Remote Airport Tower Operation with Augmented Vision Video Panorama HMI

M. Schmidt, M. Rudolph, B. Werther, N. Fürstenau

Abstract— **In this paper the initial results of the DLR project Remote Airport Tower Operation Research (RapTOr) are described. Within this project an augmented vision video panorama system and a corresponding HMI is developed for remote surface movement management of small airports or of movement areas not directly visible for the controller. Ground traffic management is performed from a remotely located control center, e.g. a tower at a different airport. The setup and functions of the high resolution video panorama system with integrated pan-tilt zoom camera (PTZ) at Braunschweig research airport is described. It provides the framework for integrating SMGCS traffic data, real time image processing and replay possibility of the complete 180° - panorama. Furthermore we describe how the results of a formal tower work analysis are transferred into a cognitive operator model for simulating the RTO controller work processes to be integrated into the conventional tower work environment.**

Index Terms—**Airport tower, remote operation, video panorama, augmented vision, work analysis, cognitive modelling**

I. Introduction

Remote Tower Operation (RTO) describes the goal of remote control of small airports and of movement areas of large airports which are not directly visible from the tower, by means of an augmented vision video panorama that replaces the direct far view out of the tower windows. In 2005 the DLR project RapTOr was started in order to realize an RTO experimental system as extension of the Advanced Surface Movement Guidance and Control System (A-SMGCS) at the Braunschweig research airport. Analysis and simulation of the tower work procedures support the design and development of the demonstrator. RTO is the first step on the way to the Virtual Tower (ViTo) as long term goal [1][2][3].

The direct view out of the tower windows is of central importance for surface traffic control under the present day working conditions of tower and apron controllers. That is why each attempt of surface movement management without direct view out of tower windows represents a revolution for tower controller working conditions. Consequently it is assumed that under the guideline of human centered automation, the reconstruction of the direct far view in future A-SMGCS, in addition to the abstract (birds view) ground movement situation display showing the vehicle positions, will greatly improve the transition process to the new work environment and make it acceptable to the user. The design process for a RTO (and future ViTo) work environment relies on support from domain experts (controllers) of the German Air Traffic Control Organisation (DFS), in particular with respect to the work analysis [8]. Initial design goal is the integration of the RTO workplace into an existing tower work environment of a medium size airport in order to simultaneously control one or more neighbouring small airports.

The project encompasses two major research and development goals: 1. Simulation of operator decision making within the RTO augmented video panorama workplace environment in order to support the development process and the investigation of design alternatives, without the necessity of actually realizing each of the alternative solutions; 2. realization of an RTO – experimental environment and a demonstrator for augmented video panorama based remote airport control, including tests and concept validation with professional tower- / apron controllers. The following section 2 describes initial results of a tower work and task analysis following a systematic procedure developed by K. Vicente [4] and the development of a formal colored Petri net model, realized with CPN-Tools [5]. The model serves for simulating the operator's decision making processes with the work analysis data as input. In section 3 the panoramic far view reconstruction as visual basis of the RTO experimental environment at Braunschweig research airport and its basic functions are described. In section 4 we review initial experiments on augmented tower vision (ATV) to be integrated into the video panorama. Section 5 provides a conclusion and outlook with regard to the final demonstrator and the Virtual Tower as long term goal.

II. Cognitive Work Analysis and Simulations Using Colored Petri Nets

The design and development of the experimental RTO HMI

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is supported by a cognitive work and task analysis (CWA) of the presently existing work environment and decision processes. The formalized results serve as input data for a computer simulation of controller decision making in a tower workplace design which is modified by an additional RTO HMI for controlling one or more remote small airports or movement areas. The CWA is based on a formal procedure suggested by Vicente [4], separating the analysis into five areas: work domain analysis, control task analysis, strategy analysis, analysis of social organisation and cooperation, and operator competency analysis, the latter however not being considered in this phase. A CWA at Leipzig airport with potential small airports Altenburg and Erfurt for remote control is performed with support of the German air traffic control organization (DFS). The formal mathematical background of the simulation is a colored Petri net model of the work processes. Details of the CWA as well as the cognitive modelling and simulation using colored Petri nets are described in [6], [7] and [8]. In what follows only a brief review will be presented. Fig. 1 provides a block diagram of the CWA with special focus on the analysis of Tower Leipzig processes [8].

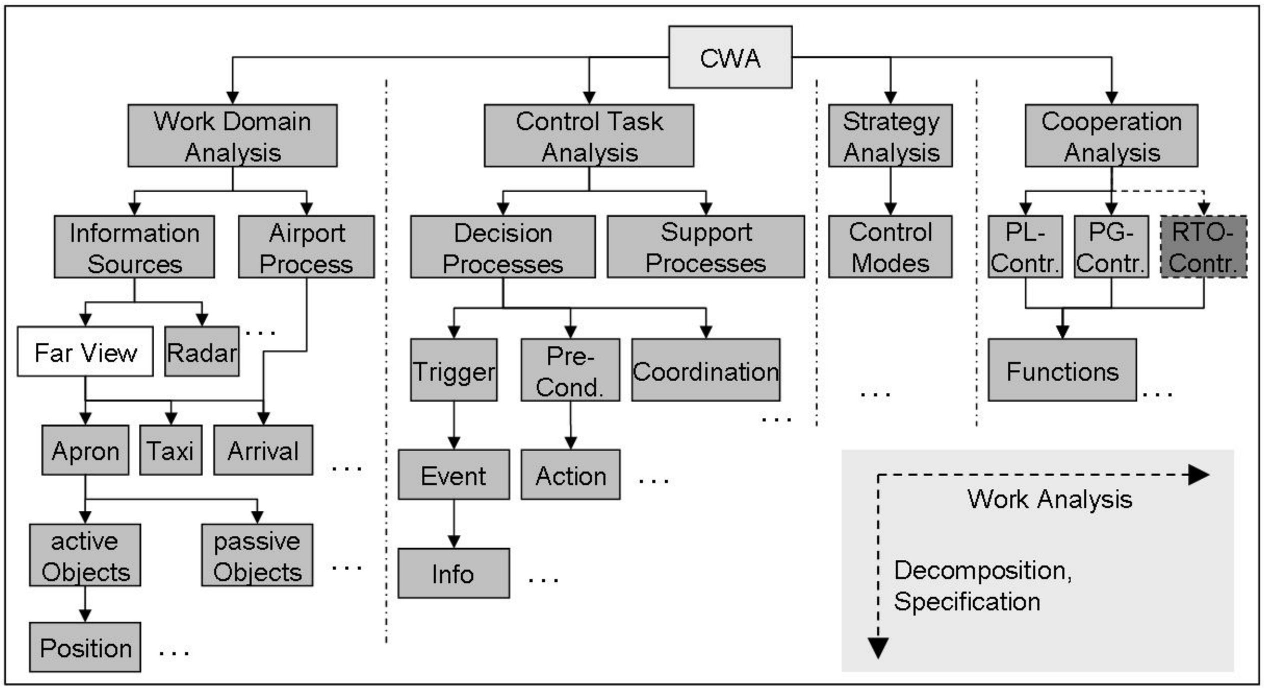

Fig. 1: Decomposition and specification of the CWA areas for a two – controller (PL, PG) tower with additional RTO workplace.

The work domain analysis aims at analysing the aircraft movements. For this purpose the air-to-air process which describes the complete movements from arrival to departure is treated separately for the different control areas (e.g. approach, runway, taxi, apron). Acquired information and possible actions are attributed to corresponding control areas. The analysis of accessible information from the different sources (e.g. far view from the tower windows, approach and ground radar) and possible actions via the corresponding interaction devices (e.g. radio, telephone) at this step is performed without considering the controllers tasks.

In the control task analysis as second step the tasks are identified which have to be completed. Here decision and support processes are treated separately. The task description follows a well defined structure which covers the triggering event, the preconditions, the task containing coordination, and the post-condition.

The strategy analysis is the most laborious step. This is because controllers to a large extent use implicit knowledge which is hard to extract. In empirical studies (e.g. [9]) strategy differences, e.g. dependent on work load were detected. The development of strategies to a large extent depends on the handling of goals under restricted cognitive resources [10]. This is one important motivation for the use of the resource based Petri net modelling technique. An important aspect of multiple task situations as typical for controllers is the relative weighting of different simultaneous goals with respect to each other. Action strategies evolve due to limited human processing capacity.

The analysis of cooperation and social organisation yields a clear tasks and functions distribution between the two controllers (ground controller (PG), runway controller (PL)) in the Leipzig tower example. The future RTO workplace, however, represents a significant change of this situation. On the one hand the augmented vision video panorama offers revolutionary new possibilities for the support of air traffic controllers. On the other hand the integration of remotely located control areas within the present day tower environment represents a completely new work condition.

Colored Petri nets (CPN) represent a compact and transparent method for modelling in discrete time intervals the evolution of complex dynamical systems with limited resources. Based on graph theory and linear algebra Petri nets provide an inherent formal method for analysing the reachability of system states. Within the present context the hierarchical structuring potential of colored Petri nets is fully utilized. The results of the single steps of the CWA are fed separately into respective levels of the hierarchy structure as indicated in Fig. 2.

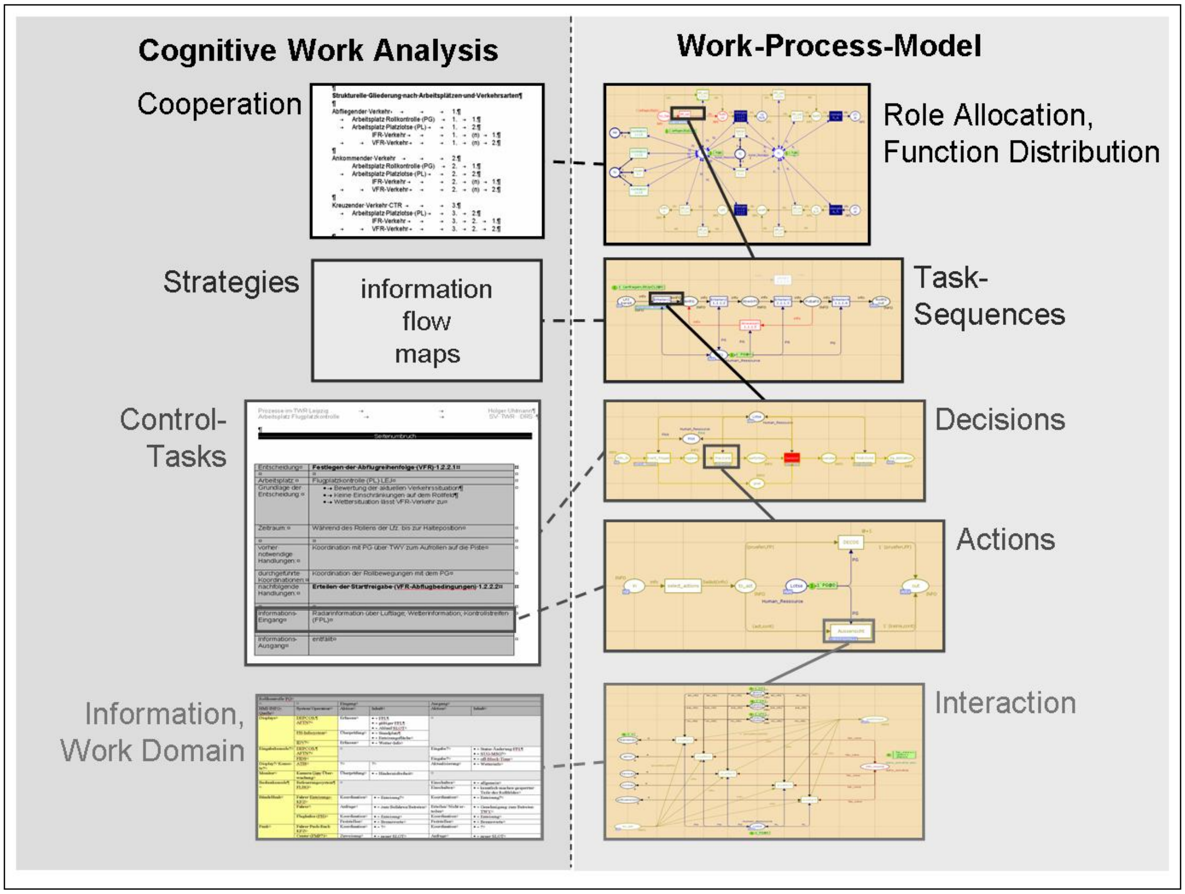

Fig. 2: Transfer of CWA results into the formal mathematical structure of Colored Petri Nets.

The results of the fourth CWA step (cooperation) are fed into the highest hierarchy level of the CPN structure. Here the distribution of roles and functions among the different human operators and their technical support systems is performed. On this level the work process is described in a holistic manner whereas on the lower levels focus is put on the single work positions.

In the next lower level of the Petri net architecture (task sequences) the goal driven actions for fulfilling the respective tasks of each operator are implemented. The results of the strategy analysis (CWA step 3) are fed into this level.

The identified control tasks in CWA step two are modelled with regard to the actions to be performed and the required and created informations. Actions are combined to decision and support processes respectively. Actions are separated into those representing preconditions and others which coordinate the task (decision process, support processes) and those actions which complete the task as post condition. The Petri net realizes this description by means of two net levels (decisions, actions).

The lowest level of the Petri net hierarchy models the results of the work domain analysis (1st step of the CWA). Here the interface is realized between the operators and the traffic processes to be controlled. The analysis of the information sources and interaction systems as basis of the work processes provides the data for the corresponding Petri net model of the HMI. Of primary interest for RTO is the far view out of the tower windows as basic information source which will be replaced by the augmented video panorama. Augmented tower vision (ATV), i.e. the superposition of additional information on the far view like weather data and aircraft labels with object tracking rises questions adressing controllers attention and perception processes. Problems like attentional tunneling and involuntary switching of perception may require separate modelling approaches [13][14][15].

With the homogeneous description of the human machine system based on colored Petri nets it is possible to investigate the consistency of the human and the process model based on formal analysis as suggested by Degani & Heyman [11]. Critical work situations can be detected and analyzed in an early phase of the system design and alternative solutions can be investigated by means of model based simulations. The transfer of the CWA results into the formal operator model allows for monitoring psychological parameters of the operators (e.g. work load), for deriving the operator requirements and for uncovering missing situational awareness by means of simulations and reachability analysis [12]. Furthermore the graphically represented formal work process model provides a valuable support for the communication between domain experts and system developers.

III. Augmented Vision Video Panorama Experimental Environment

A high resolution video panorama system is presently being set up at Brauschweig research airport as experimental environment for investigation of different aspects of the video based RTO – HMI and development of a demonstrator. A schematic showing the main concept and the integration into the local A-SMGCS is depicted in Figure 3.

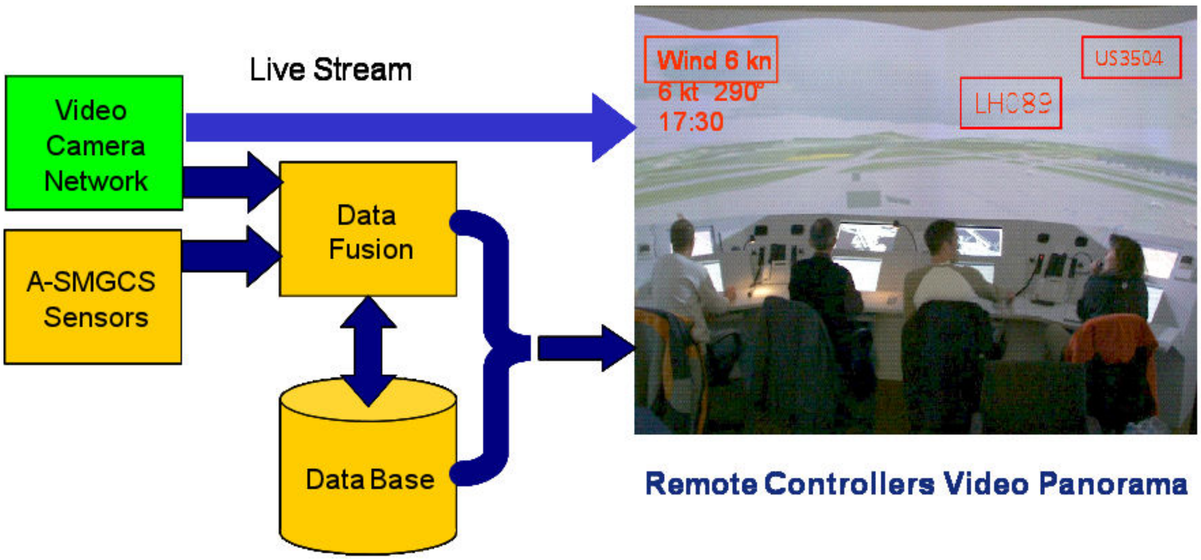

Fig. 3: Conceptual Sketch of RTO – Experimental System at Braunschweig Research Airport.

A more detailed block diagram of the RTO system with augmented vision video panorama is depicted in Figure 4.

The panorama camera system represents an additional sensor system of the local experimental A-SMGCS including a multilateration system and D-GPS. The reconstructed far view within the video panorama will be augmented by means of traffic and environmental data. While traffic data like aircraft labels move coherently with the corresponding objects other information like weather data is statically integrated into the reconstructed far view.

The present sensor system consists of four high resolution (1600 x 1200) high dynamic range (14 bit/pixel) CCD cameras (P_1 ... P_4) covering the Braunschweig airport (runway length 1.6 km, extending in E – W direction, 400 m distance from viewing position) within 180° and a remotely controlled pan-tilt – zoom camera (PTZ). The system is positioned ca. 20 m above the airport surface on top of a building at the southern boundary of the airport with 100 m distance to Braunschweig tower and central view looking north with horizontal alignment. Figure 5 shows a photo of the system.

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. The object resolution per pixel in 500 m distance is about 0.25 m vertical and 1 m along the line of sight. Camera signals with 25 frames/s are split into two outputs for real time image processing and simultaneous data compression for transmission to the remote RTO – HMI. 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 (depending on degree of compression, brightness and image content) of the panorama system and PTZ over a distance of 450 m to the DLR 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 and vertical angle as well as zoom (23-fold, focal width 3.6 mm – 82.8 mm, corresponding to 54° - 2.5° visual angle).

In addition to the visual information digitized acoustic signals of a microphone and weather data (temperature, wind speed, static pressure) from a weather station at the camera position are transmitted to the control room via the same fiber optic link.

The panorama visualization in the present state of development (Fig. 6) is realized with one row of a high resolution tiled wide angle backprojection system (WAP, 4 x 2 single 1280 x 1024 SXGA projectors) and in parallel via four conventional SXGA monitors arranged as a cylinder section for reproducing the azimuth angles of the cameras. Both options are realized within ACCES, based on a PC cluster with central workstation for controlling the tiled projection wall and interaction. Figure 6 depicts the live video panorama in the top row, with the zoomed apron area below and a birds view of Braunschweig airport with camera sectors indicated in the two lower right projection tiles. The monitor based live panorama with separate PTZ monitor can be seen below the projection wall.

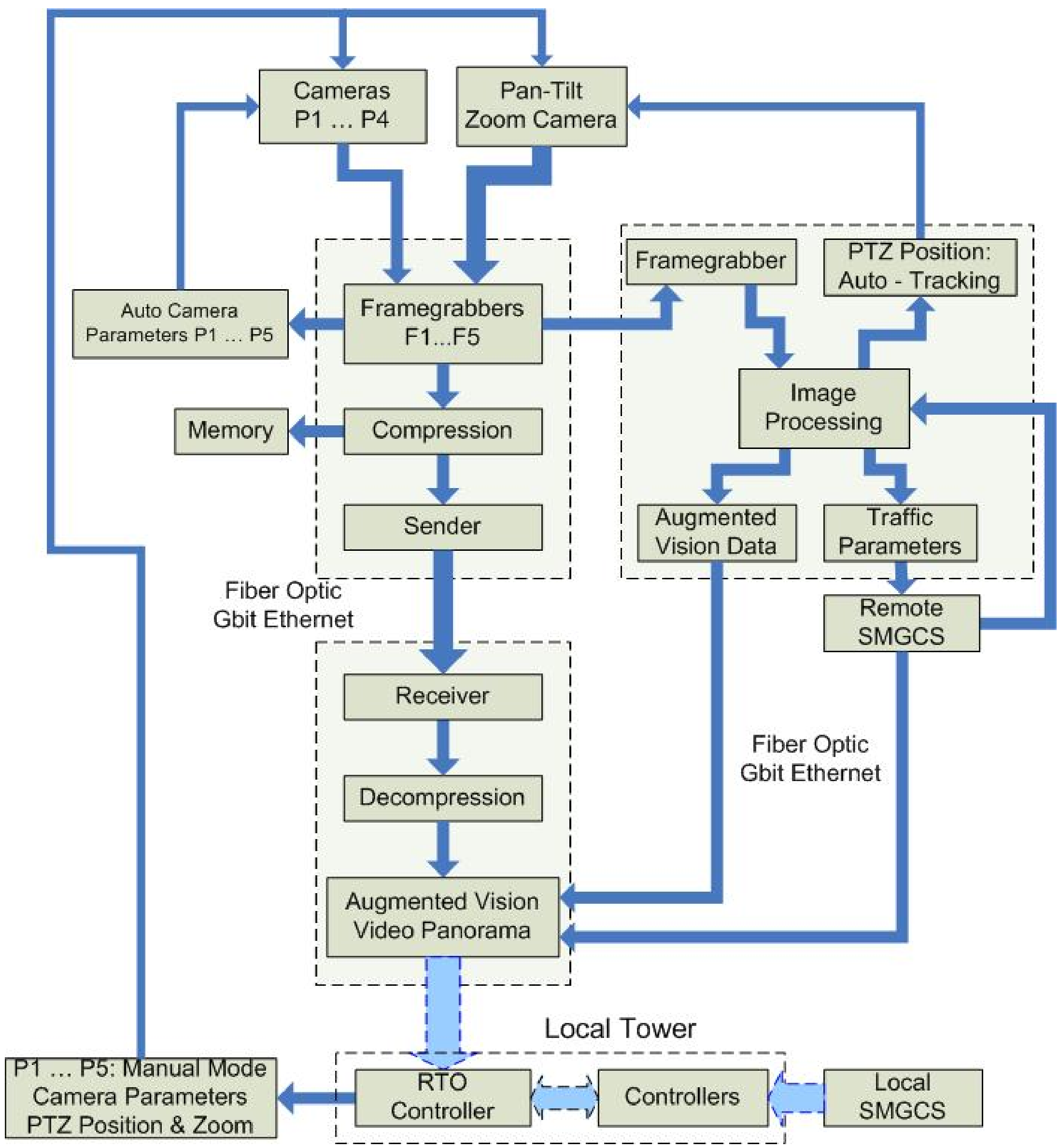

Fig. 4: Schematic block diagram of augmented vision video panorama system.

Interaction of the operator with the panoramic system (cameras P1 ... P4, PTZ, weather station, microphone) in the present development stage is performed via keybord and mouse for modifying contrast, brightness and gamma correction of cameras. Contours of the movement areas filled with transparent coloring can be superimposed on the reconstructed panorama. The latter kind of image augmentation is particularly helpful for guiding the operators attention during darkness or bad weather conditions to those areas where moving vehicles are expected.

For positioning the PTZ camera the target can be defined manually or by automatic movement detection. In the manual mode a rectangular contour is positioned at the required point of the panorama, defining the area to be enlarged. The center of this area defines the new line of sight of the zoom camera as position command value. With the tracking mode turned on

Fig. 5: High resolution panorama camera setup and pan-tilt zoom camera of the video panorama system. Braunschweig tower in the background (Photo DLR).

Fig. 6: High resolution wide angle projection with Braunschweig airport video panorama in the Advanced Control Center Simulator (ACCES) of the DLR Inst. for Flight Guidance (Photo DLR)

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.

The five recording PC's with the compression software at the camera position allow for storing panorama and zoom data which amounts to typically 140 MByte / min / camera (i.e.

roughly 40 GByte of data per hour). This feature provides the possibility of complete panorama replay. Besides future operational applications it is of great value for the augmented vision HMI development and validation because, e.g. real traffic scenarios can be repeatedly presented to operators with modified augmented vision content.

IV. AUGMENTED TOWER VISION: INITIAL EXPERIMENTS

One important advantage of the digital video panorama is the easy integration of augmented vision features which was proposed also for enhancing the real view [19]. Initial field trials as well as laboratory experiments with superimposed information on the far view have been performed in order to address the question of acceptance of augmented vision systems by controllers and the aspect of head down time reduction by using transparent displays for reducing the number of monitors.

A field trial was performed at the (old) tower of Dresden airport with a transparent holographic back projection display (HOPS). The photo in Fig. 7 shows the HOPS between the controllers workplace and the tower window. With respect to the see – through characteristics the HOPS function is similar to the head – up display (HUD) frequently used in military aircraft. In contrast to HUD's however, the (relatively cheap) HOPS system provides no collimated view, i. e. instead of a virtual image in the far distance a real image is created on the pane. The goal of the system is to provide a very bright image, which is of use under daylight conditions. Technically a holographic foil between two glass panes collimates the light from the projector (beamer) positioned on the ceiling or floor behind the screen under an angle of 36° with respect to the normal of the projection plane. Typical resolution is 100 lines/mm; visibility ranges are ±10° vertical and ±30° horizontal. The main effect is the concentration of the light from the beamer to a limited range on the opposite (operator’s) side of the screen and the suppression of ambient light which does not originate from the projector. As can be seen in Fig.7, the brightness of the white symbols as obtained with a 4100 lm – DLP projector (XGA resolution) is sufficient for recognition of the text. It is evident that colors have to be chosen according to the see through condition and are different as compared to the standard monitor situation: the background has to be black (no color); good results concerning readability of the symbols are obtained with white, yellow or bright red.

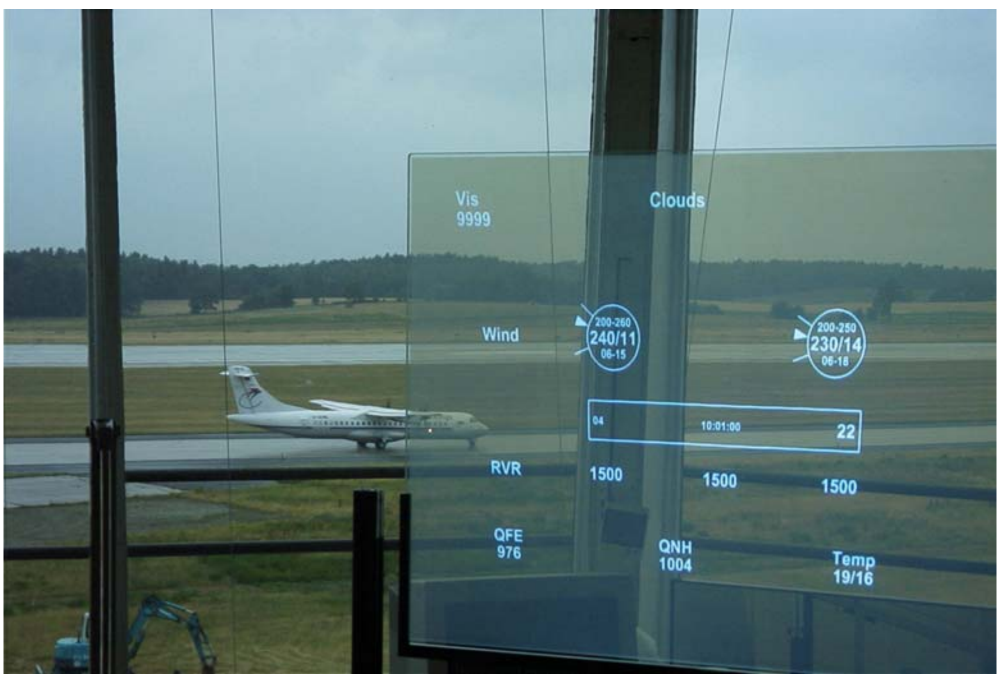

Fig. 7: Field Trials withTransparent Holographic Backprojection Display at Dresden Tower Showing Real Time Weather Data (Photo DLR).

Augmented vision systems are expected to reduce head–down times of controllers, i.e. time intervals needed to read data from displays instead of controlling traffic by means of the far view out of the windows. As a rule of thumb the head – down time should not significantly exceed more than 30 % of the working time.

A large number of experimental results have been obtained in recent years concerning attention and perception effects with augmented vision using head – mounted (HMD) and head-up displays (HUD) which are used in cockpits of military aircraft and helicopters (e.g. [13][16] [17] [18]). It was found that the expected advantage of reduced visual scanning between the head-down instruments and the far domain is not stable under all circumstances and may be counteracted by effects such as cognitive tunneling and visual interference.

In order to obtain initial quantitative data on the expected head-down time reduction by means of augmented vision systems we performed a schematic laboratory experiment with the HOPS system of Fig. 7 [19]. The setup consisted of a wide angle background projection with the transparent HOPS projection screen in the foreground. The latter one superimposed a list with numerical information on the background scene. Subjects (18 participants) had to perform a visual search task and response times (RT) were measured. Sets of abstract objects (geometric shapes: circle, square, triangle) had to be scanned in the background in order to decide if a specified one was within the set. The alphanumeric foreground information consisted of a list potential target objects together with individual codes. The specific code for the target object to be searched in the background was shown in the background together with the set of objects. The subject's search task consisted of three steps: find the code between the background objects, associate code and target object on the superimposed numerical list, decide if the target is present within the set of background objects. The same visual search task was repeated with four different modes of presenting the foreground information: 1. conventional display positioned below the line of sight to the background (requiring no head movement), and 2. 45° to the side of the line of sight, 3. HOPS display superimposing information, and 4. alphanumeric list integrated into the background (corresponding to the case of augmented vision information integrated into the panorama of Fig. 6). In these initial experiments addressing attention and perception aspects of augmented tower vision only condition 2 showed significantly longer RT (ca. 400 ms) as compared to all other conditions with similar RT's.

V. Conclusion and Outlook

The formal cognitive modelling and simulation of work processes based on a detailed work analysis in combination with the technical development of a revolutionary new work environment appears to be a promising approach for introducing new concepts into the conservative and safety critical ATM field. For remote control of small airports and movement areas from a local tower at a larger airport the present work conditions have to be modified in order to integrate the RTO controllers workplace in the tower environment. One important question to be investigated by simulating the work processes refers to the number of operators: can the additional control of the remote airport be performed by the existing controller team or is an additional RTO controller required? This question of course is closely related to the design of the new RTO workplace and the integration into the existing tower environment as well as work organisation and training procedures. It is expected that the utilization of advanced augmented vision and virtual reality technologies may help improving the integration of functions and collaboration of operators. The stability of work processes under all conditions has to be proven by realistic simulations based on the formal work process model. Problems associated with augmented tower vision systems may require additional experimental and modelling approaches as indicated in section 4.

Compared to the human factors related questions of the RTO work environment the technical problems appear to be a minor problem. Nevertheless the usage of most advanced high resolution and high dynamic range cameras in combination with automatic zoom and tracking functions and the augmented vision wide-angle video panorama projection represents also a new challenge within the ATM technology field which has to be validated within the RTO experimental environment. Systematic tests in the (tower) simulator environment with active controllers are planned for the final project phase, by utilizing the panorama replay function.

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Michael Rudolph was educated as Mathematical Assistant at Airbus Industries in Bremen and studied Informatics at the Technical University of Braunschweig, After receiving the Diplom Informatiker degree in 2002, he joined the Human Factors Department of the Inst. for Flight Guidance in the same year. Presently he is responsible for the realization of the video panorama and augmented vision software of the RTO experimental system.

Bernd Werther studied electrical engineering at the Technical University of Braunschweig and received the Diplom Ingenieur degree in 1999 with a thesis on fiber optic sensor technology, performed at the German Aerospace Center (DLR). In the same year he joined the sensor technology group of the DLR Inst. for Flight Guidance. He joined the Human Factors department in 2000 and in 2001 started PhD research in the field of cognitive modelling. He finished his dissertation in 2005 with a work on cognitive modeling of human decision making using colored Petri nets. Within the RapTOr project he is presently responsible for the work analysis, modelling and simulation of tower work processes for RTO - HMI design.

Norbert Fürstenau studied physics at the universities of Braunschweig, Darmstadt and Frankfurt. He received the Diplom Physiker degree from the Inst. of Nuclear Physics of Techn. Univ. of Darmstadt in 1977 and Dr. phil.-nat. degree from Frankfurt University in 1981 with a work in applied Laser physics and physical chemistry of molecular clusters. He joined the DLR Inst. for Flight Guidance in 1981 and was leader of the Fiber Optic Sensors group until 2000, when he joined the Human Factors Department together with two of his co-authors. He initialized the Virtual Tower (ViTo) concept study (2002 – 2004) and is presently project leader of the Remote Tower Operations (RapTOr) project. His present research interest is in cognitive modelling of visual perception and attention using nonlinear dynamical systems theory.