Using Intelligent Digital Cameras to Monitor Aerodrome Surface Traffic

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An innovative system uses intelligent video cameras to help manage airport ground movement by filling in blind spots in existing Advanced Surface Movement Guidance and Control systems.

An aircraft is most at risk for an accident when it's still on the ground—when taxiing before take-off or after landing. This is because traffic throughput on the ground is limited by inadequate airport infrastructures and is often incapacitated during conditions of poor visibility.

To help address these problems, a new Advanced Surface Movement Guidance and Control System (A-SMGCS) provides air traffic controllers with support tools for ground-movement management.[1] Its key sensors are secondary surveillance radars, which rely on cooperating aircraft fitted with suitable transponders, and surface movement radars, which can detect noncooperative targets. Unfortunately, radar has limited coverage. Reflections, multipath, and shadows from buildings, equipment, and other reflecting objects on the airport surface make it difficult if not impossible for a single surface movement radar sensor type to reliably cover the whole aerodrome. (Multipath consists of return signals to the radar that might combine with different phases to alter the direct path echo.)

In these cases, a "gap filler" sensor could help. Fusing information from multiple sensors provides detailed information about the detected targets and provides an accurate position reference. The presence of a second radar increases tracking reliability (the description of the tracked object's movement on the airport surface must be continuous) and introduces some redundancy. However, such a sensor must be relatively inexpensive—it should cost less than the main sensor whose gaps it's filling.

The INTERVUSE project, funded by the European Commission, aims to address these problems by developing a cost-effective artificial intelligence system based on a network of intelligent digital cameras.[2] The system uses image-processing techniques to detect traffic and correlates and fuses data to generate a synthetic ground-situation display.

The INTERVUSE system

The system's building blocks include new and existing components as well as external components (see Figure 1). The commercial-off-the-shelf components are the NOVA 9000 system (Park Air Systems, Norway) and Autoscope Solo cameras (ISS/DataCollect, Germany). The Autoscope Solo Wide Area Video Vehicle Detection System is a sophisticated traffic surveillance system that uses machine vision technology to produce highly accurate traffic measurements (see the sidebar).

The video cameras

Each Autoscope Solo camera (see Figure 2) can detect traffic in multiple locations in its field of view. Furthermore, each camera incorporates an associated Machine Vision Processor, resulting in the following benefits:

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Related Work in Air- and Urban-Traffic Monitoring

Air traffic management has previously used image processing to identify aircraft—for example, one system uses a video algorithm based on tail-number recognition.[1–3] Additionally, the US Federal Aviation Administration has used infrared cameras for airport security and surveillance.4 However, the Intervuse system is the first to use video cameras to track aircraft, using methods from urban-traffic monitoring.[5–10]

In particular, the system uses the Autoscope Solo Wide Area Video Vehicle Detection System (see www.autoscope.com).[11] Autoscope systems help improve urban traffic by providing highway-speed data for traffic control centers and Internet information systems. They're also used to automatically detect incidents in tunnels and on highways, thus improving local authorities' emergency response times.

References

1. J.A. Besada et al., "Aircraft Identification Integrated into an Airport Surface Surveillance Video System," *Machine Vision and Applications*, vol. 15, no. 3, 2004, pp. 164–171.
2. J.M. Molina et al., "Automatic Video System for Aircraft Identification," *5th Int'l Conf. Information Fusion*, Int'l Soc. Information Fusion, 2002, pp. 1387–1394.
3. J.M. Molina et al., "Cooperative Management of a Net of Intelligent Surveillance Agent Sensors," *Int'l J. Intelligent Systems*, vol. 18, no 3, 2003, p. 279–307.
4. R. Castaldo, C. Franck, and A. Smith, "Evaluation of FLIR/IR Camera Technology for Airport Surface Surveillance," *Proc. 10th Ann. SPIE Int'l AeroSense Symp.*, vol. 2736, The Int'l Society for Optical Engineering, 1996, pp. 64–74.
5. R.T. Collins et al., "Algorithms for Cooperative Multisensor Surveillance," *Proc. IEEE*, vol. 89, no.10, 2000, pp. 1456–1477.
6. A.R. Dick and M.J. Brooks, "Issues in Automated Visual Surveillance," *7th Int'l Conf. Digital Image Computing: Techniques and Applications* (DICTA 03), Commonwealth Scientific and Industrial Research Org., 2003, pp. 195–204.
7. J.M. Ferryman, S.J. Maybank, and A.D. Worrall, "Visual Surveillance for Moving Vehicles," *Int'l J. Computer Vision*, vol. 37, no. 2, 2000, pp. 187–197.
8. G.L. Foresti, "A Real-Time System for Video Surveillance of Unattended Outdoor Environments," *IEEE Trans. Circuits and Systems for Video Technology*, vol. 8, no. 6, 1998, pp. 697–704.
9. M. Haag and H.H. Nagel, "Incremental Recognition of Traffic Situations from Video Image Sequences," *Image and Vision Computing*, vol. 18, no. 2, 2000, pp. 137–153.
10. T. Huang and S. Russell, "Object Identification: A Bayesian Analysis with Application to Traffic Surveillance," *Artificial Intelligence*, vol. 103, nos. 1–2, 1998, pp. 77–93.
11. P.G. Michalopoulos et al., "Automatic Incident Detection through Video Image Processing," *Traffic Eng. and Control*, vol. 34, no. 2, 1993, pp. 66–75.

- The system doesn't require high-bandwidth video transmission between the camera and the MVP.
- The vision processor can have closed-loop control of camera optics such as illumination, gain, brightness, and electronic zoom.
- The system is more easily portable.[3]

We can define rectangular areas, called *virtual detectors*, on the camera image plane, which correspond to binary output. The aircraft then indicates its presence by activating these detectors. Activated detectors appear in bright green on the system display (shown in light gray in Figure 3); deactivated detectors are black. We can configure up to 32 virtual detectors per camera, and we can define more complex virtual detectors by combining detector outputs using logical and mathematical expressions (such as AND, OR, NOT, time-based considerations, averages, or sums). The main advantage of virtual detectors is that you need process only the pixels of the image's specified areas, thus reducing the computational requirements.

Once we've selected the virtual detectors' location, the MVP can estimate the background (that is, the color values of pixels within the virtual detectors) in the absence of a vehicle. Virtual detectors then detect a

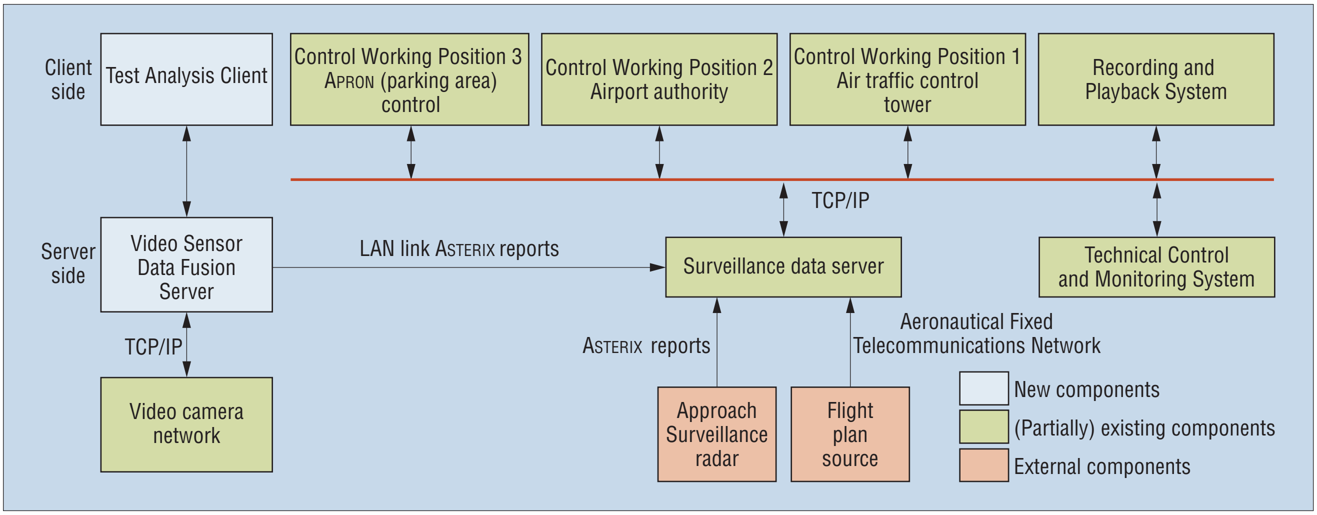


Figure 1. The Intervuse system architecture. (Asterix is a standard for exchanging radar data.)

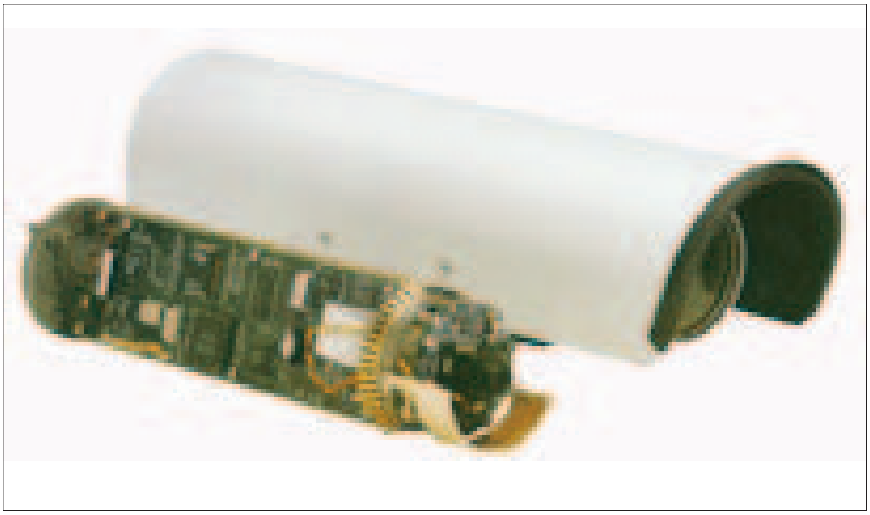


Figure 2. Autoscope Solo camera.

Figure 3. A camera's field of view and detector configuration. The aircraft indicates its presence by activating detectors, which then appear bright green on the system display (shown in light gray here).

vehicle's presence by estimating the background statistics and determining a threshold. The MVP compares the instantaneous image pixel values; if they're greater than the threshold, a vehicle is present.

The vehicle detection algorithm comprises three processing levels. In the first level, it obtains an estimate of the background detector signature from a Finite Impulse Response filter, where the current background estimate is subtracted from the incoming detector data. The next level uses a selected set of features obtained from the background suppression procedure to provide a corresponding set of instantaneous logic states. These logic states constitute important conditions for a target's presence or absence. However, the final decision is made in the highest processing level, where the *spatiotemporal state tracker* coalesces the time series of logic states into a high-confidence presence signal.[4]

The cameras are linked using RS-485 communication. Each camera unit has a unique IP address and thus can communicate with the Video Sensor Data Fusion (VSDF) server. The cameras have better resolution and night visibility than black-and-white cameras, and they use enhanced contrast detection for dark objects. Over time, the inbuilt pattern recognition software learns contrast patterns, so it copes well with fog, snow, and rain, as experience with road traffic has shown.[4]

The servers

The network of MVP sensors continuously provides information from all available virtual detectors to the VSDF server using a polling procedure. VSDF creates a synthetic representation of the supervised ground space without requiring active cooperation of the detected and tracked targets. It outputs target reports in Asterix Category 010 format (a standard developed by Euro-Control for the exchange of radar data but extendable to any kind of surveillance data).

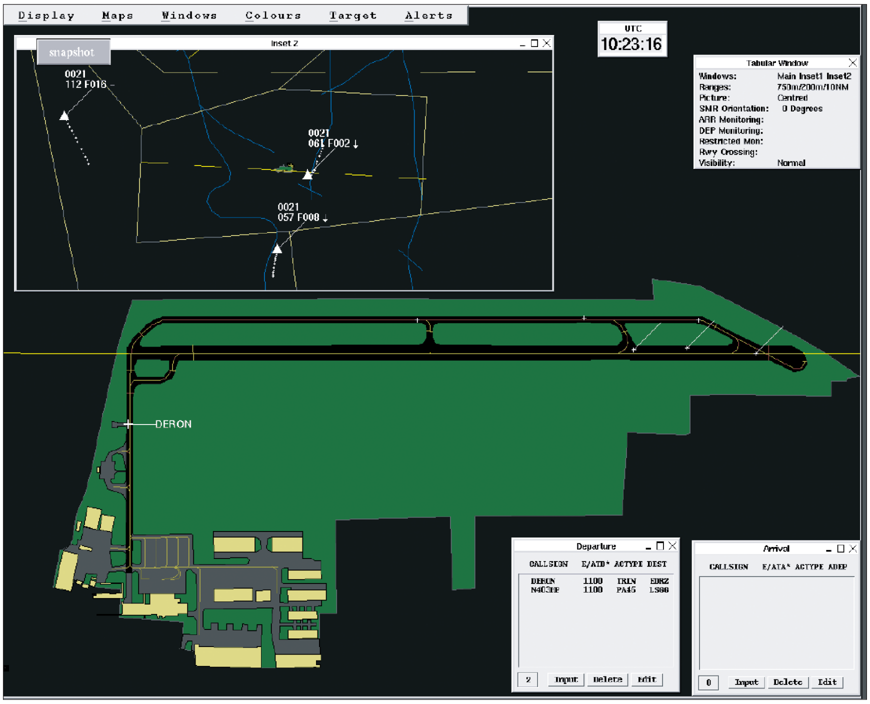
The VSDF application is a Win32 multithreaded application, which polls, processes, and transmits virtual-detector data. The VSDF server collects data about the state of detectors from all sensors and processes this data to extract observations (measurements or plots). Observations contain information about the targets' estimated position and size and the detections' date and time. The VSDF server sends these observations to the system's tracker for further processing. Specifically, processing detector data involves three stages:

1. processing layer constraints (deactivating false alarms generated at configurations containing parallel rows of detectors),
2. processing intersection constraints (deactivating detectors that have been falsely activated in case of taxiway or runway intersections), and
3. processing detector sequences in "chains" and generating observations (estimated targets).

Chains are predefined sequences of topologically consecutive detectors. In each chain, each sequence of activated consecutive detectors produces one observation. The final output is an *observation vector* containing the position (in ground coordinates) and size (in meters) of observations (targets) corresponding to the specific polling interval. A calibration procedure performed offline, once for each camera (as a preprocessing step), provides the system with ground coordinates corresponding to each detector.

The calibration procedure is based on the approached Kevin Bradshaw and his colleagues proposed,[5] which uses a homography (an eight-parameter transformation matrix) to transform image coordinates to ground coordinates and vice versa. We assume that the 3D structure that each camera captures can be modeled as a plane, which is approximately true for most airports (the area that each camera covers is limited, so the plane assumption is a good approximation for taxis and runways).

The Surveillance Data Server is an existing product that we adapted for Intervuse. The SDS receives and processes target reports from the Approach Surveillance



Tabular Window

Windows: Main Inset1 Inset2
Ranges: 750m/200m/10NM
Picture: Centred
SMR Orientation: 0 Degrees
ARR Monitoring:
DEP Monitoring:
Restricted Mon:
Rwy Crossing:
Visibility: Normal

Departure

CALLSIGN	E/ATD*	ACTYPE	DEST
DERON	1100	TRIN	EDRZ
N403HP	1100	PA46	LSGG

2

Arrival

CALLSIGN	E/ATA*	ACTYPE	ADEP

0

Figure 4. A traffic situation display for Germany's Mannheim Airport.

Radar (ASR), the VSDF server, and other sensors, if available. It uses time-invariant discrete Kalman filtering to create and maintain target tracks.[6] This server also interfaces with the Aeronautical Fixed Telecommunications Network (AFTN) to obtain flight plan data to assist in target identification.

The data flow from the sensor sources to the SDS is unidirectional. The SDS performs track-to-track correlation between video-based tracks from the VSDF and radar tracks from the ASR, plus correlation with flight plan data. (This includes time-based gating and matching and radar code-callsign correlation—callsign is a unique identifier for each aircraft.) The SDS merges the correlated information into an integrated air-ground traffic situation representation, which it sends to the clients. In addition, an internal database stores flight plan data from the AFTN and distributes it to specified clients in a timely manner.

On the network's client side, several *Controller Working Position* display workstations are attached to the LAN. The CWPs are existing products that have we adapted with the necessary *human-machine interface* to suit the A-SMGCS application at each of the two INTERVUSE test sites. The HMI displays the traffic situation on the ground and in the air and provides the controller with lists of aircraft due to arrive or depart (see Figure 4).

Also on the client side is the Test Analysis Client, which analyzes test results and provides a statistical analysis of detection probability. This client runs on its own workstation connected via LAN to the VSDF.

Support services

Besides the core architecture, system support services are available through the Technical Control and Monitoring System (TECAMS) and the Recording and Playback System. TECAMS is a tool for technical control and monitoring of various system components. The RPS meets the International Civil Aviation Organization recommendations[7] for recorded information to be used for accident or incident investigation.

Implementation

We tested the system at two airports—Mannheim Airport, Germany, and Thessaloniki International Airport, Greece. The two differ in infrastructure, traffic patterns, and weather conditions. The project consortium consisted of the Informatics and Telematics Institute (Greece), Park Air Systems, Data-Collect, Deutsche Flugsicherung, and Airport Mannheim.

Installation

We installed 10 cameras at Mannheim to provide full airport coverage—of the parking lot, runway, and taxiways. Nevertheless, the system's tracker experienced significant problems caused by gaps between cameras. The track should be continuous so that air traffic controllers know that an object in a certain position is the same object that appeared in a different position a few seconds ago. This is especially true when the controller can't see the aircraft because it's nighttime, because of bad weather or low visibility, or because his or her view is blocked owing to the airport layout. Unfortunately, providing enough cameras for full airport coverage without any gaps would significantly increase the system's cost. However, as a gap-filler in an A-SMGCS to cover the APRON (parking area) and sections of taxiway, the system showed great potential.

Furthermore, tests at Mannheim led to important conclusions regarding camera installation and the set up of virtual detectors. Specifically, cameras should be mounted as high as possible and close to the area to be surveyed to reduce shadowing and occlusion effects. The camera mount should be also reinforced to prevent camera movement (due to strong winds, for example), which can raise false detections to an unacceptable level. Additionally, the horizon shouldn't appear in the camera's field of view, because cameras are sensitive to sudden changes in light conditions.

We also learned that each virtual detector's sensitivity level is proportional to the number of pixels changing from scan to scan—in other words, small detectors are more sensitive. However, a compromise was necessary to reduce unwanted detections to an acceptable level. Additionally, the cameras' fields of view should partially overlap to avoid gaps between virtual detectors of different cameras and thus to avoid tracking problems.

On the basis of knowledge gained from tests at Mannheim, we installed five cameras to cover only a portion (800 meters) of the main taxiway at Thessaloniki. We avoided gaps between cameras and installed them as high as possible for better detection. Furthermore, tests at Thessaloniki airport showed that it's better to use small rather than large detectors to detect vehicles such as follow-me cars or ambulances.

However, many small detectors are likely to be activated by different features of the same aircraft, providing multiple targets for the system and creating serious problems for

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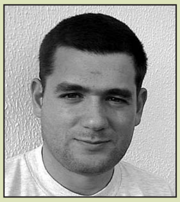

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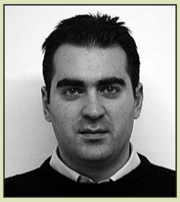

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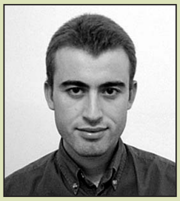

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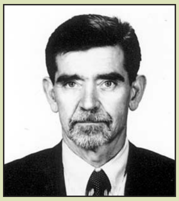

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the tracker. Replacing large detectors with many small detectors, connected with an OR gate, addresses this problem. Whenever one or more of these detectors are activated, the OR gate indicates a target's existence. The result is that the final detector covers the same area as a large detector but is sensitive enough to detect small targets.

Performance

The system's accuracy and resolution depend on the virtual detectors' length and the cameras' calibration. A good compromise for the length of virtual detectors is 15 m, which lets the system discriminate between targets separated by 15 m or more and provides a theoretical obtainable accuracy of 7.5 m (the center is considered the target's position). This compares favorably to the performance of surface movement radars.

We conducted numerous tests with both aircraft and vehicles to evaluate system performance. These tests fell into three categories:

1. *Static tests* checked critical positions such as stop lines or parking positions. These tests also examined they system's ability to recognize targets that remained stationary for a long time.
2. *Dynamic surveillance tests* dealt with moving targets, which move with constant velocity from a known point A to a known point B.
3. *Tests using the Test Analysis Client*, a tool developed during the project to evaluate system performance, required the simultaneous record of system logs and video from the camera tested.

Tests showed that the recommended target velocity is between 0 and 100 kmh. Also, some problems were observed when a target remained stationary for a long time, because it was assimilated by the background. Tests at Thessaloniki also produced a false-detection error of approximately 1.5 percent, and the missed detection error was approximately 4 percent (these figures are based on results from the Test Analysis Client).

We held the final review 32 months after the project began, on 19 February 2004 at the Thessaloniki airport. We demonstrated the system to a European Commission review team, who considered the effort a success and concluded that the system shows great potential as a gap filler for A-SMGCS systems.

Tests proved that the Intervuse technology can achieve, and in some respects exceed, most of the performance requirements of a surface movement radar.[7–9] A video detection system's strengths are no radiation, lower cost, provision of video, and a higher update rate. Weaknesses are limited coverage, poor detection in heavy fog, and false detections due to occlusions or sudden changes in light conditions.

In the future, the VSDF server could be redeveloped for Unix, although a prerequisite would be to port the Autoscope Software Development Kit (currently only available for Windows) to Unix. Furthermore, modifying the Autoscope detection system's algorithm for airport ground traffic—rather than road traffic—could significantly improve system performance (the software is proprietary, and the company allowed neither knowledge nor control of the image-processing algorithm).

Our next step is to install the proposed system at a Prague airport within the framework of the EMMA (European airport Movement Management by A-SMGCS) FP6 IP project. We expect the tests will unveil further information about the system's potential.

References

1. *Proc. Int'l Symp. Advanced Surface Movement Guidance and Control System* (A-SMGCS), German Inst. Navigation, 1999.
2. N. Pavlidou et al., "First INTERVUSE Project: Integrated Radar, Flight Plan And Digital Video Data Fusion For A-SMGCS," *4th European Congress and Exhibition on ITS (Intelligent Transportation System and Services)*, 2004; www.iti.gr/files/its_europe2004.pdf.
3. D.P. Panda and P.G. Michalopoulos, "Deployment of the Next Generation Machine Vision Technology and Integration with SCOOT in the City of Minneapolis," *Proc. 5th ITS (Intelligent Transportation System and Services) World Congress*, Springer-Verlag, 1998.
4. P.G. Michalopoulos, "Vehicle Detection Video through Image Processing: The Autoscope System," *IEEE Trans. Vehicular Technology*, vol. 40, no. 1, 1991, pp. 21–29.
5. K.J. Bradshaw, I.D. Reid, and D.W. Murray, "The Active Recovery of 3D Motion Trajectories and Their Use in Prediction," *IEEE Trans. Pattern Analysis and Machine Intelligence*, vol. 19, no. 3, 1997, pp. 219–233.
6. R.G. Brown and P.Y.C. Hwang, *Introduction to Random Signals and Applied Kalman Filtering*, John Wiley & Sons, 1992.
7. *Manual of Surface Movement, Guidance, and Control Systems*, ICAO document 9476-AN/927, Int'l Civil Aviation Org., 1986.
8. *Manual of A-SMGCS*, ICAO document 9830, Int'l Civil Aviation Org., 2004.
9. J.-C. Vallée, *Advanced-Surface Movement Guidance and Control Systems*, STNA Technical Rev., no. 61, 2001; www.stna.aviation-civile.gouv.fr/gb/actualites_gb/revuesgb/revue61gb/61pgarticle2gb/fr61art2gb.html.