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REMOTE TOWER: THE DEVELOPMENT VISION OF LOCATION-INDEPENDENT AERODROME CONTROL TAILORED FOR MILITARY PURPOSES

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ABSTRACT: *The first conceptual ideas regarding the provision of location-independent aerodrome control, also known as Remote Tower Service, were outlined over a quarter of a century ago. Despite the enormous technological leaps since then and the increasing prevalence of its application, the common notion persists that the paradigmatic symbol of air traffic control is a tower building with slanted windows, providing a circular view. Nonetheless, the tangible version of this concept developed directly for military purposes is yet to be unfolded but given proper nurturing, this technology has the capacity of positively transforming the conventional operational framework of military air traffic services, propelling its operational value. Therefore, the objective of this paper is to showcase the development directions that currently appear most promising from a military standpoint in the context of location-independent aerodrome control.*

KEYWORDS: *remote tower, location-independent aerodrome control, ATM, ATC*

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INTRODUCTION

The control tower, a symbolic icon of air traffic control, has traditionally loomed over airports, providing an unobstructed circular view through its slanted windows. However, this symbol is on the verge of transformation, largely driven by the remarkable advancements in the semiconductor industry that have unfolded over the past several decades. At the core of this transformation lies Moore's Law, a principle stating that computing capability, measured by the number of transistors on a chip, doubles every 18–24 months.[1] The exponential growth inherent in Moore's Law finds its foundation in the process of miniaturization, a defining characteristic of computer technology and the digital systems that underpin location-independent aerodrome control. Until recently, each aerodrome relied on a dedicated air traffic control tower, and the integrated systems within this facility, to ensure the safe, orderly, and expeditious flow of aircraft.[2] However, the field of Information and Communication Technologies has witnessed momentous progress lately, leading to the emergence

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[1] DeBenedictis 2017, 72–75.

[2] Faber 2009, 18.

of the Remote Tower Service (rTWR) concept, encompassing the requisite components for implementing the provision of location-independent aerodrome control services at and in the vicinity of an aerodrome.[3] As already stated, the process of miniaturization plays a fundamental role in the development of these components, not only reducing their physical size but also diminishing their proportional energy consumption, while simultaneously driving down production costs.[4] These advantageous characteristics have culminated in a pivotal juncture, where the reliance on traditional airport control towers has become less imperative for providing modern air traffic services. With the aid of rTWR's toolkit, primarily comprised of camera systems, the task of aerodrome control can now be effectively carried out from remote locations, making this service less constrained by distance. The implications of this paradigm shift can lead to reshaping the whole landscape of – civilian and military – air traffic management, disclosing new possibilities that can be even further propelled by artificial intelligence. In this context, it is crucial to underscore that the objectives pursued by the civilian and military applications shall diverge to a considerable extent. The civilian sphere primarily seeks to augment flight safety, achieve fiscal optimization, and ideally, ascertain a more cost-effective alternative to conventional methods through the utilization of rTWR technology.[5] Conversely, the military domain shall primarily envisage gains that can be quantified in terms of human lives, owing to the fact that military air traffic controllers could provide air traffic services from a secured facility that might be placed at a distance from areas of operations. Therefore, the primary objective of this study is to outline the most optimized course for a military-centric development direction for the provision of location-independent aerodrome control services.

CONCEPT OVERVIEW

As evident from the introductory section, a fundamental distinction between the conventional control tower and the rTWR solution lies in their respective approaches to visual observation regardless of civilian or military applications.[6] Traditionally, controllers rely on unaided human vision from a tower situated at the airport. Conversely, in the case of a fully materialized rTWR concept, the controller's area of responsibility is comprehensively surveyed using digital imaging devices. These devices, primarily consisting of cameras installed at the aerodrome as presented in *Figure 1 (right)*, predominantly operate within the visible range of the electromagnetic spectrum, although not exclusively. The resulting motion imagery captured by these cameras is then relayed to a Controller Working Position (CWP), established remotely at the airport via a wired, wireless, or hybrid data connection, aiming for seamless communication *(Figure 1, left)*.

With regard to the aforementioned rTWR CWP, it is vital to underscore its nature as a consolidated station that integrates an array of monitoring and control functions. Therefore, its purpose extends beyond image data display for real-time air traffic tracking. It includes communication management, radar surveillance and flight data display, alert systems, weather information integration, operational tools, automation, and incident/event

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[3] Fürstenau 2016.
[4] Horváth 2023, 55–68.
[5] Horváth 2023, 68–72.
[6] Fürstenau 2016.

Figure 1 *rTWR CWP (left) and rTWR camera configuration (photos taken by the author)*

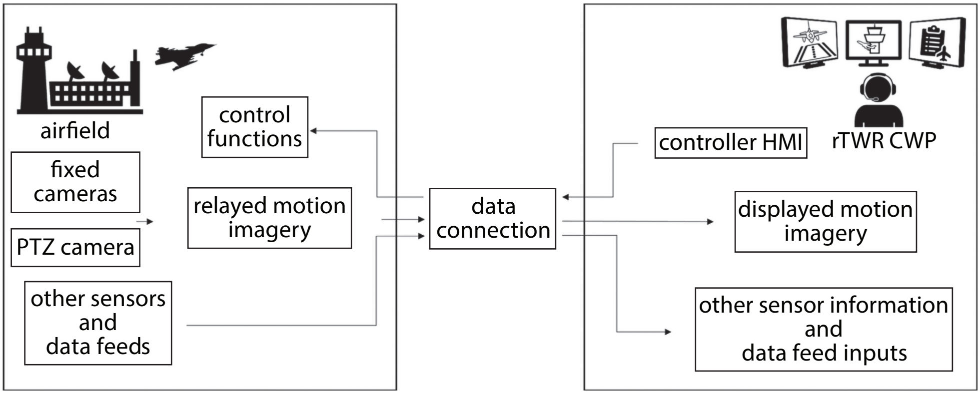

Figure 2 *Conceptual block diagram of rTWR (edited by the author)*[*]

[*] Technical and operational requirements for remote tower operations, 2017.

logging functions. Utilizing this description, *Figure 2* presents a conceptual block diagram of the rTWR system's operational overview.

The Initial NATO Position on Remote Tower Services concept fused the decades-long military experiences of remote sensing and piloting with the disruptive nature of location-independent air traffic control services.[7] This approach made it possible to realize rTWR's inherent military potential characterized by resiliency and deployability. Consequently, when considering military application, a distinction must be made between stationary-based rTWR solutions and those designed with deployability in mind.[8] In the case of stationary solutions, the airbase and the corresponding rTWR center are typically situated within a domestic environment. From these locations, they cater to general and specialized air traffic needs, predominantly military, during both peacetime and non-peacetime operations. This setup offers the advantage of a well-established infrastructure to support service provision and relatively straightforward redundancy implementation. How-

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[7] NATO: *Initial Position on Remote Tower Services (RTS) concept*, Reference: AC/92WP- (2015) 0001, 2015.

[8] Vas 2019, 31–45.

Table 1 *Conceptual military environments of rTWR (edited by the author)*[*]

	Stationary rTWR (domestic environment)	**Deployable rTWR (operational environment)**
Applicability	at air bases, in times of peace and conflict, for GAT and OAT	at captured air bases or territories otherwise suitable for flight operations in times of conflict, mainly for OAT (note: it might be used for the aid of foreign and domestic humanitarian missions)
Regulations	civilian and military	military
Services	control, advisory, information, alerting	control (highly dependent on the reliability of data connection), advisory, information, alerting
Threat detection	desired	desired
Redundancy	must (mainly relying on wired connections and hardware elements)	recommended
Acronyms within this table: **GAT:** General Air Traffic (GAT) encompasses all flights conducted in accordance with the rules and procedures of the International Civil Aviation Organization (ICAO). These may include military flights for which ICAO rules satisfy their operational requirements. **OAT:** The term Operational Air Traffic (OAT) is applied to all flights which do not comply with the provisions stated for general air traffic (GAT) and for which rules and procedures have been specified by appropriate national authorities. Most OAT flights are operated by military agencies.		

[*] Horváth 2023, 37–51.

ever, within this context, the system in some cases must also adhere, as shown in *Table 1*, to civilian regulatory requirements.

It is noteworthy to revisit the introductory statement, emphasizing the iconic symbol of air traffic control: the dominant structure called the tower building with slanted windows, providing a circular view. While this control tower commands respect during times of peace, it becomes a highly valuable, easily identifiable, and non-redundant target, challenging to defend during times of conflict. Consequently, the elimination of a conventional control tower at an average airport would lead to the cessation of air traffic services in the respective area. In contrast, a well-structured rTWR configuration presents numerous smaller targets that are more challenging to identify, easier to defend, and functionally redundant. The cumulative impact of these characteristics significantly enhances the resilience of the airbase's air traffic services, bolstering their ability to successfully withstand adversarial actions. In the context of deployable solutions, the concept primarily pertains to times of conflict when air traffic services are provided by captured airbases or territories otherwise suitable for flight operations. Within the deployable context, possible hostile activities must be addressed, although the other set of challenges lies in assessing the qualitative and quantitative factors of infrastructure. However, regardless of these challenges, the utilization of rTWR technology can serve as a critical tool to enhance the resilience of air traffic services in the areas of operations and safeguard forces. Military air traffic controllers can effectively carry out their duties from protected and/or secure facilities located away from the threatened region. It is important to note that the deployable rTWR concept also raises significant technological challenges, particularly in terms of data connection. In this environment, where bandwidth is likely limited, the transmission of real-time high-resolution image data with low latency becomes a fundamental concern.

VISION OF OPERATION

The vision of location-independent aerodrome control systems tailored for military purposes is built upon four pillars: hardware, software, manware, and netware collectively referred to as the *4W principle.*[9] While certain aspects of these elements find existing civilian applications, and in some cases, specific elements may already have adapted military versions, a comprehensive conceptualization of a military rTWR system based on the given essentials is yet to be presented. The 4W principle unfolded below omits, to the possible extent, redundant references to the sub-elements (e.g.: cameras) mentioned in the concept overview, as these have already enjoyed ample publicity rTWR scope-wise and more.

Hardware

To ensure optimal service quality within the designated airspace, an air traffic controller must precisely locate and track aircraft and other relevant elements, such as birds, in real time.[10] Embracing the rTWR concept, the integration of active and passive surveillance hardware, uncommon at civil airports, might be beneficial regardless of the cost. In the former category, Light Detection and Ranging (LiDAR) stands as a particularly promising option. LiDAR is a remote sensing method that uses laser pulses to measure distances and create precise three-dimensional representations of objects and environments.[11] Its accuracy, real-time data capabilities, and ability to penetrate certain weather conditions offer significant advantages for enhancing military air traffic services. However, cost, limited range, line of sight limitations, vulnerability to atmospheric conditions, and integration challenges are aspects that should be carefully considered before implementing LiDAR-based systems in rTWR environments. Assessing the specific needs and requirements of each rTWR facility is essential to determine whether LiDAR is the optimal choice for their operations. In the context of the latter category, landscape, at least R&D-wise, might become more intriguing. While passive surveillance trackers like VERA-NG[12] already utilize multilateration, the Time Difference of Arrival principle,[13] offering a novel solution integrating this passive surveillance approach with diverse optical (including passive infrared) and acoustic sensors, holds a two-fold promise. First, with the envisioned surveillance solution, which currently resides solely in the conceptualization described in this paper, one can utilize the Johnson criteria[14] values from detection through recognition to target identification. Second, the discreteness of this surveillance procedure is ensured by the passive nature of the device. Even though the R&D procedure of such a system requires a substantial investment,

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[9] The 4W principle, developed by the author, primarily summarizes the essential development pillars of an rTWR system tailored for military purposes (and may potentially be applicable for the description of other development concepts tailored for military purposes as well). Manware is a made-up word for this principle and is derived from two words: human and hardware/software. Netware is also a made-up word for this principle and is derived from two words: network and hardware/software.

[10] Palik (ed.) 2018.

[11] Peyrin et al. 2023.

[12] VERA-NG passive radar is an electronic support measures system that uses three or four sites to accurately detect, recognize, and track airborne emitters. The manufacturer is ERA a.s., based in Pardubice.

[13] Time Difference of Arrival (TDoA) principle is a positioning methodology that determines the difference among the time-of-arrival of radio signals.

[14] The Johnson Criteria is a standard used for DRI (Detection, Recognition, and Identification). It is calculated based on how many pixels are necessary in order to make an accurate evaluation of your object.

the system's advantages perceived in augmenting military operations, enhancing threat detection and flight safety may justify the associated costs in a mission-critical context. Notably, the integration of sensor data from a remotely piloted aviation system (RPAS) tailored for rTWR can substantially elevate the operational value of the provided air traffic service.

Software

The exponential growth of artificial intelligence (AI) and big data operations presents promising software opportunities for location-independent aerodrome services. However, akin to hardware, the primary objective remains the same: ensuring the quality of service through the production of the best-recognized air picture available.[15] Consequently, the already existing pivotal functions encompass the following:[16]

- following (PTZ),
- tracking,
- labeling,
- alarming.

The following (PTZ) function is a control mechanism, digitizing the use of physical binoculars in order to provide enhanced resolution and close-up views of specific locations or objects. Tracking involves focusing on designated pixels using image processing algorithms or direct selection of the operator. Labeling associates and displays relevant information from a database (e.g., flight plan data) in connection with the tracked/followed aircraft, while the rTWR system must promptly issue visual and/or auditory alerts in case of adversarial actions, critical malfunctions, or flight safety risks. Nonetheless, these examples merely encompass presently known civilian rTWR implementations, while the integration of artificial intelligence and big data management into the military concept demands exquisite creativity and thinking beyond traditional boundaries. First, by processing real-time data from the system's sensors, big data analytics and AI algorithms could provide comprehensive situational awareness to military air traffic controllers. This enables the detection, recognition, and identification of potential targets, distinguishing between friendly and hostile objects, and detecting anomalous activities. AI also offers decision support for optimal flight paths, mission planning, and risk assessments. Furthermore, these technologies can automate routine tasks, reduce the cognitive load on operators, and aid in emergency situations by processing vast amounts of data in real time. With the integration of various surveillance systems, AI enhances the detection of stealthy or low-observable threats. It also facilitates data fusion from multiple sources, improving intelligence gathering and cybersecurity, thereby ensuring the system's resilience against potential cyberattacks. Continuous learning and adaptability can enable military rTWR systems that are propelled by AI to handle dynamic operational environments effectively. In conclusion, the assimilation of big data and AI technologies empowers location-independent aerodrome control systems tailored for military purposes to achieve optimal air traffic control, airspace management, and swift responses to potential threats. This seamless integration bestows a competitive edge, bolstering safety and security within the controller's airspace and elevating the overall effectiveness of military operations.

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[15] Csengeri 2018, 159–175.

[16] Zhang et al. 2020.

Manware

In the aviation domain, and more particularly in air traffic management, human involvement remains paramount, even in future scenarios where direct human intervention evolves into a supervisory role. This statement, even as machine learning and artificial intelligence become increasingly prevalent, must be taken into account in all software and hardware development, particularly in ensuring situational awareness for air traffic controllers. A significant challenge facing military rTWR operations gravitates toward the paradox of determining the optimal image refresh rate (frames per second, FPS).[17] Striking the right balance is critical, as an excessively low FPS may lead to mission-critical failures and flight safety risks, while an excessively high FPS can strain bandwidth and degrade image resolution, compromising the quality of the service. In operational environments, the challenge becomes more pronounced, particularly when providing air traffic services for fast, maneuverable military aircraft and other objects requiring following, tracking, and/or labeling with limited bandwidth availability. Here are two possible solutions to address this bottleneck:

1. *Less is more principle:* transmitting rTWR sensor network data to a remote location, which is far from the conflict zone, through satellite communication, since other wired or wireless options are not suitable, ultimately embracing the bandwidth bottleneck nature of the system. This calls for optimal use of available bandwidth and prioritizing data sources based on task-centric relevance. Presumably, this principle will result in a limited air traffic service requiring serious compromises but the protection of the personnel is guaranteed with great certainty.
2. *More is a must principle:* integrating the rTWR sensor network data into a center situated at a suitable distance, using wired, wireless, or hybrid connections, providing the required data throughput with minimal delay in order to address the bandwidth bottleneck challenge. In the case of an occupied airport, this implies that the implementation of an rTWR center would offer superior protection compared to a conventional tower due to its hard-to-reach location and fortified design. Presumably, this principle will result in a good level of air traffic service without making any serious data-related compromise but the protection of the personnel is guaranteed with a lower level of certainty compared to the *less is more principle*.

Additionally, the perception of digital imagery by air traffic controllers, acquired through conventional means from a controller tower, significantly influences the system's efficacy. Intensive simulator training and practice acquisition can be effective measures to address this factor.

Netware

Many systems that exhibit remarkable tolerance to failures share a defining characteristic: highly interconnected and intricate networks. A cell's robustness is concealed within its complex regulatory and metabolic network; society's ability to bounce back is rooted in the interwoven social fabric; the economy's stability is upheld by a delicate web of financial and regulatory organizations; an ecosystem's ability to survive is encoded in a

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[17] Jakobi – Hagl 2018, 22–26.

meticulously crafted network of species interactions. It appears that nature's inclination towards interconnectivity serves as a widespread strategy to achieve robustness.[18] With this in mind, a tridirectional network architecture of rTWR must be the prevalent choice to advance. The present landscape of military and civilian rTWR applications, as depicted in *Figure 2*, primarily involves a bidirectional data exchange between system components and the controller. However, this approach fails to fully encapsulate, and consequently unlock, the full military potential of this technology, namely, the incorporation of the NATO Network Enabled Capability (NECC)[19] concept. When developing a location-independent aerodrome control system tailored for military purposes, it naturally yields a substantial volume of high-quality, mission-critical data, currently restricted to the confines of air traffic management operations. Nonetheless, by factoring in the NECC concept, a new realm of data connections emerges – emanating from the military ATM system, yet profoundly beneficial for other stakeholders. Naturally, this endeavor entails identifying potential beneficiaries who can leverage the data delivered by the military rTWR system to augment their performance. These beneficiaries may extend beyond the NATO Integrated Air and Missile Defence (IAMD),[20] encompassing strategic and tactical air defence elements, while also extending to fortifying the physical defence capabilities of the pertinent airbase. The NECC integration unlocks the potential for seamless data sharing, fostering a collaborative operational environment among diverse military entities. This enables various stakeholders to access real-time, comprehensive situational awareness, facilitating informed and timely decision-making. For instance, strategic air defence units can capitalize on the rTWR's precise and timely air traffic data to bolster their threat assessment capabilities and deploy resources effectively. Simultaneously, tactical air defence units can optimize their response strategies based on the real-time surveillance of airspace activities facilitated by the rTWR system. Additionally, the data generated by the military rTWR system can significantly contribute to mission planning and execution, elevating operational efficiency and effectiveness, thereby harnessing the potential of each component and amplifying the collective impact.

CONCLUDING REMARKS

It can be reasonably asserted that the disruptive nature of location-independent aerodrome control will result in a paradigm change in, both civil and military, aviation domains. This becomes an ever more intriguing statement when Imre Porkoláb's thoughts – that nowadays military research and development (R&D) is based on the basic research of the civilian scientific world[21] – are added to the formula. Interpreting it, as it was highlighted throughout this paper, the partial or full application of rTWR technology in military environments, both foreign and domestic, promises substantial advantages by enhancing the quality and the resiliency of the air traffic services. The conceptualized deployable rTWR solution following the *more is a must principle* stands out as the most beneficial direction

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[18] Barabási 2014.

[19] NNEC is the Alliance's ability to federate various capabilities at all levels, military (strategic to tactical) and civilian, through an information infrastructure.

[20] IAMD is an ability to protect Alliance territory, populations, and forces against air and missile threats and attacks.

[21] Porkoláb et al. 2021, 11–22.

for the military context. This statement characterizes the conventional air traffic systems, necessitating a reasonable degree of compliance with civil regulations while relying on non-redundant, easily targetable control towers. In contrast, rTWR solutions offer functionally redundant, separated, and more defensible targets, bolstering the survivability of the service and ultimately, the personnel. These attributes can be achieved in an rTWR system tailored for military purposes by following the *4W principle*. This entails that, as the hardware element integrates active and passive surveillance systems, the software elements propelled by artificial intelligence and big data analytics are pivotal in achieving comprehensive situational awareness, target detection, and risk assessment, ultimately enhancing military air traffic management in dynamic operational environments. Furthermore, the manware element emphasizes the importance of human involvement revolving around the issue of situational awareness, with particular attention to the conundrum of defining the optimal FPS rate. The last element discussed is netware that brings attention to the significance of tridirectional rTWR networks supporting mainly, but not exclusively IAMD needs. In summary, the development and the deployment of rTWR in military contexts have the potential, given proper nurturing, to change the landscape of the military aviation domain. Particularly, the deployable rTWR solution standing on the pillars of the *4W principle* can deliver tactical superiority and strategic advantage, while elevating the effectiveness, alongside the security and the safety of military air operations. The synergy created through the overarching technological integration fosters a highly adaptive and formidable military force, equipped to safeguard national interests and address contemporary security challenges effectively. This ultimately culminates in a more robust, resilient, and adaptable military ecosystem beyond air force needs, capable of countering evolving threats and dynamic challenges.

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