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Norbert Fürstenau *Editor*

Virtual and Remote Control Tower

Research, Design, Development and Validation

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Foreword: On the Origins of the Virtual Tower

It's a pleasure to write a personal account regarding the origins of the virtual air traffic control tower as reflected in our work at the NASA Ames Research Center. This type of air traffic display is now sometimes called the remote tower, but I think there is a significant difference between the two. The virtual tower is actually a much more radical proposal and is only in the last few years becoming clearly possible at a reasonable cost. But, as I discuss later, whether it provides any additional benefit beyond the remote tower depends strongly on the specific content and application.

The Ames work on the virtual tower can be traced to a meeting I had with my boss, Tom Wempe, to whom I first reported in the late 1970s. I was a National Research Council (NRC) postdoc working for him studying pilot's eye movements looking at a newly proposed Cockpit Display of Traffic Information. This display was an electronic moving map that was intended for use in commercial aircraft cockpits to aid air traffic avoidance and to help pilots accept automatic avoidance commands. When Tom not so subtly hinted that "It would be good for me to known around here as a displays person rather than an eye movement person," I got the point. This was the first time I had ever been explicitly directed to work on something specific. Even in grad school at McGill University, I never got specific direction. Part of the education there was to be able to figure out for yourself what was important to work on.

So when Tom got even more specific and pointed out that "We were having trouble coming up with a good way to depict vertical separation on the 2D plan-view map" and that he would like me to work on this problem, I really began to worry. I didn't want to work on a display! So in some desperation I suggested, "Well, why don't we make it look like a view out the window?" At the time I drew on his blackboard a sketch of what a pilot might see out the forward window. And Tom said, "OK, why don't you work on that." But I had absolutely no idea what I would do or how I would do it.

I proposed that I should try to find some interested colleagues for this project in Professor Larry Stark's lab at Berkeley and the next week at his lab meeting suggested we find a student to work on the project. He had a new student named Michael McGreevy who was interested in the Bioelectronics Option for a graduate engineering program. He turned out to be perfect. He was an engineer with a background in art who was also interested in computer graphics, which he was then studying in a class by Brian Barsky. We began a multiyear collaboration in which we worked on the design, implementation, and testing of a perspective format for a Cockpit Display of Traffic Information (CDTI). What interested me particularly were the perceptual phenomena associated with interpreting an accurate geometric projection of the relative position and direction of targets that might be presented on a pilot's display of surrounding aircraft. Mike was beginning to program the Evans and Sutherland Picture System 2 and we initiated a design collaboration to investigate the geometric and symbolic elements that would be needed to make a perspective CDTI suitable for a cockpit. The goal was to make a traffic display useable at a glance. Before our project all CDTIs were plan-view. The perspective CDTI was eventually called VERT. It ultimately was evaluated with respect to a conventional plan-view CDTI called INTRUD (Ellis et al. 1987).

From the design and testing of prototypes, we learned many things. For example, a "God's-eye" view from behind and slightly offset was better than a forward, egocentric view as if directly out the cockpit. But most interestingly was that we found from systematic testing of pilot's direction judgments an apparent perceptual distortion we called the "telephoto" bias. It was as if when spatially interpreting the display, the users were seeing through a telephoto lens and that their visual attention would therefore not be correctly directed out the window for visual contact with traffic. It turned out that theoretical models developed from work with Mike (McGreevy and Ellis 1986), and later Arthur Grunwald (Grunwald et al. 1988), and still later Gregory Tharp (Tharp and Ellis 1990), provided several alternative but related techniques we could use to distort the display for better spatial interpretability.

It should be noted that considerable effort went into the initial design of the three-dimensional symbolic content of the perspective CDTI. In this design process, we learned that many of the difficulties of spatially interpreting perspective displays can be removed by appropriate design of its geometry and symbology. Consequently, it became apparent that simple performance comparisons of perspective versus plan-view formats could be misleading. Symbology can be introduced to remove interpretive difficulties with the perspective format. For example, segmented vertical reference lines can remove spatial ambiguities due to the geometric projection.

Later in the early 1980s after being hired as a Civil Servant at Ames, Mike McGreevy became interested in jumping into the data space of the maneuvering aircraft as seen on at CDTI, as if it were a virtual environment. He began a series of projects to develop a head-mounted display for visualization of a variety of data spaces and environments. This was the birth of "VR" at NASA in 1985. The very first real-world digital content viewed in this was a complex pattern of interacting air traffic called the "Atlanta Incident." It was a series of worrisome close encounters of aircraft generally within the Atlanta TRACON. Despite the very poor visual and dynamic quality of the early NASA HMDs, which was not reflected in the contemporary accounts of the work in the press, the reincarnation of Ivan Sutherland's "Ultimate Display" was clearly demonstrated with these air traffic data.

I was generally not directly involved with development of the virtual environment displays at Ames until the early 1990s when I began to work on the relationship of objective measures of system performance to virtual environment system usability. We studied, for example, full system latency and countermeasures for it such as predictive filtering. My principal collaborator for this work was Bernard "Dov" Adelstein. The visual environments we studied at the time for our scientifically motivated design work were generally not particularly visually interesting, so it became strategically and programmatically important to show realistic possible uses of the display format for applications that would interest NASA.

Since we were receiving support from both space and aeronautics programs at Headquarters, I felt we needed two separate demonstration environments. The "space" one was a fly-around of the Shuttle Orbiter with the task of identifying damaged tiles. The "aeronautics" one was a visualization of simulated aircraft landing at SFO. Initially, we used synthesized trajectories but later replaced them with recordings of live approach and landing data from DFW which was provided by Ronald Reisman. I called our display a virtual tower in that the head-mounted display user would appear to be immersed in the traffic pattern. I was surprised how much attention this second demo attracted. One possible reason was the high visual and very high dynamic fidelity we achieved for the 1990s, attracting attention outside our agency. This time, however, the popular representations of our system's performance were more accurate.

However, I ultimately became concerned that advocacy for a virtual tower would involve way too much technological push, so rather than pursuing a line of system development, I sought to back up and investigate the visual aspects of tower operation. I wanted to better understand the visual requirements for tower operations beyond the visual detection, recognition, and identification functions that seemed to circumscribe the visual concerns of the FAA when it came to visual tower operation. Better understanding of the visual features used by Tower controllers would help establish performance requirements for either virtual or remote towers. Two of our papers as well as six chapters in this volume ("Visual Features Used by Airport Tower Controllers: Some Implications for the Design of Remote or Virtual Towers," "Detection and Recognition for Remote Tower Operations," "Videopanorama Frame Rate Requirements Derived from Visual Discrimination of Deceleration during Simulated Aircraft Landing," "Which Metrics Provide the Insight Needed? A Selection of Remote Tower Evaluation Metrics to Support a Remote Tower Operation Concept Validation," "Model-Based Analysis of Two-Alternative Decision Errors in a Videopanorama-Based Remote Tower Work Position," and "The Advanced Remote Tower System and Its Validation," including the quasi-operational shadow mode validation) address this concern.

The virtual tower history sketched above describes work leading to a virtual tower that could be essentially worn on a controller's head as a totally immersing virtual environment. Such a format isolates its users from their immediate physical environment and probably only makes operational sense when compactness, low power consumption, and portability are important. In fact, this head-worn display format might be appropriate for use by Forward Air Controllers on a battlefield. These soldiers have a job somewhat similar to an air traffic controller, though their goal may be different. In fact, a version of such an application called the Forward Air Controller Training Simulator (FACSIM) was developed at TNO, the Hague.

But now, as can be seen in the following volume, the time for a virtual, or more properly labeled, remote tower has come. The sensors, communications links, rendering software, and aircraft electronics needed for implementation of a practical system all seem to be in place. As will be evident from the following chapters, much of the system integration work needed to complete such systems is afoot.

Moffett Field, CA Stephen R. Ellis

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Preface

The paradigmatic symbol in air traffic control (ATC), essentially unchanged since the beginning of commercial air traffic early last century, is the characteristic control tower with its large tilted windows, situated at an exposed location, and rising high above the airport. Besides the impressive 360° panoramic far view out of windows, it provides the tower controller an aura of competence and power. It actually hides the fact that tower controllers as employees of the air navigation service provider (ANSP) are members of a larger team of collaborating colleagues at different locations, including the apron, approach, and sector controllers, not all of them enjoying the exciting view out of the tower windows (for more details, see Sect. 1 in chapter "Introduction and Overview"). Only the apron controllers supervising the traffic on the movement area in front of the gates, mostly as employees of the airport operator, enjoy a similar panorama, although usually from a lower tower. The topic of this book, Virtual and Remote Control Tower, questions the necessity of the established direct out-of-windows view for aerodrome traffic control. It describes research toward an alternative work environment for tower and apron controllers, the Virtual Control Tower. It is probably no exaggeration to assert that this book is about a paradigm change in air traffic control, where paradigm in this context means a generally accepted way of thinking and acting in an established field of technology.

As explained already by Steve Ellis in the Foreword to this volume, Virtual and Remote Tower refers to the idea of replacing the traditional aerodrome traffic control tower by a sensor-based control center which eliminates the need for a physical tower building. For small low-traffic airports, the main topic of this book, the out-of-windows view will be reconstructed by a high-resolution videopanorama which may be located anywhere on the airport or even hundreds of kilometers away at a different location. This concept quite naturally leads to a new type of aerodrome control center which allows for remote control of several airports from a single distant location. It is understandable that many tower controllers are not really happy with this revolutionary idea, viewing videos instead of enjoying the reality behind the windows. The detailed research toward the Virtual Tower presented in the following chapters will show that their skepticism is partly justified, and it is the responsibility of us researchers to take their critique serious and understand their requirements in order to maintain and exceed the safety and performance level with the new system which the traditional one has achieved within nearly a hundred years of technical evolution.

After surfacing of the Virtual Tower idea, several requirements for "Future ATM Concepts for the Provision of Aerodrome Control Service" were formulated by the International Federation of Air Traffic Controllers Associations (IFATCA), such as:

The controller shall be provided with at least the same level of surveillance as currently provided by visual observation

Controllers shall be involved in the development of aerodrome control service concepts

While the first condition relates to official regulations of International Civil Aviation Organization (ICAO) concerning visual traffic surveillance on aerodromes, the second one addresses the methods for design, research and development, validation, and implementation of the proposed new human–machine systems for aerodrome traffic controllers. It appears self-evident that the introduction of a revolutionary new work environment in the safety-critical field of aeronautics which attempts to replace an established operationally optimized and validated existing one requires intensive cooperation between developers and domain experts. In Germany, most of them are employees of the Air Navigation Service Provider DFS (Deutsche Flugsicherung), cooperation partner in the recent Remote Tower projects.

While the development of any new human–machine system by definition is an interdisciplinary undertaking, nowadays involving at least experts from engineering, computer science/informatics, and engineering psychology/cognitive engineering, this book is about an especially challenging case. On the one hand, a revolutionary concept based on latest technologies is suggested which promises a significant increase of efficiency and decrease of cost. On the other hand, it attempts to replace a well-established system with a hundred years of operational experience which has to satisfy two often competing goals: safety and efficiency.

One of the problems with this kind of interdisciplinary research and development is that the field of engineering psychology and cognitive ergonomics addressing the human operator side of the system has a much weaker scientific foundation concerning established and usable formal theories as compared to the technical-engineering side. The engineers and scientists on the technical side can usually rely on a well-accepted and established basis of theoretical, mathematically founded knowledge (e.g., applied optics for the realization of a high-resolution videopanorama) and powerful software tools for simulating engineering problems and prediction of the technical system performance. The human factors experts/psychologists on the other side usually have to work with data derived from a huge amount of statistically quantified experimental results, backed up by only a relatively small number of generally accepted formal theories of human perception and behavior (e.g., Weber-Fechner Law/Steven's Function and the Signal Detection Theory; see Appendices A and B). Moreover, there are only very few if any usable quantitative approaches and simulation tools for addressing concepts like operators "mental model," "situational awareness," or "human performance" and decision-making in a way which would allow for the numerical prediction of, e.g., decision errors. System performance under operationally relevant conditions is typically derived from human-in-the-loop simulations, with participant's responses derived from subjective questionnaires (for cost reasons often only students instead of well-trained domain experts and not seldom with questionable statistical relevance). This situation makes it difficult to obtain reliable quantitative statements about the operators' performance in the new environment. For specific questions regarding requirements and performance, experiments under more laboratory kind of conditions at the cost of reduced operational relevance can be designed which have a better chance to be comparable with theoretical predictions. Within the framework of the Remote Tower work system research, this truly interdisciplinary book contains chapters addressing, on different levels, both the technical system engineering, the human operator and (cognitive) ergonomics, and the human–system interface aspects.

At this point, we would like to acknowledge several contributions and preconditions without which much of the research work described in the following chapters probably would not have been possible, probably it would not have started at all. Starting point within DLR was the first visionary projects competition launched in 2001 by the DLR board of directors under Walter Kröll. In this novel approach to generate and support innovative ideas, the "Virtual Tower" proposal, submitted by the editor together with Markus Schmidt (one of the coauthors) and Bernd Werther (now with VW-Research), won a first prize. Well equipped with the prize money, the core team was able to start the initial 2-years concept study and engage a software engineer (Michael Rudolph, coauthor of chapter "Remote Tower Prototype System and Automation Perspectives") as fourth team member. In the years to come, he designed and wrote all of DLR's Remote Tower related software code.

We acknowledge the contributions of the growing Remote Tower staff during the following two RTO projects (RApTOR: 2004–2007; RAiCE: 2008–2012): Maik Friedrich, Monika Mittendorf, Christoph Möhlenbrink, Anne Papenfuß, and Tristan Schindler, some of them co- and chapter authors of this book. They increasingly took over workshares of the RTO research, in particular addressing simulation trials and validation. The RTO team furthermore was supported by colleagues from the DLR Institute of Optical Sensor Systems (Winfried Halle, Emanuel Schlüßler, Ines Ernst), who contributed to the image processing, movement, and object detection (see chapters "Remote Tower Experimental System with Augmented Vision Videopanorama," "Remote Tower Prototype System and Automation Perspectives"). RTO validation gained additional momentum with the start of an EC-funded validation project together with DFS within the SESAR ATM research joint undertaking, after finishing the RAiCe shadow-mode validation experiments.

The editor of this volume is particularly indebted to Steve Ellis (NASA-Ames/Moffett Field), author of the Foreword, of Chapter "Visual Features Used by

Airport Tower Controllers: Some Implications for the Design of Remote or Virtual Towers" and coauthor of chapter "Videopanorama Frame Rate Requirements Derived from Visual Discrimination of Deceleration During Simulated Aircraft Landing." As a kind of spiritus rector of the Virtual Tower idea, he demonstrated in his Advanced Displays Lab. the initial concrete realization, based on stereoscopic head-mounted displays, which inspired us for submitting our initial proposal in 2001. Nearly 10 years later, in 2010 he again advanced our research as host for the editor, spending a research semester as a guest scientist in his lab. In turn, during this period also Steve worked for two weeks as a guest researcher in the DLR Remote Tower Simulator where he introduced his profound psychophysics expertise into the methodology repertoire of the RTO research, supervising, performing, and analyzing the video frame-rate experiments described in Chapter "Videopanorama Frame Rate Requirements Derived from Visual Discrimination of Deceleration During Simulated Aircraft Landing."

At the occasion of several international Remote Tower workshops and mutual visits and meetings at DLR's Braunschweig research facilities, with the Swedish air navigation service provider LFV in Malmö, with FAA/Washington, and with companies Searidge/Ottawa and Frequentis/Vienna, we exchanged ideas and discussed problems and perspectives. I am very happy that besides Steve Ellis also several of the other colleagues and experts from external institutions and companies involved in the RTO research and development were able to contribute chapters to this book. Specifically I would like to express my sincere thanks to the following colleagues who invested a considerable amount of work and time to help this book to provide the first overview on the worldwide endeavor toward the Virtual Control Tower: Rodney Leitner and Astrid Oehme from Human Factors Consult/Berlin for Chapter "Planning Remote Multi-Airport Control–Design and Evaluation of a Controller-Friendly Assistance System" on Multiple Airport Control, Dorion Liston from San José State University and NASA-Ames as coauthor to Chapter "Visual Features Used by Airport Tower Controllers: Some Implications for the Design of Remote or Virtual Towers" on the basics of visual cues used by controllers, Jan Joris Roessingh and Frans van Schaik from NLR/Netherlands who together with colleagues from LFV and Saab/Sweden contributed chapters "Detection and Recognition for Remote Tower Operations" and "The Advanced Remote Tower System and Its Validation" on the basics of detection and recognition and on the Swedish RTO system, and Vilas Nene from MITRE/United States who provided an extensive overview on the US activities.

At this point one remark should be included concerning possible missing information and errors which may have been overlooked during the iteration of the manuscript to its final state. Most chapters are extended versions derived from previous publications, e.g., in conference proceedings volumes that underwent a selection process, usually including modest reviews, which typically, however, are less strict than journal contributions. All chapters were reviewed by the editor and all of them underwent at least one revision, some of them more. Nevertheless, we cannot exclude that the critical reader and in particular the domain experts may detect unclear, maybe even false statements or missing information. Of course, the editor and all Chapter authors will be happy about any feedback concerning errors and suggestions for improvements that may be included in a follow-up edition of this volume.

Mentioning the domain experts we certainly have to express our greatest appreciation for long years of support and cooperation by active controllers and expert managers from Deutsche Flugsicherung (DFS), the German Air Navigation Service Provider. In particular in the early phase basic domain knowledge was provided during numerous discussions and meetings with Detlef Schulz-Rückert, Holger Uhlmann, Dieter Bensch, and others which was used for a systematic work and task analysis. Later on, a formal Remote Airport Cooperation (RAiCon) was started and many more experts and managers (we would like to mention Thorsten Heeb and Nina Becker) helped in defining requirements and setting up the experimental system at Erfurt airport for performing the initial validation experiment under quasi-operational conditions.

Special thanks are due to Dirk Kügler, director of the DLR Institute of Flight Guidance since 2008. One of his first tasks was a signature under the just finished RAiCe project plan. Since that time he showed continuous interest in the RTO activities and supported the project by intensifying the cooperation with DFS, resulting in the formal RAiCon cooperation. Due to his engagement, the Virtual Tower patent was successfully licensed to company Frequentis/Austria and a cooperation agreement signed in 5/2015. A month later Frequentis won the DFS contract for realizing the first commercial RTO system in Germany to be installed and validated on the airport of Saarbrücken. After successful validation, DFS plans to set up two more RTO systems at airports Erfurt (location of the DLR-DFS validation trials of 2012; see chapters “Remote Tower Prototype System and Automation Perspectives,” “Which Metrics Provide the Insight Needed? A Selection of Remote Tower Evaluation Metrics to Support a Remote Tower Operation Concept Validation,” “Model-Based Analysis of Two-Alternative Decision Errors in a Videopanorama-Based Remote Tower Work Position”) and Dresden (location of DLR’s initial live Augmented Vision test; see Chapter “Introduction and Overview”) and start with a first Remote Tower Center operation from airport Halle/Leipzig for the three remote airports.

Last but not least, we would like to express our thanks to Dr. Brigitte Brunner as the responsible science officer of the DLR program directorate. In an always supportive way, she accompanied both DLR Remote Tower projects from the beginning. She provided extra resources when there was urgent need, e.g., when the necessity of tower controller recruitment for human-in-the-loop simulations surfaced and it turned out that we had been kind of naïve with regard to the cost involved. She was tolerant and supportive also when things did not run as planned (as every active scientist and engineer knows, this is of course characteristic of any “real” research project) and when toward the planned project end it turned out that an extra half year was required for the shadow-mode trials, for initial data evaluation, and for finishing the undertaking with an international final workshop. The proceedings booklet of this event, containing the extended abstracts of the presentations, was the starting point for this book.

Finally, I would like to thank the team of Springer Publishers for their professional support, specifically Mrs. Silvia Schilgerius, Senior Editor Applied Sciences, who encouraged me to start this endeavor more than 2 years ago, Mrs. Kay Stoll, Project Coordinator, and Mrs. S. Gayathri from the technical service, who in a competent and helpful way and patiently accompanied the gradual evolution from abstract collection through repeated manuscript iterations into the present 13 chapters volume: thank you, it was fun!

Braunschweig, Germany Norbert Fürstenau
25 February 2016

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Abbrevations

2-D	Two-Dimensional
3-D	Three-Dimensional
A/C	Aircraft
ACC	Area Control Center
ADD	Aircraft-Derived Data
ADS-B	Automatic Dependent Surveillance—Broadcast
AFIS	Aerodrome Flight Information Service
AGL	Above Ground Level
AMS	Acquisition Management System
ANSP	Air Navigation Service Provider
ANT	Automated NextGen Tower
AOI	Area of Interest
APREQ	Approval Request
AR	Augmented Reality
ART	Advanced Remote Tower (EC-FP6 project)
ARTCC	Area Route Traffic Control Center
ASDE	Airport Surface Detection Equipment
A-SMGCS	Advanced Surface Movement Guidance and Control System
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATCT	Air Traffic Control Tower
ATIS	Automatic Terminal Information Service
ATM	Air Traffic Management
AV	Augmented Vision
CAMI	Civil Aerospace Medical Institute (US)
CAT	Category
CERDEC	Communications-Electronics Research, Development, and Engineering Center (US Army)
CHI	Computer Human Interface

CoDec	Compression-Decompression
CTAF	Common Traffic Advisory Frequency
CWA	Cognitive Work Analysis
CWP	Controller Working Position
D.C.	District of Columbia
DG-TREN	Directorate General for Transport and Energy
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DST	Decision Support Tool
EFS	Electronic Flight Strip
E-OCVM	European Operational Concept Validation Methodology
FAA	Federal Aviation Administration (US)
FMS	Flight Management System
FOD	Foreign Object and Debris
FOV	Field of View
FSS	Flight Service Station
GA	General Aviation
GEC	Ground Executive Controller
GMC	Ground Movement Control
GMU	George Mason University
GPS	Global Positioning System
HF	Human Factors
HITL	Human-in-the-Loop (Simulations)
HMI	Human–Machine Interface
ICAO	International Civil Aviation Organization
ID	Identification
IDVS	Information Data Handling System: System for displaying weather information
IEA	International Ergonomics Association
IFAC	International Federation of Automatic Control
IFATCA	International Federation of Air Traffic Controllers
IFIP	International Federation for Information Processing
IFORS	International Federation of Operational Research Societies
IFR	Instrument Flight Rules
IPME	Integrated Performance Modeling Environment
JND	Just Noticable Difference (Webers Law)
JPDO	Joint Planning and Development Office
KATL	Hartsfield-Jackson Atlanta International Airport
KBBG	Branson Airport
KDCA	Ronald Reagan Washington National Airport
KDFW	Dallas-Fort Worth International Airport
LFV	Luftfartsverket, Swedish Air Navigation Service Provider
MANTEA	Management of surface Traffic in European Airports (EC Project)
MIT	Massachusetts Institute of Technology

MLAT	Multilateration System
NAS	National Airspace System
NATCA	National Air Traffic Controllers Association (US)
NextGen	Next Generation Air Transportation System
NIEC	NextGen Integration and Evaluation Capability
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium
NT	NextGen Tower
NTA	Non-Towered Airport
OTW	Out-the-window
PIP	Picture-In-Picture
PTZ	Pan-tilt-zoom
RAiCe	Remote Airport traffic Center (DLR project 2008–2012)
RApTOR	Remote Airport Tower Operation Research (DLR project 2004–2007)
RNLAF	Royal Netherlands Airforce
ROT	Remotely Operated Tower
RTC	Remote Tower Center/Remote Tower Control
RTM	Remote Tower Metrics
RTO	Remote Tower Operation
RVR	Runway Visual Range
SA	Situational Awareness
SDT	Signal Detection Theory
SESAR	Single European Sky ATM Research
SFO	San Francisco Airport
SID	Standard Instrument Departures
SMR	Surface Movement Radar
SNT	Staffed NextGen Tower
STARS	Standard Terminal Arrival Routes
TAR	Terminal Approach Radar
TCAS	Traffic Alert and Collision Avoidance System
TEC	Tower Executive Controller
TFDPS	Tower Flight Data Processing System
TMC	Traffic Management Coordinator
TMI	Traffic Management Initiative
TRACON	Terminal Radar Approach Control
TS	Tower Supervisor
TWR	Tower
U.S.	United States of America
UNICOM	Universal Communications
VDOT	Virginia Department of Transportation
VET	Visibility Enhancement Technology
VFR	Visual Flight Rules
VFR	Visual Flight Rules
VHF	Very High Frequency

ViTo	Virtual Tower (DLR project 2002–2004)
VPA	Verbal Protocol Analysis
VR	Virtual Reality
VSATS	Virginia Small Aircraft Transportation System (SATS) Laboratory
WAM	Wide Area Multilateration
WdV	Wettbewerb der Visionen (DLR visionary projects competition)
WJHTC	William J. Hughes Technical Center (FAA)

Part I
Fundamentals and Preconditions

Introduction and Overview

Norbert Fürstenau

Abstract Since more than 10 years, an increasing interest is observed worldwide in remote control of low-traffic airports by means of some kind of virtual control tower. As outlined in the Foreword by Steve Ellis and in the Preface to this book, “Virtual Tower” depicts the idea of replacing the conventional control tower on airports by an advanced sensor-based control center. It eliminates the need for direct visual traffic surveillance and consequently the requirement for a costly tower building at an exposed location in visual distance from the runway. The virtual/remote tower idea is connected with a paradigm change in air transportation due to the growth of low-cost carriers and the corresponding increased usage of small airports which, nevertheless, require controlled airspace provided by air navigation service providers (ANSPs). Cost constraints require new ideas and concepts to meet these requirements, and the control of one or more small airports from a remote location without direct visual surveillance from a local tower is one of these visions.

After providing in Sect. 1 of this introduction some basics of air traffic control in the airport vicinity, I will continue in Sect. 2 with a personal account of Virtual and Remote Control Tower research from the DLR perspective, starting around 2000. In Sect. 3, I present an overview of goals, requirements, technical issues, achievements, and initial steps towards industrialization. The concluding Sect. 4 contains an overview of the 13 chapters and two technical Appendices.

Keywords Airport control tower • Control zone • ICAO • Remote tower operation • Virtual tower • RTO concept • RTO history • Video panorama • Augmented vision • Goals • Achievements

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1 Some Basics

The following brief overview refers to typical procedures of IFR (instrument flight rules) traffic. For VFR traffic (visual flight rules, a large part of the general aviation), the procedures may be somewhat different in detail. An in-depth presentaion of the diverse aspects of air traffic control is provided, e.g. in (Mensen 2003). Classically, airport traffic control is performed via cooperation between a group of controllers at different locations as outlined in the workflow schematics of Fig. 1. Controllers of the area control center (ACC, en route traffic, sector control) take over/hand over the traffic from/to the terminal or approach control (US terminology: TRACON, typically up to 30–50 nautical miles or 50–90 km from the airport). Approach control in turn hands over/takes over the traffic to/from the local or tower control for final approach or departure (airport environment, up to 5–10 nm from the airport).

The control functions relevant for the remote tower operation (RTO) work environment are the start-up, apron, ground, and tower control. During approach (upper part of Fig. 1), the flight is handed over from the area control center (ACC) to the approach controller. At a large airport or "Hub" the ACC until recently was often located also in the tower building, although not in the tower cab with out-of-windows view because ACC controllers are responsible for the traffic outside the control zone. Under good visibility the out-of-windows view from the tower cab allows for visual surveillance inside the control zone (i.e., < ca. 20 km). In Germany, nowadays ACC and approach usually are combined and colocated in the center. The work of the tower and ground controllers begins after the approach

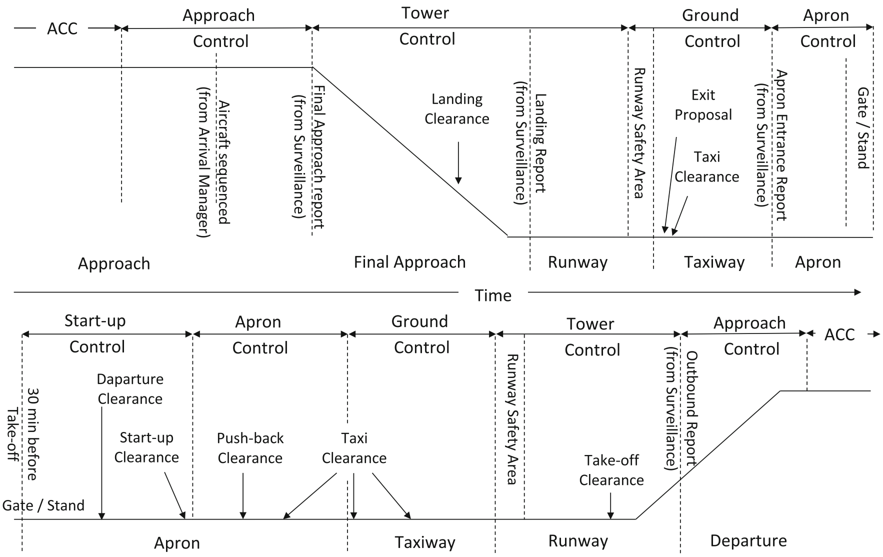

Fig. 1 Workflow schematic of the airport traffic control, separated in arrival traffic (*top*) and departure traffic (*bottom*)

controller has handed over the flight. The tower controller (tower executive, TEC) together with the ground controller (ground executive, GEC) manages the traffic on runways and taxiways. Ground executive hands over/takes over the traffic to/from APRON control (usually a separate control tower on larger airports for the traffic and activities in front of and at the gates/stands, owned by the airport operator). The tower controller is responsible for final approach and landing and hands over to the ground controller who manages the taxiing after the A/C exits the runway. The Apron controller takes over and manages the final maneuvering and docking. The mirrored procedure for departure is depicted in the lower part of Fig. 1. An additional function here is start-up control with departure clearance and start-up clearance. With small airports, the main focus of RTO, all functions within the control zone may be in the hands of only two controllers or even a single one.

In what follows, we will continue in Sect. 2 with a historic survey of the development of the Virtual and specifically the Remote Tower idea that kind of continues the personal account of Steve Ellis in the Foreword. Section 3 briefly summarizes the goals, technical issues, achievements, and industrialization aspects followed in Sect. 4 by an overview of the separate chapters of this book.

2 Background and History of the Virtual and Remote Tower Concept

This section is a personal account of the editor of the present volume from the perspective of DLR's Virtual and Remote Tower research and development. One very early proposal for a revolutionary new Virtual Control Tower work environment was put forward by Kraiss and Kuhlen (Kraiss and Kuhlen 1996) within a scientific colloquium of the DLR Institute of Flight Guidance, organized by the editor (Fürstenau 1996). In their contribution on "Virtual Reality—Technology and Applications," they proposed a VR concept for ATC, based on what they called "Virtual Holography." One proposed solution was the so-called virtual workbench, a table-like stereoscopic projection of the aerodrome traffic, allowing for viewing of 3-D trajectories with free choice of perspective for the controller. VR projection systems of this type are nowadays commercially available, but the actual research towards remote tower operation (RTO) went a more conservative way.

A couple of years after this event, the preconditions emerged for the research and development work described in the present book. The initial research environment began to take shape at the DLR Institute of Flight Guidance when the editor proposed a research topic in advanced display systems which built on 15 years of research in optical sensing technologies for aerospace applications. The idea of investigating the potential of the emerging VR technologies for aerospace applications had been presented at an internal meeting already back in 1989 after a visit of the editor at NASA Ames (Scott Fisher's VR Lab.) and at Jaron Larnier's famous VR-company VPL Research in Redwood City (Silicon Valley), where the so-called data glove had been invented as advanced interaction device for virtual environments. In 1999, the author together with coworkers of the optical sensors group (Markus Schmidt, coauthor in this volume, and Bernd Werther, now with VW-research) initiated the research on advanced VR-based human–machine interfaces and interaction systems as first step towards the Virtual Tower idea. They were motivated also by futuristic concepts and ideas which were put forward in a comprehensive study on the future of air traffic control by Wickens and others (Wickens et al. (1998)).

Two years later, it was a lucky incident which pushed the realization of Virtual and Remote Tower ideas at DLR a large step forward: the Advanced Displays team had submitted the "Virtual Tower (ViTo)" research proposal to DLR's first Visionary Projects competition in 2001 ("Wettbewerb der Visionen," WdV), initialized under the former chairperson of DLR's board of directors, Walter Kröll. Somewhat unexpected, it actually won a first prize, well endowed with 200,000 € for 2 years of initial studies and concept development. So in 2002, DLR's Virtual Tower research took off, and remembering the Kraiss and Kuhlen presentation of 1996, the team started with a basic survey on the state-of-the-art of VR technology in Europe and the USA and the shaping of an initial concept (Fürstenau 2004). The most inspiring Virtual Tower ideas, however (because based on well-founded psychophysics experiments and theories [see the Foreword to this volume and, e.g., (Ellis 1991)]), were imported in the same year after a visit of the author at Stephen R. Ellis' Advanced Displays Laboratory at NASA Ames Research Center. Steve, at that time, performed research in fundamental problems and applications of head-mounted stereoscopic displays (HMD), including virtual and augmented reality applications in aerodrome traffic control. One problem was the latency problem involved in updating high-resolution virtual environments such as an aerodrome with synthetic aircraft driven by real data in a fixed laboratory frame of reference. The operators' movements have to be tracked and time-varying HMD coordinates synchronized with the room-fixed aerodrome coordinates and aircraft positions in real-time in order to generate a 3D-VR environment, a problem that was solved with the help of predictive Kalman filtering of the movement data.

An important step towards initial experimental systems during the 2 years of the WdV study was the engagement of a software engineer (Michael Rudolph, coauthor of chapter "Remote Tower Prototype System and Automation Perspectives") who in the years to come realized all of DLR's Remote Tower software. The first realized code supported augmented vision experiments using self-made head tracking devices. Later on, the complex software environment for videopanorama reconstruction of the tower out-of-windows view, the pan tilt zoom camera control, and augmented vision functions was realized (chapters "Remote Tower Experimental System with Augmented Vision Videopanorama" and "Remote Tower Prototype System and Automation Perspectives").

This made it possible to start the initial experimental research, beginning with a focus on Augmented Vision aspects for support of tower controllers (Tavanti 2007) using wearable computing and (at that time) futuristic techniques such as the head-mounted Nomad Retinal Laser Scanning Display (HMD). One motivation for the investigation in this so-called optical see-through technology (Barfield and Caudell 2001) was the perspective to reduce head-down times in the tower so that controllers can read display information without losing visual contact to the traffic

Fig. 2 Demonstration of a laser retinal scanning display, tested by operational controllers at Frankfurt tower (2/2003). Inset: superimposed text depicts augmented vision information displayed by HMD via direct image projection onto the retina by means of a laser scanner. Wearable HMD-computing device at the back of DLR team member Markus Schmidt

situation on the movement areas (Tavanti 2006) (Pinska 2006). Figure 2 shows the first practical testing of a retinal scanning HMD at Frankfurt tower.

Another example is the transparent head-up display in the form of the holographic projection screen which was investigated by means of laboratory experiments (Fürstenau et al. 2004) and tested under operational conditions at Dresden tower as shown in Fig. 3. Here, the idea was investigated to augment the air traffic controller's direct view out of the Control Tower windows, e.g., by weather data, approach radar, and flight data information superimposed on the far view, without additional head-worn gear.

The DLR team during that time decided to turn away from the original idea of augmenting the controller's view out of the real-tower windows by means of the optical see-through technology and instead to follow the video see-through paradigm, i.e., using the video reconstruction of the environment as background for superposed additional information (Barfield and Caudell 2001). This eliminates the latency problem, i.e., the real world superimposed information delay. The augmented vision research for tower controller support using the holographic projection system was continued for a couple of years through several Ph.D. theses at Eurocontrol Experimental Center in Bretigny/France and NASA Ames Advanced

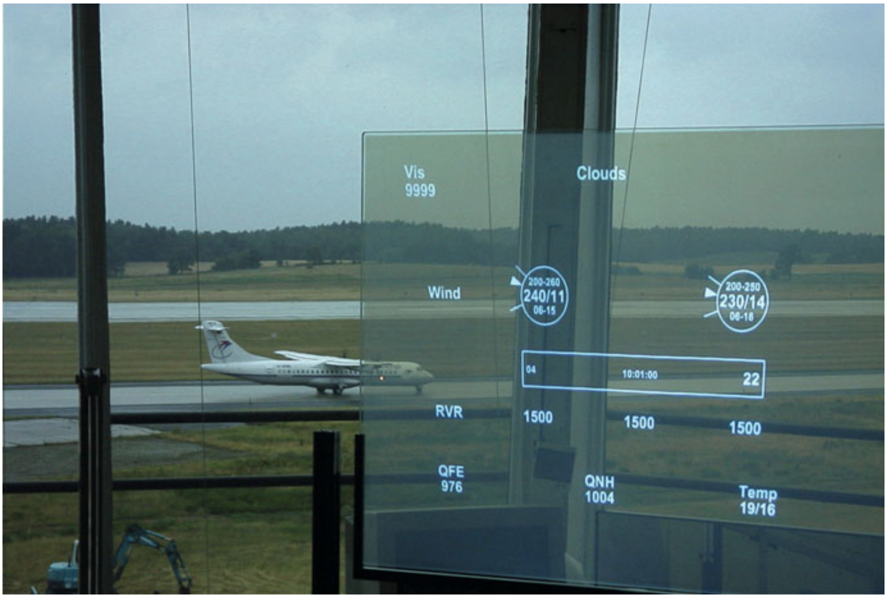

Fig. 3 Demonstration of head-up display-based augmented tower vision using a holographic projection display for superimposing live weather information on the out-of-windows view (non-collimated view: image at display distance, tower at Dresden airport, 7/2003 (Schmidt et al. 2006)

Displays Lab. under the guidance of Steve Ellis. The focus there was research in stereoscopic systems (Peterson and Pinska 2006).

One reason for this change of research direction at DLR was contacts to the Tower Section of the German air navigation service provider DFS (Deutsche Flugsicherung) which were initiated right from the beginning of the Virtual Tower research and later on evolved into formal collaborations. Many discussions with domain experts during this time led to the question if the Virtual Tower idea could provide a solution for a rather urgent requirement: cost reduction in providing aerodrome control service to small low-traffic airports. The reason was the paradigm change in air transport mentioned above: small low-traffic airports without electronic surveillance (usually surface movement radar SME) are increasingly used by low-cost carriers which, nevertheless, request controlled airspace, although often only for a few flights or a couple of hours per day. Previous “Dark Tower” experiments of DFS aiming at remote control of a low-traffic airport during nighttime (with nearly zero traffic) from the tower of a large airport, however, without transmission of visual information, had provided initial experience on the potential feasibility of this concept. This requirement for cost reduction and increase of efficiency leads to the main topic of this book: the Remote Tower as paradigm change, for low-traffic airport surveillance from a distant location, and the perspective of a single remote tower center (RTC) for aerodrome traffic management of several small airports. The original Virtual Tower idea with synthetic vision displays and VR technologies for large hub airports would remain the

Fig. 4 Initial tests (2003) of video-based far view reconstruction with standard video technology. Camera position on DLR telemetry antenna tower, ca. 25 m above ground. Camera aiming at Braunschweig airport tower on the dark roof top. White building to the right is location of initial experimental videopanorama camera system (chapter “Remote Tower Experimental System with Augmented Vision Videopanorama”). Runway visible above the camera, extending in west direction

long-term goal. “Remote Tower” was taken as the more realistic intermediate step with relaxed technological problems and as little as possible changes of operational procedures for a single RTO working position.

At this point, the idea of reconstructing the “far view” out-of-tower windows by means of a suitable assembly of high-resolution digital video cameras emerged—a “down-to-earth” solution compared with the original “virtual holography” ideas and the VR-HMD display as developed at NASA Ames Research Center. Variants of the latter, nevertheless, remain a perspective for the future as completely sensor driven synthetic vision solution for contingency centers and eventually for the actual Virtual Tower on large airports. Figure 4 depicts the initial experiments during the ViTo concept study with available standard video technology of the late 1990s for reconstructing the far view out-of-tower windows. These tests demonstrated the limits of this technology with regard to resolution and contrast and led to the requirement for the emerging high-resolution cameras (UXGA; HD) based on latest CMOS or CCD chip technology. At that time, the cost for a camera of this type was typically $>$15,000 €, without optics.

The corresponding high-quality video reconstruction of the "far view" became the main technical research topic of the Remote Tower team of the DLR Institute of Flight Guidance for the next 8 years (2005–2012), with resources provided by two internally funded projects including a budget of more than 6 M€. The first one (RApTOR: Remote Airport Traffic Operation Research, 2005–2007) as follow-up of the initial ViTo concept study started with intensive contacts between DLR's RTO team and DFS domain experts. Detailed work and task analysis by numerous structured interviews with domain experts were performed by one of the initial core-team members who finished the first doctoral dissertation related to this field (Werther 2005). At the same time, the worldwide first digital 180° high-resolution live-videopanorama as reconstruction of the tower out-of-windows view was realized at the Braunschweig Research Airport, the location of DLR's major aeronautics research facilities [chapter "Remote Tower Experimental System with Augmented Vision Videopanorama", and (Fürstenau et al. 2008b)], based on a RTO patent filed in 2005 and granted in 2008 (Fürstenau et al. 2008a).

In parallel to DLR's research and development of RTO systems, related activities continued in the USA. An experimental system for single camera based remote weather information for small airports using internet-based data transmission had been set up in a NASA–FAA collaboration (Papasin et al. 2001). Clearly, such a system could not fulfill requirements comparable to the high resolution low-latency videopanorama system of the DLR approach. Within the USA, the ATC-modernization initiative NEXTGen (an analogue to the European SESAR joint undertaking) another direction of research aimed at the so-called Stafffed NextGen Tower (SNT), addressing the integration of advanced automation into conventional tower equipment with the same long-term goal as DLR's WdV-proposal: a completely sensor-based work environment without the need for the physical tower building (Hannon et al. 2008). An overview of the US activities is presented by Vilas Nene (MITRE Company) in chapter "Remote Tower Research in the United States".

After realization of DLR's experimental system, it turned out that meanwhile also the Swedish ANSP (LFV) together with company Saab had started the same kind of development (see chapters "Detection and Recognition for Remote Tower Operations" and "The Advanced Remote Tower System and Its Validation"), also targeting low-traffic airports and using more or less the same videopanorama concept. A demonstrator facility was realized in Malmö for initial verification and validation of remote control of a distant airport. This development was continued within the 6th Framework EC project ART (Advanced Remote Tower). Since 2010, under the Single European Sky SESAR Joint Undertaking (project 6.9.3), the NORACON consortium with Saab, LFV, and other partners continued the Swedish RTO development and validation. In 2006, the DLR and Saab/LFV teams met for the first time for discussing the remote tower topic at the occasion of the international mid-term assessment workshop of DLR's RApTOr project.

Meanwhile, DLR's Virtual Tower team kept on growing and besides submitting a second RTO patent application, they published first results obtained with the experimental RTO system and initial human-in-the-loop simulations. The most