Research Topics in Aerospace

Norbert Fürstenau *Editor*

Virtual and Remote Control Tower

Research, Design, Development, Validation, and Implementation

Second Edition

Co-edited by Anne Papenfuss and Jörn Jakobi

DLR

Springer

Research Topics in Aerospace

Series Editor

Rolf Henke, Mitglied des Vorstands, DLR, Cologne, Nordrhein-Westfalen, Germany

DLR is Germany's national centre for space and aeronautics research. Its extensive research and development work in aeronautics, space, transportation and energy is integrated into national and international cooperative ventures. Within this series important findings in the different technical disciplines in the field of space and aeronautics, as well as interdisciplinary projects and more general topics are addressed. This demonstrates DLR's outstanding research competences and capabilities to the worldwide scientific community and supports and motivates international research activities in exploring Earth and the universe, while also focusing on environmentally-friendly technologies and promoting mobility, communication and security.

More information about this series at https://link.springer.com/bookseries/8625

Norbert Fürstenau
Editor

Virtual and Remote Control Tower

Research, Design, Development, Validation, and Implementation

Second Edition

Co-edited by Anne Papenfuss and Jörn Jakobi

Springer

DLR
Deutsches Zentrum
für Luft- und Raumfahrt
German Aerospace Center

Editor
Norbert Fürstenau
Institute of Flight Guidance
German Aerospace Center
Braunschweig, Germany

ISSN 2194-8240 ISSN 2194-8259 (electronic)
Research Topics in Aerospace
ISBN 978-3-030-93649-5 ISBN 978-3-030-93650-1 (eBook)
https://doi.org/10.1007/978-3-030-93650-1

1st edition: © Springer International Publishing Switzerland 2016
2nd edition: © The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG 2022
This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

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 a 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 Prof. 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 convention plan-view CDTI called INTRUD (Ellis & McGreevy, 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 interesting 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 working with Mike (McGreevy & Ellis, 1986), and later Arthur Grunwald (Grunwald, Ellis & Smith, 1988), and still later Gregory Tharp (Tharp & 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 the 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 the 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 counter measures 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 by 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. A 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 (2, 3, 16, 9, 10 and 18, 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 goals 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 the 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, USA Stephen R. Ellis

References

Ellis, S., McGreevy, M. W., and Hitchcock, Ro. (1987). Perspective traffic display format and airline pilot traffic avoidance. *Human Factors*, *29*, 371–382.

Grunwald, A., Ellis, S. R., and Smith, S. R. (1988). Spatial orientation in pictorial displays. *IEEE Trans. on Systems Man and Cybernetics* , *18*, 425–436.

McGreevy, M. W. and Ellis, S. R. (1986). The effect of perspective geometry on judged direction in spatial information instruments. *Human Factors*, *28*, 439–456.

McGreevy, M. W. and Ellis, S. R. (1991). *Format and basic geometry of a perspective display of air traffic for the cockpit. NASA TM 86680.* Ames Research Center, Moffett Field, CA.

Tharp, G. K. and Ellis, S. R. (1990) *The effects of training on errors of perceived direction in perspective displays NASA TM 102792.* NASA Ames Research Center, Moffett Field CA.

Preface to the Second Edition

Nineteen years after the proposal of the Virtual Tower project within DLR's Visionary Projects competition of 2002 (Fürstenau N., 2004), sixteen years after the grant of the first Virtual Tower patent ((Fürstenau, et al., 2008), application 2005 (German patent)), and six years after the first edition of the present volume, the worldwide implementation of Remote Tower Systems has gained speed. After licensing of the DLR-patent to industry, on December 4, 2018, the German Air Navigation Service Provider (ANSP) DFS had started its first Remote Tower Operation of Saarbrücken international airport with a Remote Tower Control Center (RTC) located 450 km to the east at Leipzig airport, to be followed by airports of Dresden and Erfurt. This event followed two years after the worldwide first start of RTO control by the Swedish ANSP LFV, with the RTC located at Sundsvall airport for air traffic management of Örnsköldsvik (2016). In Norway, the ANSP AVINOR opened a RTC on October 20, 2020, in Bodö north of the Arctic circle for remote control of two airports, and the plan is to extend it to a total of 15 by the end of 2022.

These RTC installations represent many others all over the world such as Stockholm, Budapest, London City, and they provided the motivation and sufficient material for an update to the first edition of the RTO book. In nine new chapters, it covers a number of additional topics which gained increasing attention during recent years: from Multiple Remote Tower (MRT) validations over workload measurement and analysis under MRT operation to advanced technologies and low-cost remote systems for non-certified air traffic services (ATS) like AFIS or UNICOM.

In the thirteen chapters of the 2016 Virtual Tower book edition, the focus was on basic preconditions for prototype development like visual features used by Air Traffic Controller Officers (ATCOs), technical aspects, and RTO design with integration of a high-resolution video panorama with broadband fiber optic data transmission as enablers, Augmented Vision functions based on real-time image processing, e.g. for automatic object detection and tracking, human factors questions for workplace design and workload issues, and field tests of RTO prototypes in Germany (DFS) and Sweden (LFV). Authors from NLR, LFV, and Saab described the first passive shadow-mode field testing of advanced video functions such as overlaid approach radar information moving with tracked aircraft, taking place at the RTC test facility of Malmö Sturup airport observing Ängelholm 100 km to the north.

One major motivation of the Remote Tower Operation (RTO) research of course is cost effectiveness. Particularly with the transition from single to Multiple Airport Operation (MRTO), this is a key driving factor. It enables a flexible RTC work environment that would allow for a variable number of staff and flexible allocation of airports to a multiple remote tower module (MRTM) for the centralized control of several airports under large variations of traffic density. The corresponding MRTO research and development work had already started in the prototype phase described in the 1st edition of the book (Part II of the present one). It was focused, however, on Human-in-the-Loop (HITL) simulation experiments for workplace design and workload aspects, with field testing restricted to single airport RTO.

With nine new chapters and two new appendices, the content of the present 2nd edition has nearly doubled. Due to the large number of new chapters, we decided to re-structure the content so that most of the new chapters concentrate in Parts III and IV. Besides Introduction and the basic preconditions for RTO development like required visual information by ATCOs, Part I now includes two chapters with RTO aspects of historical interest: an extended review of the corresponding activities in the United States by V. Nene and a contribution by S. Inoue et al. (ENRI, Tokyo) on Aerodrome Flight Information System technology (AFIS) with remote visual surveillance of small uncontrolled airports in Japan as a kind of RTO predecessor. These introductory chapters are followed in Part II by the technical research and development chapters including augmented vision experiments using image processing for pan-tilt-zoom camera object tracking, and initial prototype field testing. It includes another new contribution by Inoue et al. (ENRI/Tokyo) on the integration of cooperative multilateration surveillance data with visual object identification and tracking via image processing.

Part III puts the focus on the important HITL simulation experiments, starting with the extended Remote Tower Laboratory environment at DLR-Braunschweig where several HITL experiments with domain experts provided new data on video frame-rate effects, object tracking issues, situation awareness, and workload. Quantification of workload effects under different work conditions represents one aspect of increasing interest (conventional tower vs. RTO vs. MRTO). Besides being addressed in different chapters, basic additional information is provided in two new Appendices (C and D).

Part IV addresses usability experiments with field testing of advanced technologies such as fusion of the video panorama with thermal camera information. Moreover, following the description of a controller friendly MRTO assistance tool by R. Leitner and A. Oehme, a large-scale validation experiment is described by Li et al. (Cranfield University) together with the Irish Aviation Authority (IAA), concerning the certification process for the new Dublin RTC MRT Center with remote control of Shannon and Cork international airports. The AFIS topic from Part I is taken up again describing a detailed validation study of an advanced although low-cost visual surveillance system for small low-traffic airports, based on a PTZ-camera remotely controlled by a VR-headset with head tracking.

Following the shadow-mode field tests of the initial DFS prototype at Erfurt airport in 2012 within a DFS–DLR cooperation, several European cooperations with EC-co-funding by the Single European Sky Air Traffic Research (SESAR) initiative were performed for developing and validating Remote Tower Operation. Within the European Organization for Civil Aviation Equipment (EUROCAE), a Remote Tower working group had been set up (WG100 "Remote and Virtual Tower") that published a document on Minimum Aviation System Specifications (EUROCAE, 2016). In parallel to an increasing number of industrial (M)RTO development activities, the breakthrough of this interdisciplinary research and development effort proved successful after more than 15 years, leading to a paradigm change in airport traffic control that will eventually lose its 100 years old symbol, the airport control tower.

Two of the editors (N.F., J.J.) were happy to be awarded the Manfred-Fuchs Innovation prize in 2019, for the "Successfully Realized Innovation 'Remote Tower'". This success would not have been possible without the fundamental contributions of the initial "Virtual Tower" technical team: Markus Schmidt as a chief engineer who realized (to our best knowledge) the worldwide first experimental system for field testing (The chapters "Remote Tower Experimental System with Augmented Vision Videopanorama" and "Remote Tower Prototype System and Automation Perspectives"), Bernd Werther as an analyst of the tower work procedures who designed and realized within his Ph.D. dissertation a colored Petri-net computer model of the controllers task and work network, in close cooperation with DFS (Werther, Cognitive modeling with Coloured Petri Nets for the analysis of human behaviour, 2005)(Werther & Uhlmann, Ansatz zur modellbasierten Entwicklung eines Lotsenarbeitsplatzes, 2005) (Werther, Airport control model for simulation and analysis of airport control processes, 2007), and Michael Rudolph as a software developer, who designed and wrote the basic RTO-software including augmented vision features, for field testing and human-in-the-loop simulation (The chapters "Remote Tower Experimental System with Augmented Vision Videopanorama" and "Remote Tower Prototype System and Automation Perspectives" and references therein).

As a editor of the 2016 volume, I am indebted to my co-editors of the present 2nd edition, Dr. Anne Papenfuss and Jörn Jakobi (Chairman, EUROCAE WG100) who were involved already in part of the research described in the 1st edition and in most of the research work described in the new chapters. They spent much of their time in motivating chapter (co-) authors for contributing to this volume and in reviewing the manuscripts. Together we express our sincere thanks to Satoru Inoue, Mark Brown, and Yasuyuki Kakubari (ENRI/Tokyo); Wen-Chin Li and Graham Braithwaite (Cranfield University, Bedfordshire, UK); and Peter Kearney (IAA, Dublin) for their contributions and their patience during the recent two (or so) years.

Special thanks of one of the editors (N.F.) are to Thea Radüntz (Unit Mental Health and Cognitive Capacity, Federal Inst. for Occupational Safety and Health (BAUA), Berlin) who together with Thorsten Mühlhausen (ATC Simulator Division, DLR) organized the first HitL-simulation experiment for validating the new EEG-based "Dual Frequency Headmap" method (DFHM, (Radüntz, 2017), see Appendix C) through quantifying workload under realistic ATC conditions. It provided basic data for the derivation of the logistic and power law WL-models (see Appendix D) for prediction and statistical estimation of MRTO WL-parameters in the chapter "Model Based Analysis of Subjective Mental Workload during Multiple Remote Tower Human-In-The-Loop Simulations". Last but not least, I am indebted to Jürgen Rataj (Head of Controller Assistance Division) for his support of the DLR-BAUA cooperation and for enabling this book project through a consulting contract with one of the editors (N.F.) after his retirement in 2016.

Braunschweig, Germany
November 2021

Norbert Fürstenau

References

EUROCAE. (2016). *Minimum Aviation System Performance Specification for Remote Tower Optical Systems.* Internal Report, Malakoff, France. Retrieved 2018, from www.eurocae.net.

Fürstenau, N. (2004). *Virtual Tower. Wettbewerb der Visionen 2001–2004* (pp. 16-19). Köln: DLR.

Fürstenau, N., & Radüntz, T. (2021). Power law model for Subjective Mental Workload and validation through air-traffic control human-in-the-loop simulation. *Cognition, Technology, and Work*. Retrieved 05 30, 2021, from https://doi.org/10.1007/s101011-021-00681-0.

Fürstenau, N., Rudolph, M., Schmidt, M., Werther, B., Hetzheim, H., Halle, W., & Tuchscheerer, W. (2008, 12). Flugverkehr-Leiteinrichtung (Virtueller Tower). *European Patent EP1791364*.

Radüntz, T. (2017). Dual Frequency Head Maps: A New Method for Indexing Mental Workload Continuously during Execution of Cognitive Tasks. *Frontiers in Physiology, 8*, 1–15. https://doi.org/10.3389/fphys.2017.01019.

Werther, B. (2007). Airport control model for simulation and analysis of airport control processes. *Proc. HCII2007: Lecture Notes Computer Science. vol. 4558.* Beijing: Springer.

Werther, B., & Uhlmann, H. (2005). Ansatz zur modellbasierten Entwicklung eines Lotsenarbeitsplatzes. *VDI-Fortschrittberichte: Zustandserkennung und Systemgestaltung*, *22*, 291–294. Berlin: VDI.

Preface to the First Edition

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 Chapter 1, Introduction, section 1). 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 towards 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 video-panorama 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 towards the Virtual Tower presented in the following chapters will show that their scepticism 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 ICAO (International Civil Aviation Organisation) 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 realisation 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, 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 questionaires (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 the present 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 one of the editors (N.F.) together with Markus Schmidt (one of the co-authors) 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, co-author of Chapter 7) 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 the present book. They increasingly took over workshares of the RTO research, in articular 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 6, 7). 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 2, and co-author of Chapter 16. As a kind of spiritus rector of the Virtual Tower idea he demonstrated in his Advanced Displays Lab. the initial concrete realisation, based on stereoscopic head mounted displays, which inspired us for submitting our initial proposal in 2001. Nearly ten 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 16.

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 the present 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 endeavour towards the Virtual Control Tower: Rodney Leitner and Astrid Oehme from Human Factors Consult/Berlin for Chapter 20 on Multiple Airport Control, Dorion Liston from San José State University and NASA-Ames as co-author to Chapter 2 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 3 and 18 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 can not 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 sugggestions for improvements that may be included in a followup edition of the present volume.

Mentioning the domain experts we certainly have to express our greates appretiation 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 Chapter 7, 9, 10) and Dresden (location of DLR's initial live Augmented Vision test, see Chapter 1), 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 ressources 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 towards the planned project end it turned out that an extra half year was required for the shadow-mode trials, 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 the present 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 endeavour nearly two years ago and Mrs. Kay Stoll, Project Coordinator who in a helpful way and patiently accompanied the gradual evolution from abstract collection through repeated manuscript iterations into the present thirteen chapters volume: thank you, it was fun!

Braunschweig, Germany Norbert Fürstenau
11 October 2015

Contents

Preconditions

Development and Field Testing of Remote Tower Prototype

Human-in-the-Loop Simulation for RTO Workload and Design

Advanced and Multiple RTO: Development, Validation, and Implementation

About the Editor and Co-Editors

About the Editor

Dr. Phil. nat. Norbert Fürstenau, Dipl. Phys. Since 1971 study of physics at the Universities of Braunschweig, Darmstadt, and Frankfurt. In 1981, Dr. Phil. nat. degree from Frankfurt University with a work on Laser Micro Mass Analysis in Biophysics. After postdoc research on Laser-induced cluster molecules, since 1981 research associate at DLR Inst. of Flight Guidance, and until 2000 group leader of photonic sensors research. In 2001, initialization of "Virtual Tower" research in the Human Factors division. Head of DLR's Remote Tower projects (2002–2012). Since 2016 retired and as scientific consultant research continued in cognitive load analysis. More than 100 journal and conference papers and 10 patents (including "Virtual Tower") in different research fields. Editor of the "Virtual and Remote Tower" book (1st edition 2016). Winner of DLR's 1st "Visionary Projects competition" ("Virtual Tower" proposal, 2001) and the Manfred-Fuchs Innovation award (2019, together with 2nd edition co-editor J. Jakobi).

Co-Editors

Jörn Jakobi, Dipl. Psych. received his Diploma in Psychology in 1999. Since 2000, he works as a human factors expert with DLR Institute of Flight Guidance in the domain of airport airside traffic management with a particular focus on concept design and validation of A-SMGCS and Remote Tower systems. Since 2010, he took over the position of a business developer with a main focus on the topic Remote Tower. In 2014, he became Chairman of the EUROCAE WG100 "Remote & Virtual Tower" and in 2016, the Single European Sky ATM Research program (SESAR2020) launched the biggest European Remote Tower Project with more than 30 partners, which since then is managed by Jörn Jakobi in the project coordinator role. In 2019, he received the Manfred-Fuchs Innovation award for his achievements with Remote Tower innovations and implementation support (together with editor N. Fürstenau).

Dr. phil., Anne Papenfuss is a researcher at the Human Factors department of DLRs Institute of Flight Guidance since 2008. Her research field is teamwork in air traffic management, how it can be assessed and measured, with a focus on automating communication analysis. She received her Ph.D. from TU Berlin in 2019 in the field of performance-related communication behaviors of air traffic controllers. Within DLR's research on remote tower, she organized the first simulation studies for remote tower and remote tower center operations to assess the impact of these concepts on human performance.

Abbreviations

2-D	Two-Dimensional
3-D	Three-Dimensional
AC	Alternate Current
A/C	Aircraft
ACC	Area Control Center
ADD	Aircraft-Derived Data
ADS-B	Automatic Dependent Surveillance-Broadcast
AFIS	Aerodrome Flight Information Service
AFISO	Aeronautical Flight Information Services Operator
AGL	Above Ground Level
AIP	Aeronautical Information Publication (airport data)
AMC	Air Movement Control
AMS	Acquisition Management System
ANOVA	Analysis of Variance
ANOCOVA	Analysis of Covariance
ANSP	Air Navigation Service Provider
ANT	Automated NextGen Tower
AOI	Area of Interest
AP	Airport
APDU	Aircraft Position Display Unit
APREQ	Approval Request
AR	Augmented Reality
ARSR	Air Route Surveillance Radar
ART	Advanced Remote Tower (EC-FP6 project)
ARTCC	Area Route Traffic Control Center
ASD	Aeronautical Services Department (of SRD, Ireland)
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
ATMDC	Air Traffic Management Development Centre (of NATS)
ATS	Air Traffic Services
ATWIT	Air Traffic Workload Input Technique
AV	Augmented Vision
BWE	Braunschweig Wolfsburg Airport
CAMI	Civil Aerospace Medical Institute (US)
CAPAN	Capacity Planning for Networks
CAPEX	Capital Expenditure (airport capital investment)
CAT	Category
CAVOK	Clouds and Visibility OK
CDTI	Cockpit Display for Traffic Information
CERDEC	Communications-Electronics Research, Development, and Engineering Center (US Army)
CHI	Computer–Human Interface
CHMI	Collaboration Human–Machine Interface (Eurocontrol tool)
CI	Confidence Interval
CoDec	Compression–Decompression
CNN	Convolutional Neural Network
CTAF	Common Traffic Advisory Frequency
CTR	Control Range
CWA	Cognitive Work Analysis
CWP	Controller Working Position
DAA	Dublin Airport Authority
D.C.	District of Columbia
DFHM	Dual Frequency Head Maps (EEG)
DG-TREN	Directorate-General for Transport and Energy
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DME	Distance Measuring Equipment
DoT	(Irish) Department of Transportation
DRRP	Detection and Recognition Range Performance
DST	Decision Support Tool
EASA	European Aviation Safety Agency
EEG	Electro Encephalogram
EFS	Electronic Flight Strip
ENRI	Electronic Navigation Research Institute (Japan)
E-OCVM	European Operational Concept Validation Methodology
EU	European Union
EUROCAE	European Organization for Civil Aviation Equipment
FAA	Federal Aviation Administration (US)
FACE	Flight object Administration Centre
FACSIM	Forward Air Controller Traffic Simulator
FFT	Fast Fourier Transform

FHA	Functional Hazard Assessment
FMS	Flight Management System
FOD	Foreign Object and Debris
Fps	(video) frames per second
FSC	Flight Service Centre
FSS	Flight Service Station
FOV	Field of View
GA	General Aviation
GLM	Generalized Linear Model
GMC	Ground Movement Control
GMU	George Mason University
GPS	Global Positioning System
GPU	Graphics Processing Unit
GPGPU	General-Purpose GPU
HCI	Human–Computer Interaction
HD	High Definition (video)
HF	Human Factors
HFOV	Horizontal Field-of-View
HITL	Human-in-the-Loop (Simulations)
HMI	Human–Machine Interface
HR	Heart Rate
HRV	Heart Rate Variation
IAA	Irish Aviation Authority
ICAO	International Civil Aviation Organization (UN body)
ID	Identification, (tracking) Identifier
IDP	Information Data Processing
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
IFR	Instrument Flight Rules
IFORS	International Federation of Operational Research Societies
IP	Internet Protocol, also: Information Processing
IPME	Integrated Performance Modeling Environment
IR	Infrared
ISA	Instantaneous Self Assessment
ITV	Industrial Television (Camera)
JCAB	Japan Civil Aviation Bureau
JND	Just Noticeable 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
Km	Kilometer
LAX	Los Angeles International Airport
LFV	Luftfartsverket, Swedish Air Navigation Service Provider
LM	Linear Model
LSD	Large-Scale Demonstration
MANTEA	Management of surface Traffic in European Airports (EC Project)
MASPS	Minimum Aviation System Performance Specification
METAR	Meteorological Aerodrome Report
MIT	Massachusetts Institute of Technology
MLAT	Multilateration (surveillance) System
MPID	Multi-Purpose Information Display
MRTM	Multiple Remote Tower Module
MRT(O)	Multiple Remote Tower (Operation)
MWL	Mental Work Load
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATCA	National Air Traffic Controllers Association (US)
NATS	National Air Traffic Services (UK)
NextGen	Next Generation Air Transportation Program (FAA, USA)
NIEC	NextGen Integration and Evaluation Capability
NL	Non-Linear
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium
NM	Nautical Miles
NOTAM	Notices to Airmen
NRC	National Research Council (US)
NSA	National Supervisory Authority
NTA	Non-Towered Airport
NT	NextGen Tower
OCTPASS	Optically Connected Passive (MLAT) Surveillance System (Japan)
ODT	Objective Detection Time
OIS	Operational Improvement Step
OPEX	Operating Expenditure (airport operating cost)
OTW	Out-of-The-Window
PANS	Procedures for Air Navigation Services
PIP	Picture-In-Picture
PSR	Primary Surveillance Radar
PSSA	Preliminary System Safety Assessment
PTZ	Pan-Tilt-Zoom (Camera)
QNH	Atmospheric Pressure
RAG	Remote Air–Ground Communication
RAiCe	Remote Airport traffic Center (DLR project 2008–2012)
RApTOR	Remote Airport Tower Operation Research (DLR project 2004–2007)
RC	(rate or frequency of) Radio Calls
RCD	Radio Call Duration

RD	(cumulative) Radio (Call) Duration
RDP	Radar Data Processing
RJCR	Rishiri Airport (Japan)
RJEO	Okushiri Airport (Japan)
RNLAF	Royal Netherlands Airforce
RoF	Radio-over-Fiber
ROT	Remotely Operated Tower
RT	Recognition Time
RTC	Remote Tower Center/Remote Tower Control
RTM	Remote Tower Module
RTO	Remote Tower Operation
RVR	Runway Visual Range
SA	Situational Awareness
SAM	Safety Assessment Methodology
SATI	SHAPE Automation Trust Index (Eurocontrol)
SD	Standard Deviation
SDT	Signal Detection Theory
SES	Single European Sky
SESAR	Single European Sky ATM Research
SFO	San Francisco International Airport
SID	Standard Instrument Departures
SMC	Surface Movement Control
SMR	Surface Movement Radar
SMU	Safety Management Unit
SNT	Staffed NextGen Tower
SPECI	(aviation) Selected Special weather report
SRD	Safety Regulation Division (of IAA)
SSA	System Safety Assessment
SSR	Secondary Surveillance Radar
STAR	Standard Terminal Arrival Routes
STDEV	Standard Deviation
STER	Standard Error
TAR	Terminal Approach Radar
TC	Tower Controller
TCAS	Traffic Alert and Collision Avoidance System
TDU	Terminal Display Unit (weather)
TFDPS	Tower Flight Data Processing System
TIL	Traffic Information Log
TL	Task Load
TLX	Task Load Measure
TMA	Terminal Maneuvering Area
TMC	Traffic Management Coordinator
TMI	Traffic Management Initiative
TA	Time Available
TP	Time Pressure (:=TR/TA)

TR	Time Required
TRACON	Terminal Radar Approach Control
TS	Tower Supervisor
TWR	Tower
UN	United Nations
UNICOM	Universal Communications
USA	United States of America
VCS	Voice Communication System
VDOT	Virginia Department of Transportation
VET	Visibility Enhancement Technology
VFR	Visual Flight Rules
VHF	Very High Frequency
VIS	Visible Spectrum
ViTo	Virtual Tower (DLR project 2002–2004; winner of 1st Visionary Projects Competition)
VPA	Verbal Protocol Analysis
VPN	Virtual Private Network
VR	Virtual Reality
VSATS	Virginia Small Aircraft Transportation System (SATS) Laboratory
WAK	Workload Assessment Keypad
WAM	Wide Area Multilateration
WdV	Wettbewerb der Visionen (DLR visionary projects competition)
WJHTC	William J. Hughes Technical Center (FAA)
WL	Work Load
WP	Work Package
YOLO	You Only Look Once (CNN framework)

Preconditions