DETECTION OF UAS CONFLICTS IN AIR TRAFFIC OVER GERMANY

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Abstract

DFS is developing a cloud-based traffic management system for the safe integration of Unmanned Aircraft Systems (UAS) into the German airspace. The system continuously processes the air traffic situation based on several kinds of sensor systems. One of its core functions is real-time detection and alerting of tactical conflicts involving UAS. To this end, DFS and DLR are evaluating the integration of the DLR development “NDMap” into the system.

1. INTRODUCTION

U-space is a European concept for safely integrating Unmanned Aircraft Systems (UAS) into the airspace. The U-space regulations of the European Commission of 2021 [1] specify that U-spaces shall be supported by the interaction of a group of actors with their respective collaborating systems. One such actor is the U-space Service Provider (USSP), who provides a set of defined services to the UAS operators flying the drones.

For this purpose, the USSP interacts with a common information service (CIS), which may be designed either as a nationwide single CIS provider (SCISP) or as a decentral arrangement (federated CISPs). The CIS provides static and temporary geodata, U-space information, and regulative information, and it forwards Air Traffic Management (ATM) aircraft track data to the U-space participants [2]. The USSP also interacts with other neighbouring – and perhaps competing – USSPs, and possibly with its own local sensors and other service providers.

The technical foundation for the USSP services is a UAS Traffic Management (UTM) System. According to the European regulations [1], UTM systems shall provide

- a network identification service (NIS) for UAS tracks,
- a traffic information service (TIS) for a combined situation display of manned and unmanned aircraft,
- a flight authorisation service (FAS) for UAS missions requested by the operators,
- a geographical awareness service (GAS) with geoinformation for the UAS operators and alerting in case of geographical conflicts,
- an optional weather information service (WIS) with weather data specifically relevant for UAS operations, and finally
- a conformance monitoring service (CMS) – in Germany planned to be obligatory [3] – to alert UAS deviations from a mission plan to the drone operators.

Distributed among TIS, GAS and CMS is a real-time detection and alerting functionality for tactical short-term conflicts. This includes conflicts between a UAS and another manned or unmanned aircraft (short term conflict alert), conflicts between a UAS and a temporary no-fly-zone (area intrusion alert), and conflicts between a UAS and a U-space volume for which the UAS is not authorised (unauthorised operation alert). CMS furthermore includes alerts about situations that are not conflicts, in particular deviations from the authorised operation path and its buffers.

2. DFS UTM SYSTEM

DFS Deutsche Flugsicherung GmbH (DFS) is developing a cloud-based UTM system named “ZEUS” for future U-spaces. ZEUS is provided to the UTM market by Droniq GmbH – a joint venture of DFS and Deutsche Telekom AG – as a software service for UAS operators. The system runs on a private cloud environment including an internal segment for testing (new components, new sensors, new workflows) and an external segment for public operation. It is planned to expand this to a 3-stage cloud system with a segment solely for development, one for testing and experimental projects, and one for public use. The system consists of a set of redundant, managed backend processes, as well as a set of clients. The backend processes

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perform user management, database management, resource processing, geodata preparation, flight data processing, tracking and multi-sensor data fusion, linkage processing, and conflict detection and alerting. Additional services include Notice to Airmen (NOTAM) reception, filtering and distribution, as well as UAS-relevant weather data processing.

The system continuously processes the air traffic situation over Germany, based on several kinds of sensor systems and sources, both from ATM and from additional sources for the uncontrolled airspace (ADS-B, FLARM, MLAT, FANET, HOD/LTE, VPN Telemetry etc.). At the peak of a typical day, around 1500 aircraft are visible in parallel over Germany, including today's only occasional cooperative UAS. It is expected that the visible traffic will grow significantly during the next decade, due to a growing number of UAS operations and also due to an increase in the visibility of manned aircraft in uncontrolled airspace, which are highly relevant for UTM as potential conflicting traffic. An example traffic situation today is shown in Figure 1.

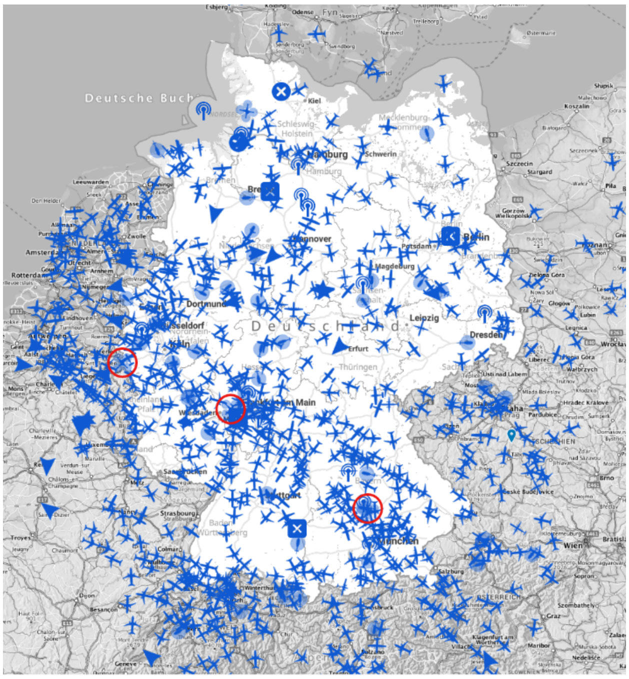

Figure 1: Air traffic over Germany displayed in the UTM system; three cooperative UAS are highlighted with red circles

Four types of clients exist within the UTM system, all clients being remotely attached to the backend via web technology through the internet to gain full location independence:

1) The operator client offers management of drones, transponders, and other assets; the definition and management of UAS operations, including uploading of flight plans, validation, and the submission for permit; a comprehensive situation display of manned and unmanned aircraft around the own location; various maps, NOTAMs, weather and other status information; and conflict warnings and alerts. For executed drone operations, a logbook is available for post-processing.

2) The USSP client serves as operational support system for the USSP. It includes a situation display; a list display of current ongoing, planned, requested, or denied operations including their detailed status and route layout; and an editor for temporary no-fly zones (NFZs) that may affect the operations in the assigned U-space. An example view of the situation display is shown in Figure 2, and the NFZ editor is shown in Figure 3.

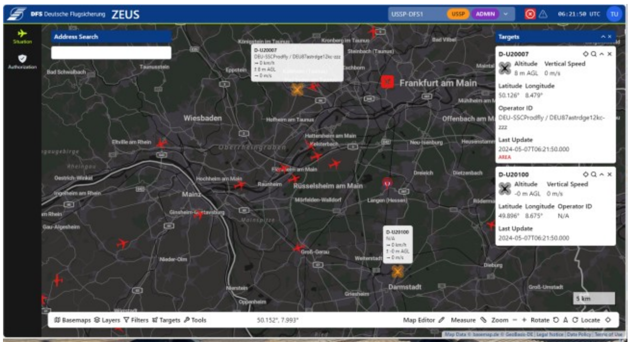

Figure 2: A closer view of the area around Frankfurt in the USSP client, with two UAS (orange) and a number of manned aircraft (red)

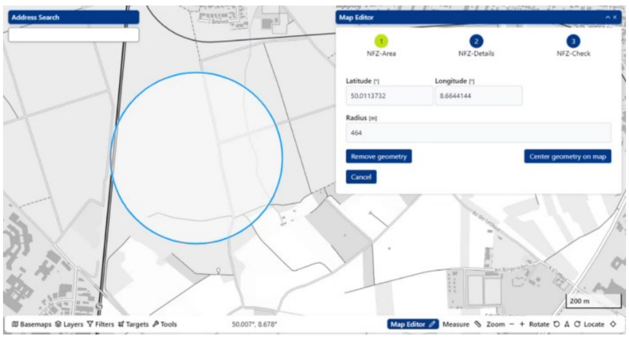

Figure 3: Editing a temporary no-fly-zone in the USSP client

3) A mobile client is also available, comprising most of the functions of the operator client. It is intended to support remote pilots in the field, which might be equipped with a smartphone or a tablet computer.

4) The fourth client type is designed for system administration purposes. Users and organisations may be created, U-spaces and areas of interest may be created or changed, and also a full situation display is available. A full map example is shown in Figure 4.

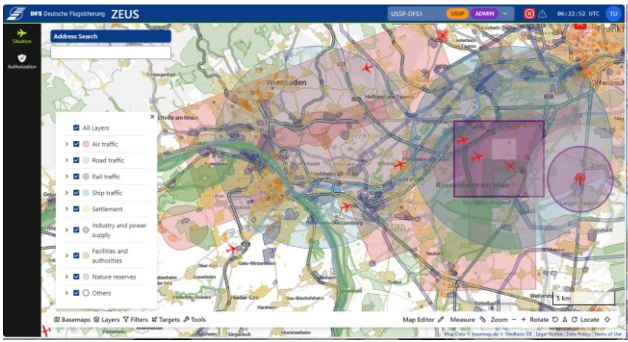

Figure 4: The administrative client showing the Frankfurt region with all the geo-zones available from the DIPUL system [4], as well as NOTAM circles and a number of additional temporary zones

For the map data, the system accesses the geo database of the German Digital Platform for Unmanned Aviation (DIPUL) [4], which is developed and operated by DFS on behalf of the German Federal Ministry for Digital and Transport.

The definition of UTM functionality is still ongoing work, also in international projects and organisations. A comprehensive collection of requirements is being elaborated at the International Organization for Standardization (ISO) in the project ISO/AWI TR 23310 [5]. DFS therefore expects future extensions and changes of the functional scope of UTM and is prepared to undertake related development work.

This paper focuses on the real-time detection and alerting of tactical short-term conflicts, as a backend functionality within the UTM system. To this end, DFS and the German Aerospace Center (DLR) are evaluating the integration of the DLR development “NDMap” into the UTM System.

3. NDMAP

The N-Dimensional Map (NDMap) [6] is an efficient algorithm for the detection (and resolution) of conflicts in large traffic scenarios. It detects conflicts between aircraft as well as violations of restricted areas. The basic idea is an N-dimensional bisection (a symmetric subdivision in all N dimensions) of the airspace in order to significantly reduce complexity.

In previous work, different setups have been investigated concerning the dimensions:

- A 2D-configuration (longitude and latitude) has been applied for geographic search in a navigation database.
- A 3D-configuration (longitude, latitude and bearing) was used for a runway-search algorithm.
- For airspace 4D is typical, covering longitude, latitude, altitude and time.
- Trials with a fifth dimension covering both the equipage of aircraft and equipage requirements for designated airspaces have also been conducted and turned out to be very useful [7].

For the 4D-setup, all relevant objects (flights with 4D trajectories, restricted airspace volumes) are added to the 4-dimensional tree. Initially, the tree holds only the root node with no objects inserted. The root node covers the relevant airspace, usually the complete Earth, and a complete day:

- longitude within [-180°, 180°),
- latitude within [-90°, 90°],
- altitude within [-1500 ft, 100 000 ft] and
- time within [0 s, 86 400 s), i.e., one day

The root node is the only node accessed from the outside. Building the tree is performed by adding objects, and conflict detection is performed while adding. An object is always added to the root node. If the root node covers the whole Earth, this object usually lies within the root node (unless it operates outside the defined altitude or time range). While adding, a node is subdivided in all (4) dimensions, if

- the node contains more than one object, because two or more objects could be in conflict, and
- the minimum node size is not reached yet. The minimum node size should be selected as small as possible but must at

least be as big as the required separation size.

The corresponding maximum depth of the tree is rather low as presented in Table 1. For manned aviation with a typical separation requirement of 5 NM laterally and 1000 ft vertically [8], the required separation is reached after 12 subdivisions for the longitude – all other required separations are reached even earlier. Upon reaching a leaf node with more than one object, a narrow phase algorithm is necessary to decide if the corresponding objects are finally in conflict or not. The high speed of the algorithm originates from the fact that a leaf node is rarely reached.

Dimension: Name	**Range**	**Required Separation**	**Range/ Sep. ($\log_2$)**
X: Longitude	[-180,180)	5 NM = 5/60 deg	4320 (12.1)
Y: Latitude	[-90,90]	5 NM = 5/60 deg	2160 (11.1)
Z: Altitude	[-1.5k,100k]	1000 ft	101.5 (6.7)
T: Time	[0,86400]	90 s	1016 (9.9)

Table 1: Maximum tree depth (manned aviation)

The above describes the basic idea of the algorithm. Additional constraints have been implemented to get it stable and efficient:

- Conflicts between neighbouring nodes
- Spherical geometry of Earth, singularities at poles, discontinuity at date-line
- Different metrics for distance calculation (cartesian, great-circle, WGS84, …)
- Several optimisations (bounding-boxes, taking advantage of monotony, …)

Details are described in [6]. Figure 5 shows the performance of the NDMap for an ambitious traffic forecast for 2050 with more than 308 000 flights on a single day [9]. Originating from independently generated trajectories put into one global scenario, the algorithm found almost 1.5 million conflicts. On average, the algorithm needed 2.1 ms to detect all conflicts of one trajectory while occupying rather large but still manageable 53 GB of memory (172 KB per trajectory). Thus, the algorithm implements a typical time-memory trade-off. All separation violations were identified in less than 11 minutes on a single processor core. Both memory usage and conflict detection time show a linear dependence from the number of trajectories, although the general complexity of comparing N trajectories with all others is $O(N^2)$. The break-in around 280k flights is caused by the sorting of flights. The scenario begins with departures on June 24th, 2050, the arrivals from flights departed on June 23rd, 2050, are added at the end.

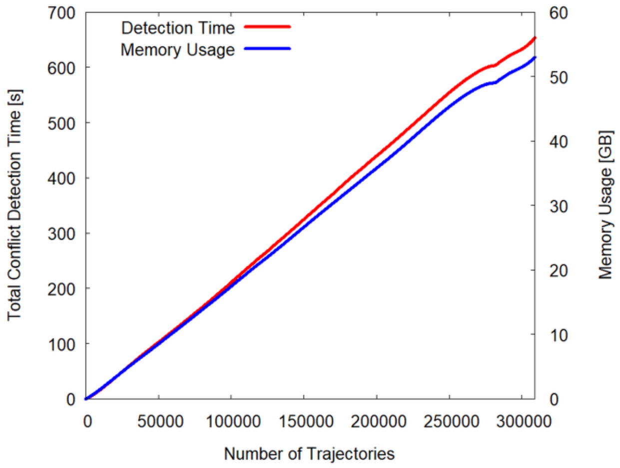

Figure 5: Linear conflict detection performance

Since the algorithm proved to be memory bound, the results are all calculated on a single core without parallelisation. Parallelisation on multiple cores is beneficial only if these cores have a separated memory bus. Distributing the NDMap on separate computers, all being responsible for their own part of airspace, would further improve overall performance. The NDMap can be used for different time-horizons, reaching from short-term covering only e.g. trajectories with a duration of 20 seconds, via medium-term covering typically 15-20 minutes to complete strategic conflict detection for whole day(s). This paper models a very short-term approach with only one actual position per object.

The NDMap supports different dynamic object types with different conflict metrics. That way, manned aircraft can be defined to have larger separation requirements than a UAS.

A technique to further improve performance of the NDMap is limiting conflict detection to objects of interest. In this paper, only conflicts involving at least one UAS are of interest. This means that conflict detection is limited to conflicts between two UAS, or one UAS with either a manned flight or a restricted airspace volume. Especially for today’s traffic mixture with many manned flights and few drones, this results in a big speed-up.

4. CONFLICT DETECTION IN THE UTM SYSTEM

The U-space concept [3] foresees that minimum separation distances between UAS and between UAS and manned aircraft are to be determined in a local risk assessment when establishing a U-space, and that the USSP will be responsible for monitoring these distances and for notifying UAS operators about violations. Such violations are what we call “conflicts” in the context of the UTM system. We also use the term “conflict” to refer to infringements of UAS into 4D volumes that they are not allowed to enter.

In the absence of concrete U-spaces, the separation values we currently use for our experiments are 5 NM horizontally and 1000 ft vertically, as is common in ATM. The values ultimately chosen in real U-spaces may well turn out to be lower, especially between UAS. From a performance evaluation point of view, this is expected to make conflict detection easier, because there will be fewer conflicts to detect.

Detecting and avoiding conflicts can be achieved strategically to some extent, i.e., already when planning a UAS operation. In particular, conflicts with permanently restricted geo-zones are best resolved already during operation planning because of the static nature of these zones. However, pre-planning and anticipating the 4D extent of dynamic trajectories and volumes have their limits; an element of uncertainty and unpredictability always remains. The UTM system offers features for strategic conflict resolution, but they are not in scope for this paper. Here, we focus on the detection of tactical conflicts as they occur in the live traffic situation, in a (soft) real-time way.

The tactical alerting component of the UTM system receives tracks and relevant geo-zones (temporary no-fly-zones and U-spaces) from other components and feeds them into an NDMap instance. The instance is configured with N = 4, i.e., as a four-dimensional map. This is intended as a foundation for working with 4D trajectories in the future, even though in the current state of development, the fourth dimension is not yet utilised: Whenever a track update arrives, it is inserted at the corresponding 3D position at time 0. Similarly, when a relevant geo-zone is created or updated, it is inserted as a polygon with lower and upper altitude bounds, at time 0. UAS tracks are defined as objects of interest in the NDMap instance, so that the algorithm only has to look for conflicts involving at least one UAS.

The altitude dimension in the NDMap instance uses altitude values above mean sea level (MSL). A challenge here is that geo-zones may also be specified with boundary altitudes above ground level (AGL). The vertical profile of these geo-zones follows the terrain, as depicted in Figure 6. A geo-zone with such a curved vertical profile cannot be directly expressed in the NDMap as a single volume. It may be approximated by using minimum and maximum MSL altitudes derived from terrain data, either for the whole geo-zone or by segmenting the geo-zone into discrete chunks e.g. using a base area of 1 m x 1 m. However, for simplicity, in the current state of development the alerting component just approximates AGL-based altitude boundaries as infinite altitudes in the NDMap instance and filters out any resulting spurious conflicts in a post-processing step that compares the AGL altitude of the track with the AGL boundary altitudes of the geo-zone.

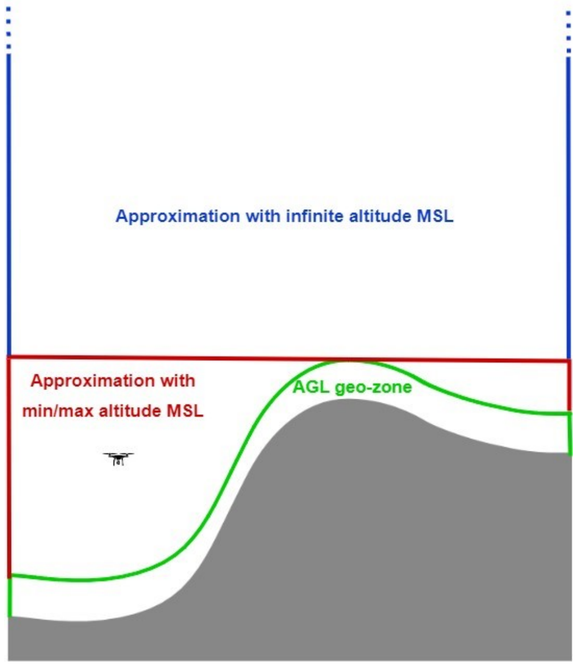

Figure 6: An AGL-based geo-zone (green) approximated in NDMap using minimum / maximum MSL values (red) or infinity (blue)

Further postprocessing steps are performed for each conflict reported by NDMap. Conflicts with U-spaces are filtered such that an alert is created only if the UAS lacks proper authorisation for the U-space. Also, an alert severity is assigned that depends e.g. on the distance between two tracks, where closer proximity is classified as an alert with higher severity. The resulting alerts are sent to the display of the UTM system, where they are intended to capture the attention of the UAS operator and/or USSP personnel.

Figure 7 and Figure 8 show some example alerts warning about conflicts between aircraft, and Figure 9 and Figure 10 show alerts about conflicts between UAS and geo-zones. Additionally, a non-conflict related alert belonging to the Conformance Monitoring Service is shown in Figure 11.

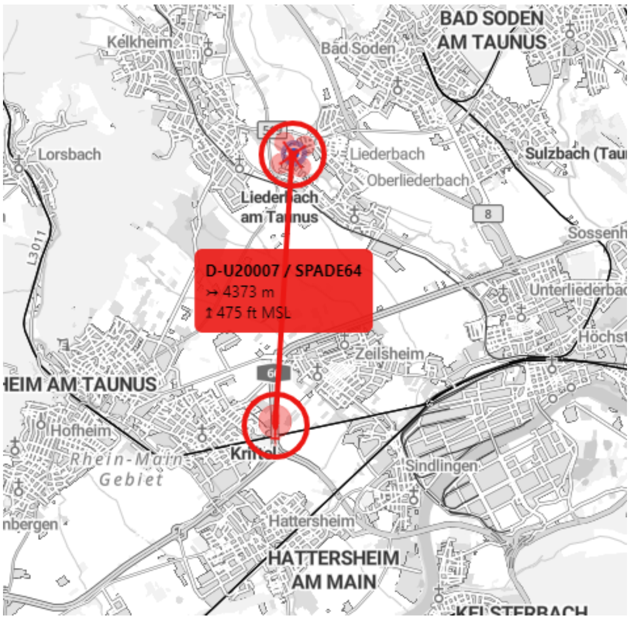

Figure 7: Short term conflict alert, warning about a conflict between a UAS and a helicopter

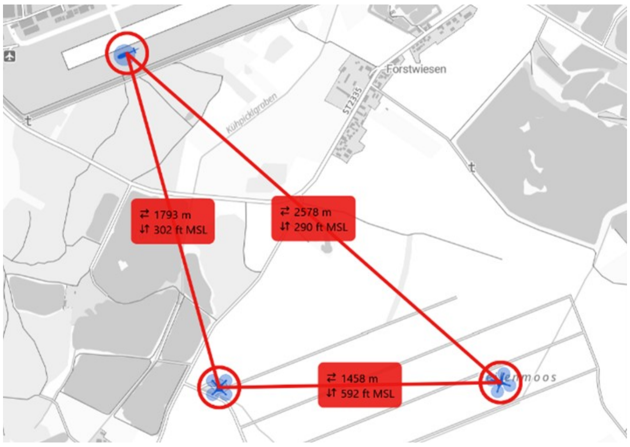

Figure 8: Three short term conflict alerts, involving two UAS and a helicopter

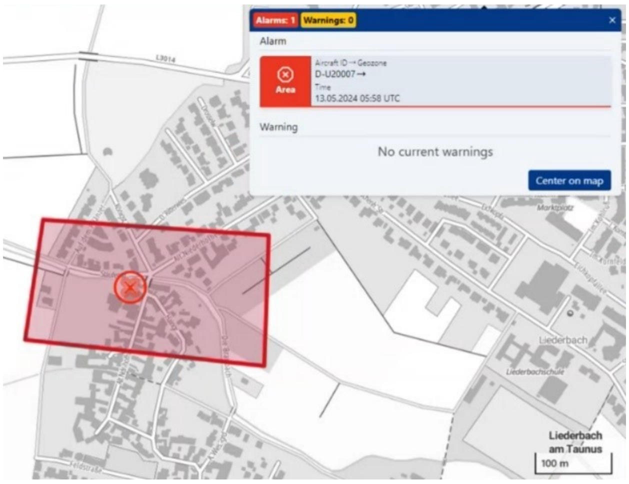

Figure 9: Area intrusion alert, warning about a conflict between a UAS and a temporary no-fly-zone (red polygon)

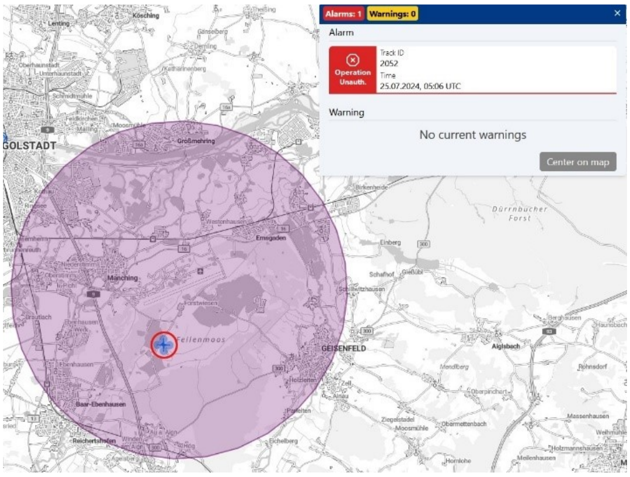

Figure 10: Unauthorised operation alert, warning about a conflict between a UAS and a U-space (violet circle) for which the UAS does not have authorisation from the USSP

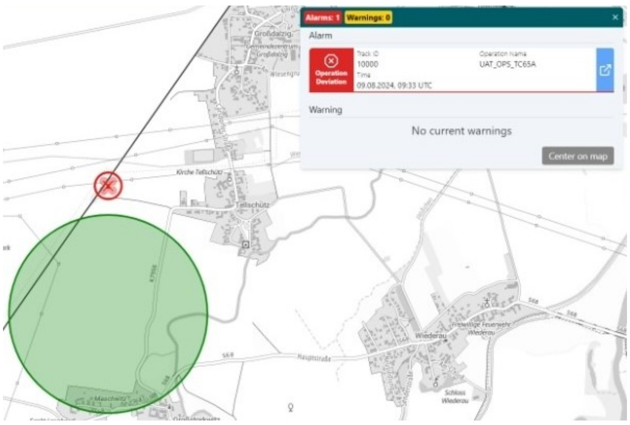

Figure 11: Operation deviation alert, warning about a non-conformance: the UAS has left its planned operation volume (green circle)

5. PERFORMANCE EVALUATION

Today's air traffic over Germany at a typical moment includes a substantial number of manned aircraft but only a handful of cooperative UAS that are visible to the UTM system. The UTM system also usually holds a few temporary no-fly-zones and U-spaces that get created for testing purposes. In this environment, the implemented conflict detection mechanism performs well: the core conflict detection latency induced mainly by NDMap is in the order of 0.2 ms, and the overall latency for processing a track update in the alerting component is in the order of 1.5 ms.

Beyond this, the challenge is to scale with an anticipated future growth in the volume of UAS traffic. To evaluate the scaling behaviour, load testing experiments with simulated traffic have been performed. The general pattern of this simulated traffic is shown in Figure 12.

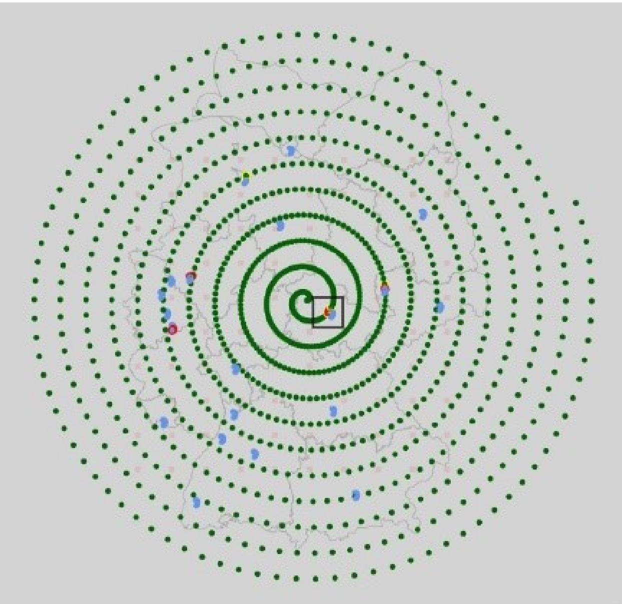

Figure 12: Load test with 1000 tracks representing manned aircraft (green), 500 UAS tracks (blue), and 100 temporary no-fly-zones (light red, in the background)

A large number of tracks representing manned aircraft were simulated circling around the centre of Germany with different radii and altitudes, intended to represent manned aviation. UAS tracks were simulated in smaller circles at specific areas which can be thought of as representing U-spaces. All tracks were updated once per second, at different moments throughout each second. Some of the circles moved clockwise and some counterclockwise. Several no-fly-zones were also simulated. Altogether, this created an artificial but dynamic traffic situation, where conflicts were continuously created, updated, and resolved in real time. An enlarged excerpt of Figure 12 with some of these conflicts is shown in Figure 13.

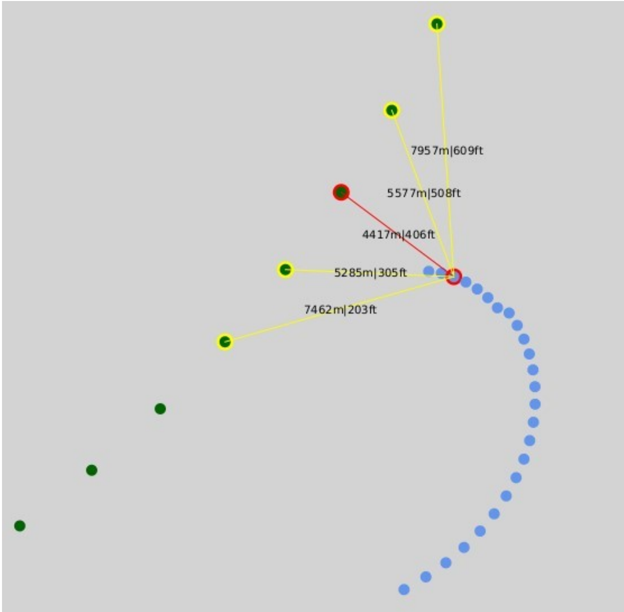

Figure 13: Zoomed-in view of the black rectangle in Figure 12, showing conflicts (yellow and red) between one UAS and five other aircraft

Using this general setup, measurements were taken to get an impression of the traffic volume that the current solution supports. The experiments were conducted on standard hardware (using an i7-4790 processor at 3.6 GHz). Memory consumption remained well below 1 GiB. The results are summarised in Table 2.

UAS	Other aircraft	Geo-zones	Conflict latency	CPU	Track processing latency
500	1000	100	0.4 ms	63%	3.5 ms
1000	1000	100	0.3 ms	68%	2.7 ms
1500	1000	100	0.3 ms	75%	2.5 ms
2000	1000	100	0.3 ms	95%	3.5 ms
2500	1000	100	0.3 ms	100%	1989.0 ms

Table 2: Performance measurements

In each new row in the table, the number of simulated UAS increases by 500, while the number of other aircraft stays at 1000 and the number of geo-zones at 100. The measured "conflict latency" is dominated by NDMap, which runs on a single thread whose Central Processing Unit (CPU) utilisation is reported in the next column. The measured "track processing latency" approximates the total latency between receiving a track update and emitting an alert, which includes conflict detection and other steps.

In the last row, the alerting component got into an overload state, where more track updates were coming in every second than could be processed. Consequently, the track processing latency drastically increased, and the alerting component was forced to drop some track updates without processing them.

It can be observed from the table that in the experiments, the conflict latency itself did not increase measurably when increasing the number of UAS. This supports the thesis that the NDMap algorithm very efficiently avoids what would otherwise be a quadratic runtime complexity in the number of tracks.

It can also be observed from the table that the conflict latency is only a small part of the overall track processing latency. Conflict detection is nevertheless the bottleneck that determines how many tracks can be handled before getting into an overload. This is because the conflict detection runs on a single thread, whereas the track processing latency is produced by an interplay between several threads. An insight into what is happening can also be gained by multiplying the number of tracks with the conflict latency: For example, in the second-to-last row, 3000 tracks were updated every second, each occupying the core thread for 0.3 ms of conflict detection time. Multiplying these values yields 3000 * 0.3 ms = 900 ms of CPU time per second in this thread. This would mean 90% CPU load for the conflict detection alone, which is congruent with the measurement of 95% overall CPU load for this thread.

6. CONCLUSIONS

The experience from integrating the NDMap in the UTM system shows that it is possible to efficiently detect conflicts with UAS involvement in the air traffic over Germany in this way. Performance-wise, the current traffic with limited UAS activity can be handled with ease, and there is room for a future growth of UAS traffic or an increased visibility of uncontrolled manned aircraft. When necessary, the approach can be made to scale further by horizontally distributing the load over parallel NDMap instances on several machines. This could be achieved by introducing a grid segmentation of German airspace where each sector is served by a separate NDMap instance and/or – perhaps most obviously – by introducing dedicated NDMap instances for individual U-spaces.

Potential future work includes predictive alerts based on short-term predictions of 4D trajectories, and conflict resolution proposals for UAS operators. Short-term predictions may allow a reduction of NDMap-access operations because an update is only necessary if the short-term prediction either is too old and holds only a short future path, or the UAS does not comply with the prediction. We expect that for such extensions the NDMap will again prove to be a very useful foundation.

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