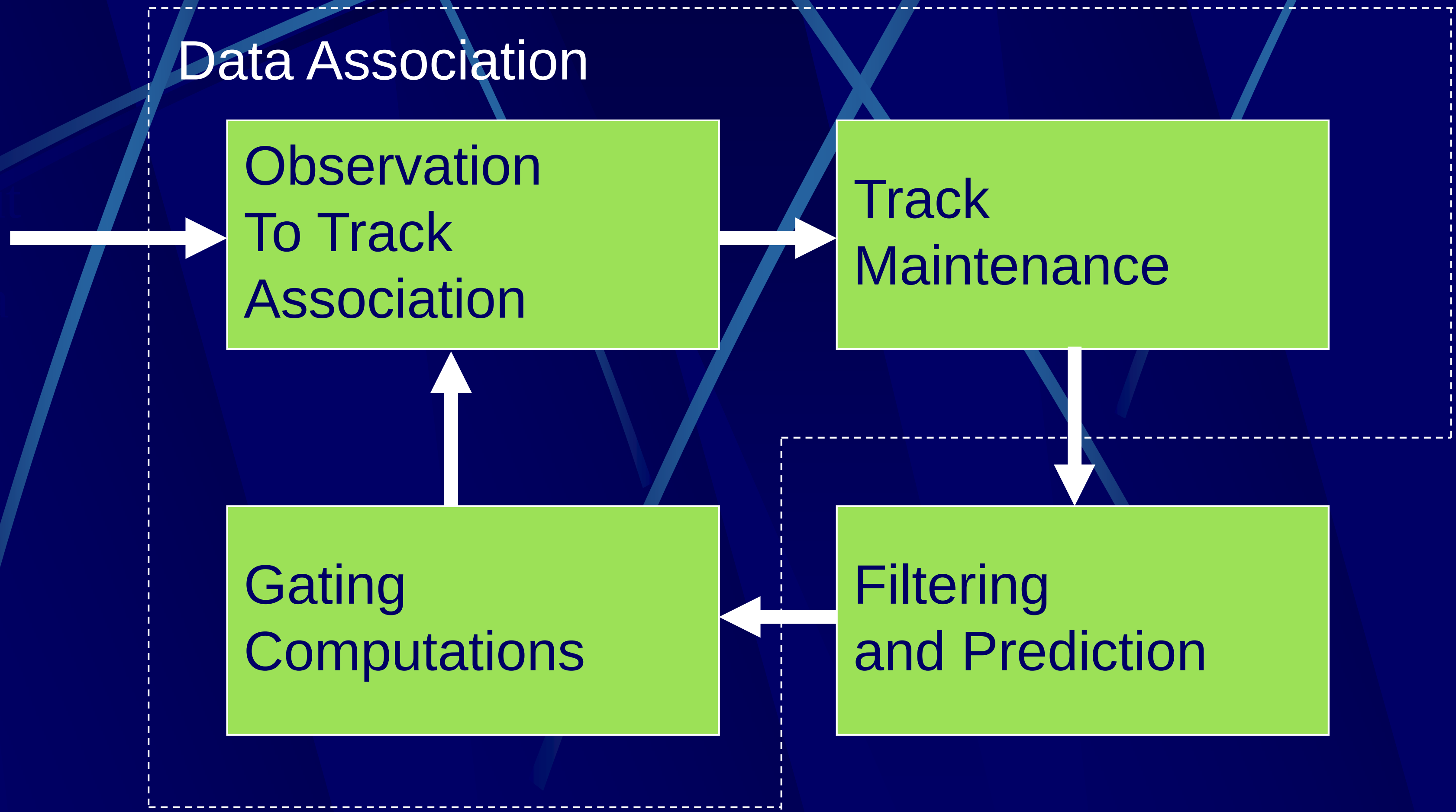
- Grid-based fusion



- Foreground map fusion



Multi-Target Tracking



Multiple Hypothesis Tracking

- MHT is a probabilistic data association algorithm that has nice properties:
  - Automatic track initiation / termination / continuation – even in the absence of measurements (temporary occlusions)
  - Explicit modeling of spurious measurements (false alarms)
  - Explicit modeling of the Uniqueness constraint: ‘1-1’ track-observation association.
- An efficient implementation of MHT using a fast algorithm to generate the k-best hypothesis [Cox96] was used.
- Any Kalman filter model may be easily used.

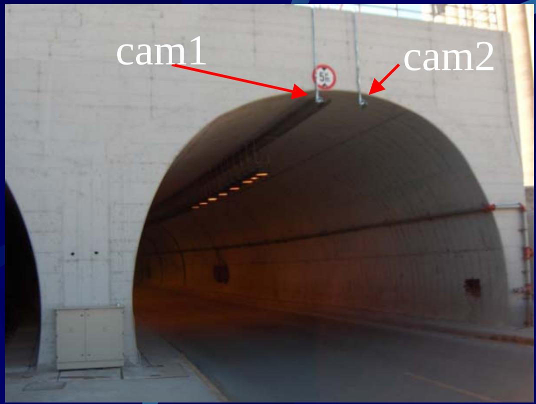
SDF server – statistics

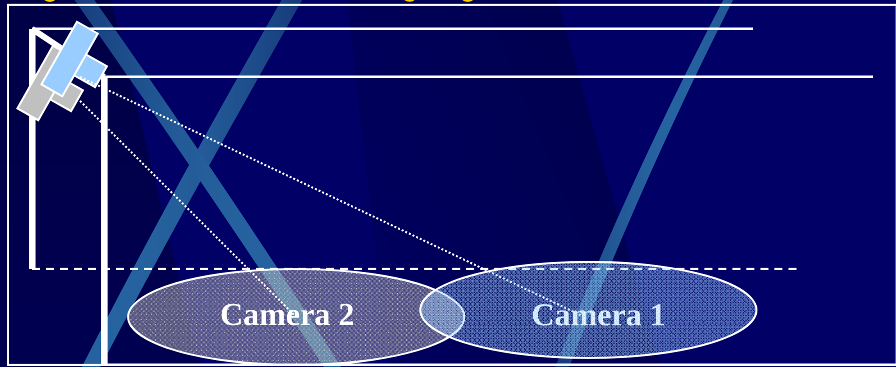
- Statistics per lane and per object class (Person, Car, Large vehicle, Motorcycle. Other)
- Minimum, Maximum and Average Velocity estimation
- Traffic flow (Vehicles/h)
- Traffic density (Vehicles/km)
- Vehicle counters
- Real time presentation of statistics and recording for post processing and analysis

Data exchange and control

- Client – Server architecture over TCP/IP network
- Use of an appointment algorithm for good synchronization in frame capture
- Use of Network Time Protocol to synchronize the ATU clocks with SDF clock
- Depending on the operation mode, data packets may contain
  - Plain text data or
  - Text + foreground maps

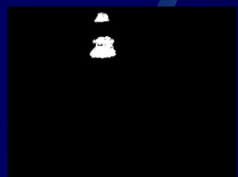
Tunnel prototype



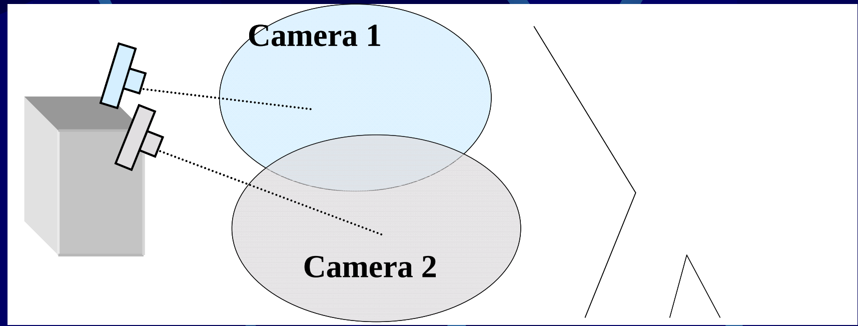


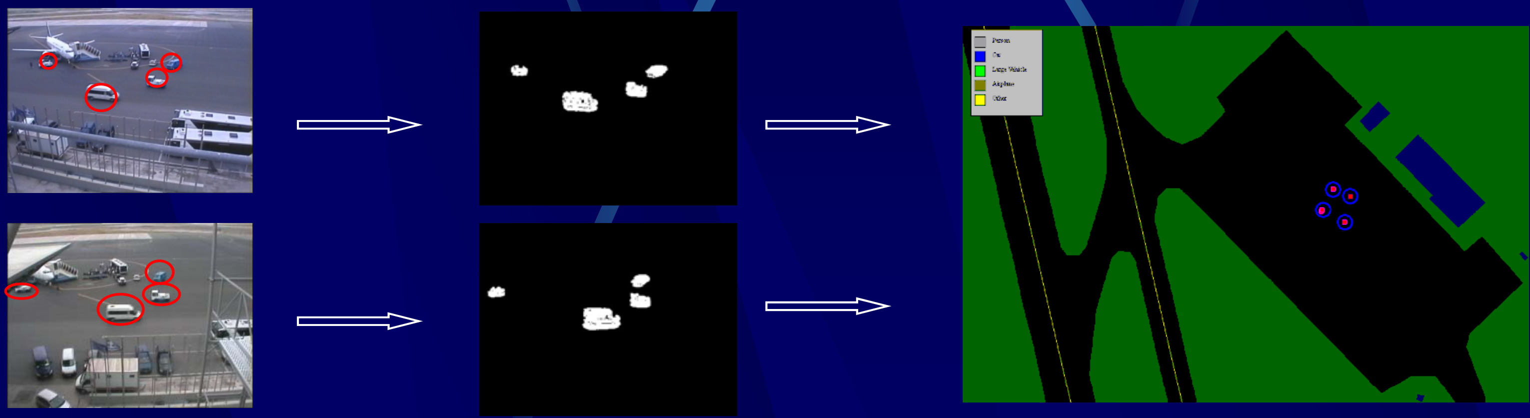
Camera 1

Camera 2



Airport prototype

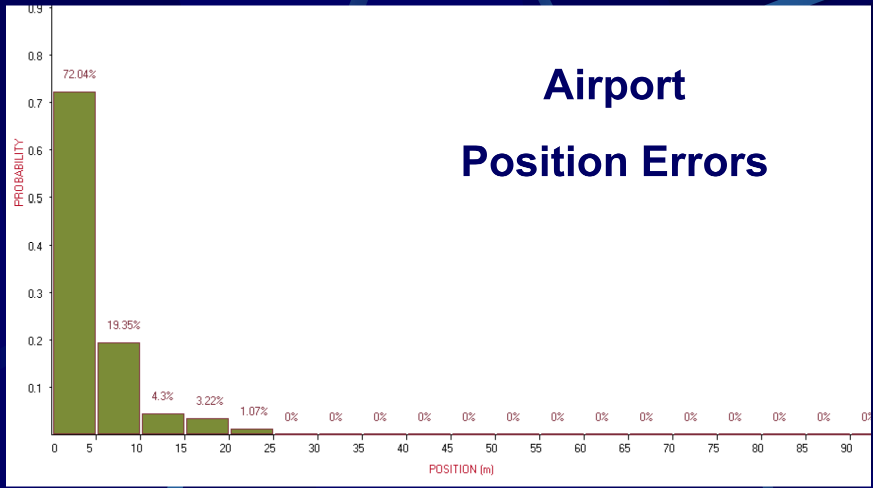


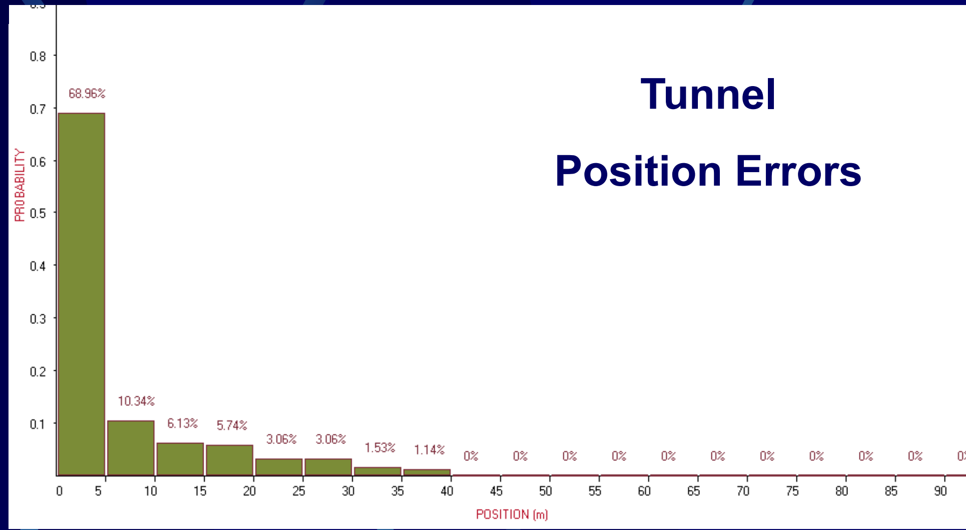


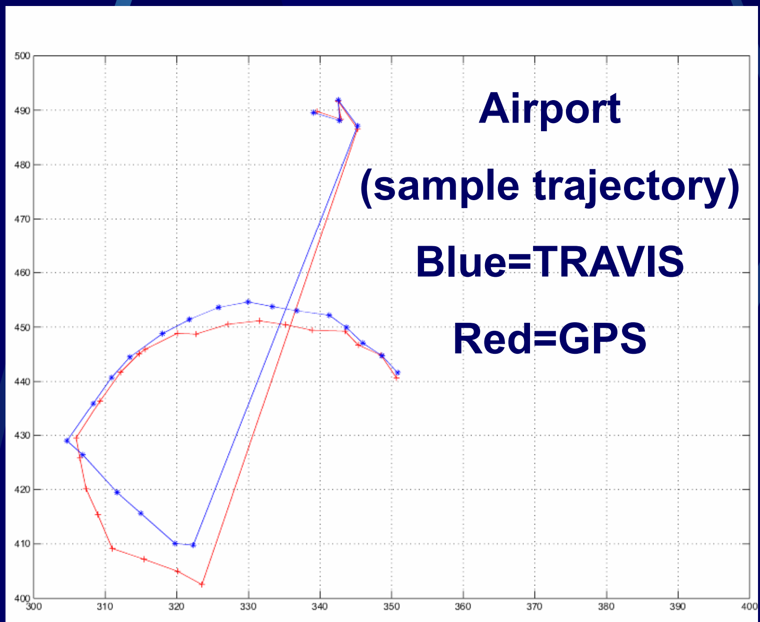
Experimental results

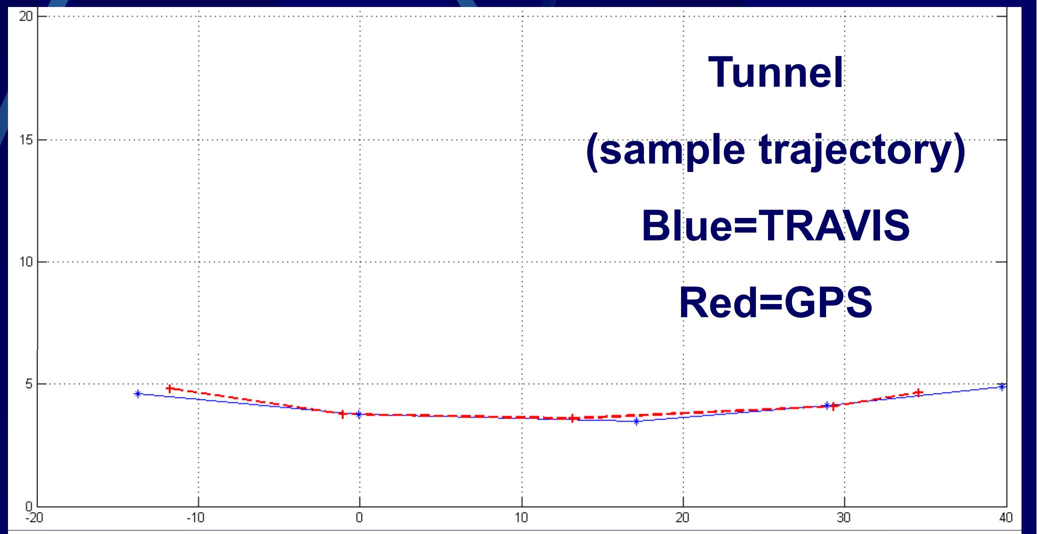
VIDEOS

Experimental Results









Execution times / Bandwidth

- Execution times:
  - Foreground map fusion (better results):
    - ATUs are extremely fast, (background extraction ONLY), but SDF is significantly slower (since extra processing and blob extraction occurs)
  - Grid-based fusion:
    - ATUs are slower(blob extraction+classification), but SDF runs faster
- Bandwidth:
  - Grid mode ~ 1KByte / frame
  - Foreground map / airport ~8 Kbytes / frame
  - Foreground map / tunnel ~15 Kbytes / frame

TRAVIS Conclusions

- Scalable / Modular architecture able to integrate new algorithms
- Inexpensive sensors based on COTS parts
- Aimed for a broad field of applications
- The non-parametric modelling method seems to provide improved background extraction results in terms of accuracy and time efficiency
- Two data fusion techniques were examined, resulting to a trade-off between efficiency, bandwidth and computational complexity.

Conclusions / Future work

- Colour-based algorithms, e.g.CAMSHIFT do not perform well (most objects are grey!)
- Occlusions: Always a MAJOR issue in computer vision apps
- Weather (Fog/Rain/Snow) may cause problems, but:
  - In relatively light fog, since the camera is closer to the target than the tower controller, it may still provide useful info to him
  - Even in more heavy fog, the camera software may still recognize small changes in pixel values, that are invisible to the human eye.
- Shadows: may be significantly suppressed by shadow suppression algorithms but still errors may occur.
- Background update: Further research is needed since ALL target have to be continuously and accurately detected (need to avoid their incorporation into background).
- Hardware implementations to increase frame rates
- Web Enabled Sensor, for use in service oriented architectures

Thank you for your attention

Questions?