Development of an Augmented Vision Video Panorama Human-Machine Interface for Remote Airport Tower Operation

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Abstract. In this paper the development of a 180° high resolution video panorama system and results of initial field test at Braunschweig research airport are described. The system serves as main HMI for remote surface movement management of small airports or of movement areas not directly visible for the controller. It provides the framework for video-see-through augmented vision by integration of traffic and weather data and it allows for panorama replay. Preliminary evaluation of initial field tests quantify the visual resolution as compared to the real far view.

Keywords: Airport tower, traffic control, remote operation, video panorama, augmented vision, work analysis, cognitive modelling, field tests.

1 Introduction

Remote Tower Operation (RTO) describes the goal of surface movement management of small airports from a remotely located control center without direct far view to the airport surface. It is the first step on the way to the Tower Operations Center (TOC) for multiple airports and the Virtual Tower (ViTo) for large airports as long term goal [1]. Because small airfields often lack any advanced electronic surveillance system a high resolution augmented vision video panorama as a potential low cost system is proposed to replace the direct far view out of the tower windows as main component of the Human Machine Interface (HMI) [2].

A number of tower work analyses performed during the recent years found visual surveillance to be the most important activity of tower and apron controllers for creating their situational awareness, despite the availability of electronic surveillance [3][4]. In the tower environment of large airports the permanent refocusing between far view and displays contribute to the workload and increases head-down time which may both be reduced by a high resolution panorama display with distance to the operator comparable to radar and flight data displays. Consequently it is assumed that under the guideline of human centered automation, the reconstruction of the direct far view for small airports with a control tower, however without electronic surveillance,

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will improve the transition process to a towerless work environment and make it acceptable to the remotely located RTO controller. The detailed design of the RTO-HMI is supported by a structured tower work analysis [5][6]. The corresponding database is used as input into the simulation of different aspects of the tower controllers decision processes using cognitive and traffic process models realized with colored Petri nets [7]. The simulations in turn support the extraction of detailed expert knowledge during interviews with the controllers and they provide input for the human interface design.

Within the DLR project RapTOr (Remote Airport Tower Operation Research) an RTO experimental system is realized at the Braunschweig research airport [2] with an augmented vision video panorama as core of the RTO controller HMI. Information from real time image processing and electronic surveillance sensors like multilateration or GPS will be integrated into the digital videopanorama for realizing video see-through augmented tower vision (ATV). ATV has been proposed by several authors before, however aiming at augmenting the real far view by means of optical see through head mounted displays, e.g.[8]. Recently initial ATV demonstrations with superimposed information in the real tower environment have been performed by using a head-up holographic backprojection display [2].

In section 2 the tower work analysis and development of model based simulation are outlined which support the RTO HMI design. Section 3 describes the augmented vision video panorama system as basis of the experimental RTO HMI. The concept for video panorama validation experiments and initial results of field trials are described in section 4. Section 5 provides a conclusion and outlook.

2 Work Analysis and Model Supported RTO Workplace Design

The design and development of the experimental RTO HMI and the new Remote Controller working environment is supported by a formal cognitive work and task analysis (CWA) [5] by means of structured interviews of domain experts (controllers) from medium sized and small airports [2][6]. The formalised results serve as input data of a Formal Airport Control Model (FAirControl) for the simulation of the controller decision making processes at the tower work positions. In [9] it is shown how the results of a CWA on a medium size airport are transferred into an executable human machine model, based on Colored Petri Nets (CPN) for simulating the controllers work processes in relation to the airport processes. The executable model supports the identification of controllers' strategies in task organization and pursuance of goals. The formal model serves for evaluation of different variants of work organization, supports the design of a new working environment, and monitoring of psychological parameters, e.g. uncovering of reduced situational awareness.

Following Cacciabue [10] the human machine model is separated into submodels for the (1) human (controller), (2) interaction, and (3) machine (process) (Fig. 1). The interaction model defines the controller-process interactions and includes sub networks for description of information resources, such as radio communication and visual perception of the traffic situation. Consequently the human model(s) and machine model(s) can work independently from each other for certain time periods. The state of the airport process model determines the type and content of visual and electronic surface traffic information (e.g. usage of taxiways, landing clearance) which can be acquired and communicated by the controller. The controller model (human model) is implemented as a Formal Cognitive Resource (FCR) Model [11] and serves for the description of controller behaviour in the tower work environment. As most important feature this model considers the motivated character of human work as related to the limitations of cognitive resources [12]. The graphically represented formal work process model as depicted in Fig. 1 provides a valuable support for the communication between domain experts and system developers.

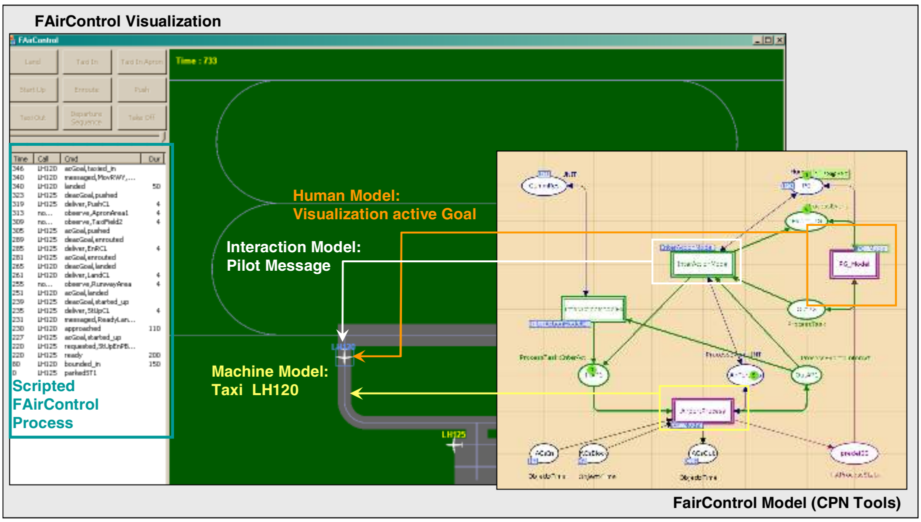

Fig. 1. FAirControl Visualization: CPN Model for simulation of interaction between the three model types (human, interaction, process; right side) and graphical visualization of the controlled work process on a simplified airport microworld. Currently pursued goal of the human model highlighted by a blue frame (orange arrow). By changing the colour of the call sign (here: LH120) the communication with the pilot is illustrated (white arrow).

3 Experimental RTO System

Motivated by the above mentioned relevance of visual information for tower work processes, a high resolution video panorama system has been set up at Brauschweig research airport as experimental environment for investigation of different aspects of the RTO HMI and development of a demonstrator [2]. A block diagram of the augmented vision video panorama system is depicted in Figure 2. The sensor component consists of four high resolution (1600 x 1200 pixels) high dynamic range (14 bit/pixel) CCD cameras ($P_{1, 2, 3, 4}$) covering the Braunschweig airport within 180° and a remotely controlled pan-tilt zoom camera (P_5: PTZ), 400 m south of the runway which extends in E-W direction.

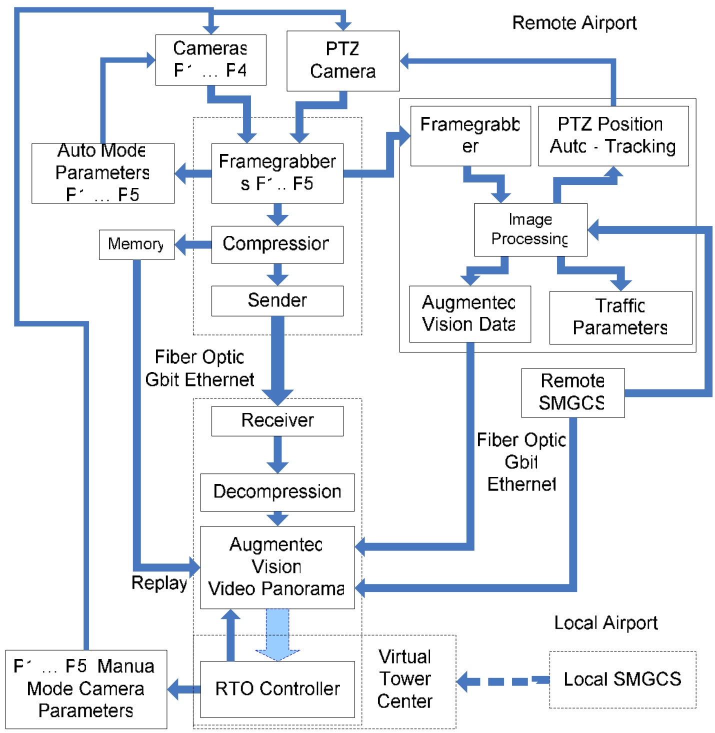

Fig. 2. Schematic block diagram of augmented vision video panorama system. Light blue: visual input.

Figure 3 gives an overview of the Braunschweig research airport with fiber-optic datalink connecting multilateration sensor containers with the main control center, and indicating camera position and viewing sectors. The cameras are positioned ca. 20 m above the airport surface, horizontally aligned on top of a building at the southern boundary of the airport with 100 m distance to Braunschweig tower, with horizontal alignment. The vertical aperture angle of about 20° (half angle with respect to the horizontal line of sight) allows for a closest surveillance distance of about 60 m. An optimistic estimate of the theoretically expected object resolution may be obtained by elementary optics and the given data of the electrooptical camera parameters using $G / B = (g/f - 1) \approx g / f$, with f = focal length = 12.5 mm, g = object distance, G = object size, B = image size. With a CCD pixel size of 7.5 μm (+ 0.5 μm gap) the vertical object size at g = 1 km distance corresponding to 1 Pixel is G / B = 0.6 m / 1 Pixel vertical, or ca. 2 arcmin angular resolution, and 1 m / 1 Pixel along the line of sight.

The observable resolution at the HMI, i.e. wide angle rear projection or monitor system, is reduced due to imperfect optics of the camera, the dynamic (illumination dependent) image compression, and resolution of the display system. The optimistic resolution value of about 2" (two times the value of the human eye) may be approached with decreasing camera aperture, which is of course possible only under good light conditions. This prediction is tested with known static objects on the airfield (see section 4). For realization of the panorama only 1424x1066 Pixels of each camera (50° viewing angle) are actually used in order to match the 180° panorama angle. For each camera the signals with 25 frames/s are split into two outputs. One feeds the data compression for transmission to the remote RTO HMI, while the other drives the simultaneous real time image processing running on a parallel workstation.

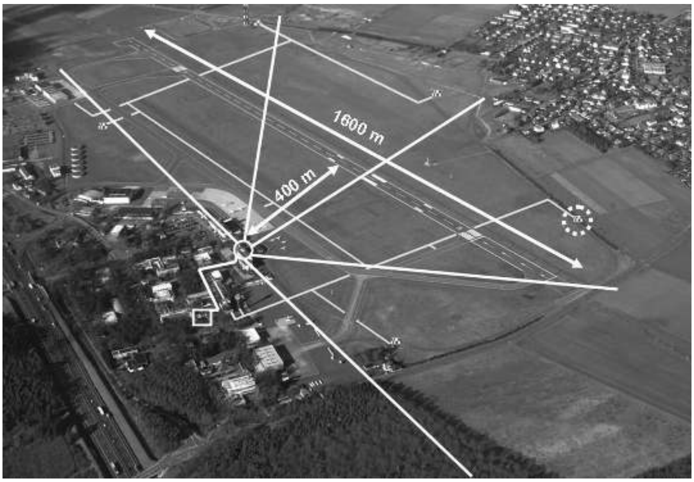

Fig. 3. Braunschweig research airport with with 1.6 km runway extending E-W, fiber optic data link (thin lines) connecting sensor containers. Circle with radiating lines indicate camera position and sectors respectively, viewing north (Photo: DLR).

A GBit ethernet switch feeds the images from the five sensors into a single mode fiber optic data link which transfers the typically 100 MBit/s data of the panorama system and PTZ over a distance of 450 m to the Advanced Control Center Simulator (ACCES). A second GBit ethernet switch splits the incoming data into five output channels for decompression with one PC per camera. Each camera is remotely controlled with respect to aperture and γ correction. The PTZ camera is controlled with respect to azimuth, vertical angle and zoom (23-fold, focal width 3.6 mm – 82.8 mm, corresponding to 54° - 2.5° visual angle).

The panorama visualization is realized in two different versions: a tiled wide angle backprojection system with one row of a high resolution SXGA projectors (1280 x 1024 Pixels) [2] and a display based system with four high resolution LCD-monitors (UXGA, 1600x1200 Pixels). Both options are realized with a PC cluster and a central workstation for display control and interaction. Figure 4 depicts the live video panorama of the monitor system, with the remotely controlled PTZ-camera displayed on a separate monitor. Interaction of the operator with the panorama system (cameras, weather station, microphone) is performed via pen touch-input display for modifying lens aperture, exposure time, γ correction of cameras and PTZ control.

For PTZ positioning the target can be defined manually or by automatic movement detection. A rectangular contour is positioned at any location of the panorama, defining the target area to be enlarged. With the tracking mode turned on the square moves coherently with the corresponding object. An algorithm for real time movement detection is running on a separate parallel processor of the image compression PC of each camera. An overall latency time between image acquisition and panorama visualization of 230 ms – 270 ms was measured by means of a special shuttered laser arrangement.

Fig. 4. Video panorama display system with additional PTZ display above (Photo:DLR)

The five recording PC's with the compression software at the camera position allow for storing panorama and zoom data (roughly 40 GByte of data per hour) and provide the possibility of complete panorama replay. Presently this feature is used for the augmented vision HMI development and validation experiments (see section 4).

Within the video panorama real-time aircraft position information is integrated as obtained from the multilateration system at the (local) Braunschweig airport via the aircraft (a/c) transponder (see Figure 4). Under reduced visibility this Augmented Tower Vision (ATV) feature allows for localizing the a/c near the correct position because the transponder code, a/c label and numerical information are integrated near the nominal a/c image location in real time. Contours of the movement areas are superimposed on the reconstructed panorama for guiding the operators attention during darkness or bad weather conditions to those areas where moving vehicles are expected.

One important advantage of the so called video see-through augmented vision technique using the digital video panorama is the easy integration of augmented vision features. This characteristic avoids the problem of (computational) delay between real scene and augmented information of the optical see-through technology as realized with the head–up and head mounted techniques (e.g. [8]). Initial laboratory experiments and theoretical investigations with superimposed information on the far view addressed the human performance such as response time and head down time reduction by using transparent displays for reducing the number of monitors [13][14], and the problem of spontaneous cognitive switching due to ambiguous stimuli [15].

4 Initial Field Trials

The main question to be answered refers to the comparability of the video panorama with the real view out of the tower windows. With the known size and distances of static objects on the airfield it is possible to evaluate the practically achieved video panorama resolution as compared to the optimistic estimate of 0.6 m / Pixel at 1 km given in section 3. We may take the red-white multilateration sensor-containers as reference objects (see Fig.3, height and width G = 2 m). The nearest containers as captured by the NE and E-looking camera $P_{3,4}$ are located at distances g_E = 400.8 m and g_{NE} = 588 m (dotted circle) respectively. With the lens equation of section 3 we obtain 7.8 and 5.3 pixels of the camera chip covered by the container image in the vertical direction. Evaluation of single video camera frames (cameras P3, P4) reveals 8-9 and 5-6 pixels, depending on the selected intensity threshold. The corresponding vertical display image size is 2.4 mm (ca. 9 Pixels) and 1.6 mm (6 Pixels) respectively. The size measured on the displays is 3 mm and 2.5 mm respectively. The red-white container coloring is resolved in both cases, however, as expected, significantly reduced as compared to the real view.

For initial steps towards validation of the system a flight-test plan was set up for experts and non-experts to evaluate identical scenarios under real view and video panorama conditions. Flight tests of two hour duration each, with the DLR DO-228 (D-CODE) test aircraft were designed with successions of approach, touch-and-go (or low approach) and takeoff. On December 13 2006 the first out of four planned 2-hour trials were performed. Five subjects (2 controllers of the Braunschweig Tower (S_1,S_2), and 3 non-experts (S_3, S_4, S_5, members of the human factors department)) observed the flyby from a position near the panorama camera system and monitored times of 11 characteristic events e_1 – e_{11}: a/c out of sight, low / steep dept. angle, take-off, touchdown, approach main / grass runway, landing gear down / up, steep approach, first sighting. The measurements were performed with time synchronized camera and notebook computers using a specially designed data input software. Significant time drifts of the individual notebooks were corrected for by comparing with the P_1-camera time as reference before and after the 2-hour experiment. Pilots received the flight plan for up to 16 approaches (with 11 realized). One out of the 11 recorded GPS trajectories is shown in Fig.5. The distance between the runway and approach turning points is 4 km and 14 km respectively. Flights were performed under VFR conditions with lower cloud boundary at 600 m. Each flyby was characterized by 6 parameters, with parameter values statistically mixed: 1. approaching main (concrete) or grass runway; 2. approach angle normal or high; 3. landing gear out: early, normal, late; 4. low level crossing of airport or touch and go; 5. touch down point early or late; 6. departure angle normal, low angle, steep angle.

While pilots had a detailed plan to follow for the sequence of approaches with different parameter values, the subjects only knew about the different possibilities (e.g. approach grass or main runway) within the approaches. They had to activate the corresponding field of their input display and set a time mark via tablet PC ($S_{1,2}$)or notebook/keyboard ($S_{3,4,5}$) at the time of their observation of one out of 11 possible events (e_1 – e_{11}) during each of the D-CODE approaches / flybys (e.g. a/c visible = first sighting of aircraft, recognized by the head light in the present experiment). Also all approaches of additional a/c were monitored. Experts and non-experts were briefed separately before the first experiment, with both groups filling separate questionaires. After the first 2-hour test raw data from all subjects and for all approaches under real view conditions were collected into a single data file. Evaluation of the different approach, touch-and-go, and departure conditions (altogether 14 approaches with 11 D-CODE and 3 other aircraft) yields the inter-subject time measurement scattering with mean and standard deviation (stdev) of the sample and standard errors (sterr) of mean for the n = 5 subjects.

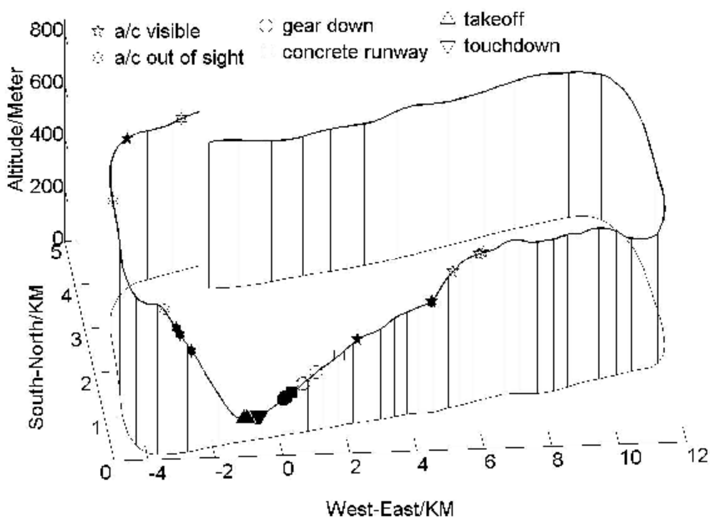

Fig. 5. GPS trajectory no. 4 out of 11 test flights of 13/12/06 (clockwise direction). Open / filled symbols represent event observation under real view / video panorama conditions.

Typical unbiased estimates of sample stdev for event e_{11} (first sighting during approach) are between 2 s and 25 s (sterr = 1 – 15 s). Comparing approach recognition time with low stdev with the GPS track yields first sighting of a/c (headlight) at distance 9 km. The minimum sterr of e.g. 1 s for e_{11} and 0.2 s for e_5 (touchdown) presumably represent the optimum observation conditions for all subjects (all n = 5 attending first sighting direction during expected apearance time).

Detailed information on the difference between real view and video panorama are obtained by repeating the experiments with the video panorama replay after a week or more in order for the subjects to no longer remember the different flight conditions. We state the hypothesis that due to lower resolution and contrast of the videopanorama (ca. 2 arc min) as compared to the real view (see section 3), distant events of approaching /departing a/c (like first / last sighting of a/c) should receive an earlier / later time mark under real view as compared to video observation. Correspondingly within-subject evaluations of the direct viewing and video panorama replay observations yields time differences t(real view, e_i) – t(video, e_i) < 0 and > 0 for approaching (app) and departing (dpt) a/c respectively. All three non-experts $S_{3,4,5}$ repeated the experiments with the videopanorama replay within 1/2007. In table 1 the results of four of the 11 possible observation types are evaluated, for the individual S_i with overall means and uncertainties. All displayed events exhibit reproducible and consistant pos.(dpt.) and neg.(app.) delays between real view and video panorama conditions. For example the significant negative delays measured as overall mean for e_8 (landing gear visible, -10 ± 2 s) and e_{11} (first sighting, -23 ± 4 s) show these events to be observable only 0.5 and 2 – 3 km respectively closer to the airport (a/c speed 100 and 200 knots respectively), as compared to the real view conditions (e.g. e_{11}(real view): a/c lights recognized at ca. 9 km).

Table 1. Time differences real view – video panorama of observation times for subjects $S_{3,4,5}$ for events e_1 (a/c out of sight), e_5 (tochdown), e_8 (landing gear visible), e_{11} (first sighting)

	t(real view) – t(video): mean(st.error of mean; st.deviation; sample size n)			
	S_3	S_4	S_5	$S_3 + S_4 + S_5$
e_1	+25(11;35;11)	+33(10;25;6)	+13(5;17;10)	+15(5;28;27)
e_5	+0.4(0.1;0.2;6)	+0.5(0.7;1.8;6)	+1.0(0.6;1.4;6)	+0.6(0.3;1.3;18)
e_8	-13(3;6;4)	-9(2;6;9)	-10(5;7;2)	-10(2;6;15)
e_{11}	-29(8;29;13)	-13(5;19;14)	-28(7;24;13)	-23(4;25;40)

5 Conclusion

Basic elements of DLR's experimental Remote Tower Operation (RTO) system at the Braunschweig Research Airport are described and initial field test results reported. The motivation for design of a high resolution augmented vision video panorama as basic RTO HMI is highlighted, based on work and task analyses. Important advantages as compared to the current work situation, such as zoom with tracking function, video-see-through augmented tower vision (ATV) for improving low visibility conditions, reduced head-down time, and panorama replay are presented. Preliminary quantitative evaluation of initial field tests for comparing real view and video panorama observation quantifies the expected reduced video resolution as compared to the real view condition, which however, may be compensated by the mentioned advantages. A RTO HMI demonstrator is presently under construction which will be integrated into the DLR tower simulator environment, allowing for shadow mode operation as well as simulation of different work scenarios, e.g. simultaneous control of two airports. Detailed evaluation of simulator and work model based RTO simulations and additional field tests will provide design guidelines for the prototype development.

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