UTM City—Visualization of Unmanned Aerial Vehicles

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Abstract—In this article, we present a digital platform for Unmanned Traffic Management, UTM City, for research on visualization, simulation, and management of autonomous urban vehicle traffic. Such vehicles orient themselves automatically and provide services ranging from transport to remote presence and surveillance, and new regulations and standards for authorization and monitoring are currently being developed to accommodate for such services. Our system has been developed in close collaboration with domain experts that have contributed with scenarios and participated in numerous workshops to explore the use of visualization in airborne drone traffic monitoring, management, and development of the air space. We share here our experiences with this system and explore the needs for visualization in future scenarios to ensure safe, free, and efficient air spaces.

Today, there is a current race in both research and industry to develop unmanned vehicles for faster, cheaper, and more accessible inspection, search, surveillance, and delivery, just to name a few services currently being defined. This even includes the development of autonomous vehicles that move around and orient themselves automatically within a defined air space. To accommodate these developments, current air space structures and regulations are discussed intensively, and adjustments are made. This can result in new sub-spaces allowing for new types of air space infrastructures at a lower altitude than the currently abundant regulated traffic occupy. Some air space segments will even be shared between regular air traffic and unmanned vehicles.

Monitoring the behavior of even a single airborne drone requires real-time analysis of large and high-dimensional temporal data in real-time, such as battery level, route length, and priority. With increasing traffic, representing complex movement patterns to monitor and detect problematic situations is challenging.

Visualization is a proven technique for analysis of complex data [5] and has been used as an efficient tool for
analyses in many different domains. In this article we focus on how to use real-time visualization to understand, monitor, and control Unmanned Aerial Vehicles (UAVs) in urban air space and present our platform for research on simulation and visualization of Unmanned Traffic Management (UTM) in urban air space. The developed system, UTM City, is designed for quick prototyping and demonstrations using touch interactions and can be run both on a large touch table (Figure 1) and on touchscreen equipped laptop. To enable an understanding of future air traffic, UTM City simulates and visualizes scenarios that can be drawn interactively. Then, different stakeholders can generate a shared visual representation of the future to discuss. This can be used to understand the impact on the city, such as risks, as well as understanding new traffic management concepts, air space organization, or automated tools.

Figure 1: Photograph of UTM City displayed on a large touch table. Drones (small spheres) can be seen following a planned path (lines) around a geofence (orange).

The system has been developed over the past six years in close collaboration with domain experts at the Swedish air traffic control provider, LFV. Throughout the development process, air traffic control officers (ATCOs) and other air traffic stakeholders have contributed with their expert knowledge in numerous discussions and workshops, exploring the future needs of traffic regulation, monitoring, and management. In our work on traffic exploration with this platform, we have crossed paths with a vast range of challenges in real-time visualization for monitoring and controlling UAVs.

2 AIR SPACE HANDLING AND UAVS

Most of the general air space is today controlled by an infrastructure called ATM, Air Traffic Management. A problem today is that current restrictions to protect regular traffic block much of the air space needed for new UAV services. To accommodate for the future need for both current, planned, and even currently unconceived types of services, there is a need to change these restrictions and introduce explicit air space handling also for UAVs.

Such air space handling should be tailored for freedom with responsibility, for a high level of flexibility accommodating for the widest range of potential services, as well as for efficiency and for fairness between all operators. This freedom will, however, be within boundaries to keep third-party impact in control, such as safety, noise, and environmental impact.

2.1 Planning and Authorization

The authorization of any flight in an air space in demand is closely related to planning. The most basic approach is to reserve the air space exclusively for a single operator to fly in, for the duration of their flights in that region, meaning a 4D restriction for all other flights spanning both time and space. Space reservation can be as simple as a set of coordinates forming a polygonal region, an altitude limit, and a start and end in time. More elaborate shapes, even in three dimensions, can potentially be needed to pack these reserved spaces closer together, for example allowing different operators to fly in separate altitude layers or long narrow corridors, tubes, or grids.

ATM uses movement monitoring and manual control to ensure aircraft separation when they are operating in a shared air space. Over the large distances traveled at high altitude aircraft can be kept at least a couple of minutes apart leaving time for communication and correction, if needed. Air traffic at lower altitudes will travel at lower speeds, but over urban areas need to be more densely packed, leaving much less time for manual adjustments.

2.2 Conditions, Capabilities and Execution

As the demand for UAV services increases, future traffic will need to share air spaces and employ both strategic and tactical conflict solving—both planning in advance to avoid flying too close and reacting to situational changes to avoid
imminent conflict, even using on-board sensors. Guidelines and rules are being developed to regulate the necessary safety margins between two aircraft in flight and between an aircraft and buildings and other structures. If the task to avoid collision is delegated to the operators, to an automatic service provided to operators, or even to automation in the aircraft, then the role of air space managers can go from unit-based management to strategic monitoring and control.

With delegated authority to control their individual motion, risk of cross-service effects also emerge. For instance, a large fleet can limit the activity of smaller services and one service may fly into a no-fly-zone to avoid collision with another. Air space developers need to understand what these situations could be like, to proactively design solutions, and traffic management needs to understand what goes on, when the traffic is running.

3 REALIZATION IN A SIMULATED ENVIRONMENT
Since 2016, currently more than six years, we have worked in close collaboration with domain experts at LFV on a research platform for interactive drone traffic simulation, visualization, and management system, UTM City. Multiple projects have made use of and contributed to the system, concerning research on diverse topics such as man–machine interaction, visualization, traffic management, logistics and optimization. The system has throughout these projects been iteratively designed through a series of formative evaluations based on knowledge and theories concerning the future of drone traffic and used in experiments and workshops to gain further knowledge on both drone traffic and other topics. The simulated communications within the system have converged towards a stable infrastructure allowing for flexibility and dynamics, as well as freedom with responsibility.

3.1 Simulation, Visualization and Management
Care has been taken to isolate different actors internally in UTM City, to sufficiently simulate interfaces and communication between such actors, for example drone operators, air space authorities and even drones. In this system, simulated drone operators are given the authority to control their drones themselves, as long as they fly within an authorized plan, and they will report the drone position to the air space authority, see Figure 2. To fly one or more drones (possibly hundreds), the operator queries the air space authority for a plan, which is adjusted in spacetime to fit the current air space design before authorized and returned to the operator. After this the operator may launch the drone(s) and fly whichever way they want as long as they fly within the margins specified, which is also monitored by the air space authority.

Figure 2. The implemented infrastructure in UTM City.

Apart from the menus and buttons for turning on or off visualization features, common in any visualization interface, the user interface has two main parts, as illustrated in Figure 3: a simulation control interface for scenario design and an air traffic management interface for controlling air space parameters and no-fly-zones. While both these interfaces are used to demonstrate and experiment with air traffic scenarios and specific situations, the management interface has also been explicitly used to experiment with the future roles of ATCOs in drone traffic management ([7]).

Figure 3. Parameters can be interactively changed in real-time. From left to right: view (global), map layers (global), UTM (global) and the currently selected, simulated service (local).
With two service abstractions, that each represent a typical service pattern and generate random flights within that pattern, a scenario designer can visually define a wide range of plausible services. A **point-to-point** service abstraction represents services for which drones travel along a predefined set of positions, such as highway surveillance or hotel shuttles, while a **point-to-area** abstraction represents services where the start and endpoints are fixed but where the drones land at different random positions over a larger area, typically deliveries or transports from a hub to residential or industrial areas.

Since the system rules dictate that all lawful drone operators follow a plan negotiated with a central authority, this central authority may potentially adjust all plans to avoid or allow overlaps and delegate to the operators to avoid flying close to other airborne objects. The current implementation lets plans overlap and mandates conflict detection and avoidance, so that drones avoid each other at a predefined distance.

### 3.2 Scenario
To illustrate typical air traffic behavior, we describe a possible future scenario over the city of Norrköping, Sweden. The scenario designer can, in real-time, add, adjust, and remove services, and the simulation and visualization interface allow for the control of a wide range of parameters (Figure 3).

The scenario (Figure 4) begins when a ship arrives early in the morning to the harbour, and immediately starts to unload its cargo. Several drones are used to deliver packages to an industrial area (point-to-area). Shortly after, a power line inspection is carried out over a separate region (point-to-point). These two services would possibly have been evaluated and approved by an air space agency to assure that the services keep a safe distance, which is the case in this scenario.

### 4 VISUALIZATION, MONITORING & MANAGEMENT
Traditional air traffic control is performed at unit level by ATCOs, a structure that cannot be copied directly into an infrastructure for UAV traffic. A single person cannot be responsible for traffic anticipated in any fraction of the air space, and a fair amount of automation will be needed (see [6]). In our research on UAVs, we see great need for visual analysis and interaction to support monitoring and control of such automation.

#### 4.1 Different Levels of Abstraction
For display of data on processes, for human **planning**, **supervision** and **control**, information can be categorized and described on levels of abstraction. Rather than dividing systems into subsystems, abstraction describes different control aspects of the same processes and objects. For instance, traffic processes can be described regarding overarching and particular goals, such as efficiency or safety. At the lowest abstraction level, the same process can be described with respect to button presses, motor power and sensor output. Making relations between these abstraction layers (Figure 5) visible and comprehensible for a user is a challenge, discussed in more details below.

In a structured manner, these levels of abstraction, and the visualizations used in UTM City can be described in terms of Levels of Autonomy in Cognitive Control (LACC) from the Joint Control Framework [4], also shown in Figure 5. The operator (subject) attempts to control an external process (object), through an interface providing visualization and controls. The object in this case is a process or air space object, either one that is isolated, such as a single service, or several that are entangled, two or more services in conflict with each other. We can map and visually represent the relation between what the operator can see in the visualization (perceptible content, PC), what the operator seeks for a decision (D), and the action leverage point (AL). We will then also need to consider developments in time.

The **effect goals** are at or just below the top of the organization, at level 5, describing what the person or organization wants to achieve. The markers in UTM City that show what goes on are thus closely aligned with effect goals. The effect goals per se are not displayed in UTM CITY. However, they could be used to further filter or highlight information within a frame.

Goal achievement can be seen as a **value** (level 4) which can reveal the possibilities in a situation to the analyst. In UTM City, we have used various techniques to quantify goal achievement, such as heat maps to display the number of conflicts.
Moving down to the lower half of Figure 5, at level 3, the operator may be engaged in work with generic aspects that potentially can re-emerge in similar circumstances. For instance, traffic patterns, such as congested corners of geofences.

Moving down to level 2, the concern turns to implementation. It concerns, for instance, the constraints that emerge from objects used for particular ends, such as the descent rate of a flying object or its turn radius. In UTM City we see this as an emergent phenomenon, such as drones being pushed into geofences by detect-and-avoid algorithms that are not sufficiently adapted to the air space.

Finally, at level 1, the concern is physical actions or objects, their physical status and layout. Although this seems easy, such as representing routes as lines, drones as dots or glyphs, we have seen in UTM City that as traffic becomes congested the visualization also at this level becomes more cluttered and thereby harder to interpret. Even though map layers and visual features can be individually deactivated, filtering to reveal the important information is a challenge. To support control with interactive visualization, both content on each individual level and content regarding the relations between levels can be crucial.

These levels have been used in both design and evaluation. During our design work, we found that working at a low-level (monitoring individual aircraft) as in ATM, is not a promising approach for UTM due to the (relative) speed of the drones versus the short distances traveled, as well as the number of drones. Instead, to aim for concepts working at a higher level seemed more promising [6]. Further, the levels have been used to evaluate a baseline scenario for UTM [7].
4.2 Spatial and Temporal Aspects

Spatial aspects lend themselves naturally to visualization techniques within this domain of geographical visualization; an overview is available in a recent survey [2]. It is easy to see how such techniques lend themselves to the visualization of traced paths or authorized plans, traffic density, pre-defined no-fly-zones, and other reserved air space. In flight visualization, however, airplanes travel both fast and efficiently over large distances, while even relatively small vertical separation is key to safe handling, and frequent vertical motion can have a major impact on fuel or battery economy. There is a clear scale difference that poses an interesting challenge in flight visualization.

Our system reads 3D map models and building models, generated from orthophotos and digital elevation maps (DEMs) and stereogrammetry from drone photos, respectively, and provides perspective rendering and real-time 3D visualization of plans, vehicles, and other features, see Figure 6. Drop lines and colors, varying continuously with height, are used to emphasize the differences in altitudes. In this example, only two services are used, but our system supports as many different altitudes as required.

![Figure 6. The 3D map is essential when planning for a service with low-flying drones so that they do not collide with any tall buildings. In this example, one service operates at 30 meters (red lines), while the other has drones flying at 80 meters (yellow lines).](image)

Either with fully automated planning and authorization for real-time operations, or with the delegation of this task to other roles, we argue that a stakeholder in an air space control infrastructure will be made responsible for adjusting and fine-tuning air space parameters, to optimize the efficiency and safety for the current situation. With different types of traffic separation, in layers, tubes or grids, this can be a matter of distributing space between regions, or to adjust tolerances and margins, or how a restricted area should be evaded. Visualization of real-time, multidimensional data, such as produced by UAVs, is inherently difficult [1], and existing techniques for static multidimensional data fail to capture various aspects when used to visualize such data [3]. Because of the large delays in such slow processes as logistic flows, a certain level of prediction and forecasting is necessary, or such control will always be out of sync with reality, posing additional challenges to both data acquisition and visualization of future time segments. Furthermore, an operator needs to be able to analyze time segments of past and present, each bringing their own challenges.

![Figure 7. Our system can predict future conflicts between planned flights, here presented with red crosses. We are experimenting with different representations encoding the properties of the conflicts, such as risk or severity levels.](image)

One important aspect of future time segments is whether drones may approach closer than the specified safety margin for the air space. Our system implements different methods for this, and we experiment with visual representation to present these and their properties, such as risk levels, see Figure 7.

5 CONCLUSIONS

Our viewpoint is that the described simulation and visualization framework, UTM City, can aid different stakeholders to acquire knowledge and understanding about several aspects of how traffic can affect an air space.
Using different interactive visualization techniques, such as 3D maps, glyphs, path and drop lines, a user can build, test, modify, and analyze complex scenarios in real-time. This is achieved by interactively changing a multitude of different parameters using a comprehensive interface. During the development process, air traffic controllers have given invaluable expert knowledge in discussions and workshops to explore the future needs of UAV traffic. During this work, we have seen the need for visualization in both the regulation process and in operational use by future stakeholders, such as drone operators, city planners and governmental control officials.

We see many future challenges in air traffic monitoring, control and visualization, and a continuous need for drone traffic simulation to explore them. Some examples include the safe and efficient allocation, packing and visualization of operator reserved spaces, the prediction and monitoring of traffic within these spaces, and the handling of unplanned situations.

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REFERENCES


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