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U-space TWICS: A meta U-space service concept to aid developing communications between autonomous uncrewed systems

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Summary: U-space is a regulatory concept for an upcoming air space targeted towards unmanned aerial systems (UAS). It requires an automatic communication of operators with mandatory services in a centralized structure. However, communication directly between UAS also needs to be anticipated. A U-space could provide a basis to foster a cooperative, collective understanding of a shared ecosystem and thereby aid in risk avoidance. We propose the concept of a meta "To Whom It Concerns Service (TWICS)" in the context of U-space to advance safe operations of UAS with a decentralized information structure. To that extent, we define an open, modifiable information exchange service between participants. TWICS provides an experimental communication infrastructure for automated information exchange and a forum targeted to create, modify, and evaluate those exchanges. Lastly, we provide an example and further discuss our proposal, its advantages and potential pitfalls.

Keywords: automatic UAS-to-UAS communication, U-space, "To Whom It Concerns Service (TWICS)", ground risk avoidance, autonomous uncrewed systems

1. Introduction

U-space is an effort of the EU Commission to regulate and create a harmonized air space for unmanned aerial systems (UAS). Central to a U-space is an initial air space assessment that is influenced, for example, by the overflown area and expected types of operations. The assessment results in specific requirements for U-space participants. Derived from those requirements, the U-space regulations aim to facilitate an ecosystem based on the interaction of UAS and service providers. With a focus on high automation in those interactions, safe and efficient flights should be enabled. There are four mandatory services (flight authorization, network identification, geo-awareness, air traffic) stated that a UAS operator is obliged to use. Two additional services (weather, conformancy monitoring) can be made compulsory, if required. All services are currently planned and influenced in the context of historic manned aircraft systems. It is a centralized setting revolving around the service providers as information authorities. A UAS depends on the received information and its capabilities to observe its surrounding. Besides few exceptions, an active participation of the UAS is not anticipated. For increasingly autonomous systems, a developer depends on the set of constraints set by the service, such as the content of shared information and its technical implementation.

Based on the U-space concept, we believe that further extensions of the U-space ecosystem are possible that advance towards an informationally decentralized, open exchange of information. We view all participants as active contributors to such a harmonized ecosystem. In particular, autonomous UAS and also other autonomous systems evaluate their surroundings based on their capabilities and mission. Hereby, the gathered information could be useful beyond its original purposes for other UAS and participants. Participants could utilize information already known in the ecosystem to plan accordingly and avoid potential risks early on. For example, a UAS on a delivery mission between two locations has planned a flight route with a designated landing site and several emergency or contingency landing sites. An emergency landing site allows for a rather safe landing without damaging the UAS or others but is not specifically anticipated to land on. U-space services only provide information about other aircraft and authoritative no-fly zones or geozones at the moment. Whether emergency landing sites are actually available can only be assessed with a UAS's perception. They could be blocked by ground vehicles, people or environmental factors. However, in an emergency case, the own detection of a blocked site could be too late to deviate to another landing site. Furthermore, at the moment there is no easily accessible infrastructure to facilitate such an information exchange between participants known to us.

We present a communication concept for a meta U-space "To Whom It Concerns Service (TWICS)" to aid in the exchange of relevant information in a harmonized ecosystem. TWICS primarily offers a common infrastructure for information exchange based on participant-defined topics to which they can contribute to and receive information from. TWICS targets developers in the U-space ecosystem who aim to share relevant information. Participants define the topics in a joint forum based on a minimal service understanding of all exchanged information that builds on top of U-space regulations and understandings. The developers of autonomous uncrewed systems and U-space connected systems should then be able to identify relevant topics and implement them quickly. We expect two significant benefits from such an approach. For once, we aim to enable cooperative behavior and collective awareness of the U-space ecosystem. Second, we aim to provide a solid basis for developing additional services by lowering the entry barrier in technical and contractual aspects.

The remainder of this paper is structured as follows. We provide the necessary background and related concepts in Section 2. Section 3 defines and specifies our concept, whereas Section 4 aims to discuss it with a specific example. Finally, we conclude our efforts in Section 5.

2. Background and Related Work

U-space is defined in the EU regulation 2021/664 [1]. It aims to provide a regulatory foundation for the harmonized operation of multiple UAS in a safe, secure, and efficient manner. It designates a territorial area for safety, security, privacy or environmental factors.

The U-space is implemented with services provided by U-space service providers (USSPs), which must ensure the validity of their shared information with a common information service provider (CISP). In Figure 1, we show an example of communication in the context of a partial traffic information service, one of four mandatory services. We have two UAS flying in the U-space: an automated UAS and a conventional UAS connected via a ground control station (GCS). Both are connected via a mobile network to a USSP, although they do not necessarily have to use the same USSP. The UAS knows its position and shares it with its connected USSP. The USSP then propagates it further to other USSPs. Finally, each responsible USSP shares the position on their end as traffic information to connected UAS. For disclosure, the example in Figure 1 is our interpretation of the regulation that implements a likely interaction between the participants. Other implementations are possible. Furthermore, the traffic information service also provides crewed traffic information and is not exclusive to uncrewed aircraft. Besides the traffic information service, three other mandatory services are offered: flight authorization, network identification and geo-awareness. Every UAS operator and autonomous UAS is obliged to use them to be able to fly in the air space (Art 6 1.b [1]). The UAS flight authorization service is an essential service aimed at mitigating air risk. A UAS operator files and receives a flight authorization from the flight authorization service that ensures a conflict-free flight path with other planned authorizations. In contrast, the geo-awareness service should provide information about current air space restrictions, geozones, and temporal restrictions. The network identification service informs third parties about the U-space and its participants.

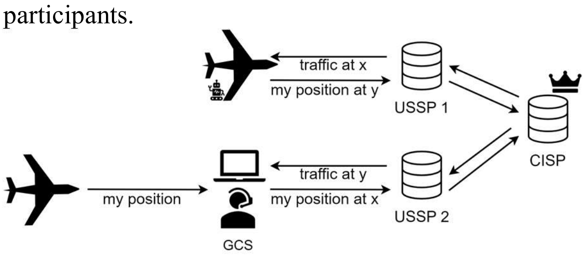

Fig. 1. Schematic U-space infrastructure at the example of traffic information.

UAS operators and USSPs have to adhere to requirements formed by the U-space air space assessment (Art 3 4. [1]). It is created by considering ground and air risk, the geographical overflown area, or expected types of operations. USSPs must shape the communication based on a common, secure, interoperable, open communication protocol. They have to ensure information currentness, quality, and protection, for example, by utilizing authentication, encryption, or implementing organizational policies. EU 2023/203 [2] defines further details on information handling. According to Art 6 1.c [1], UAS operators must use the mandatory services and ensure they comply with the service's performance requirements. Furthermore, they are expected to prepare and share contingency measures and procedures.

UAS operations are defined in EU 2019/947 [3]. Currently, most operations take place in the open category, with development going towards the specific category. UAS operators must ensure the safety of their operations, such as logistic transport. They must perform a risk assessment based on their configuration and planned operation. The Specific Operations Risk Assessment (SORA) provides the basis for the evaluation of risk in the specific category. Of particular interest is the assessment and mitigation of ground risk, e.g., when flying over people or operations near assemblies of people.

3. Service and Communication Concept

TWICS aims to create a foundation for an open information exchange between U-space participants. It is a meta service as it creates no new information but acts as an infrastructure and information broker. Figure 2 provides an overview of our concept. Topics reside in the communication server and build the semantic core. They are modified by developers through a forum and utilized by UAS and additional systems through a common application programming interface API. In the following paragraphs, we describe our necessary infrastructure, the parties involved, their roles, and our minimal service understanding.

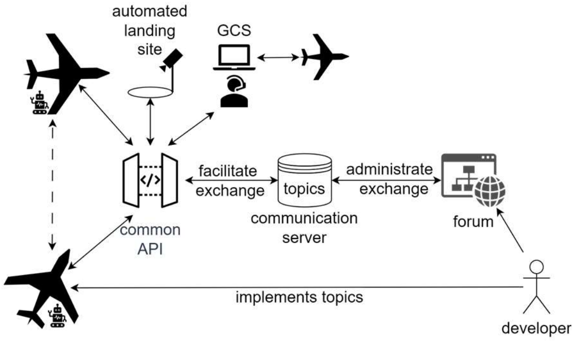

Fig. 2. Schematic overview of TWICS concept.

3.1. Infrastructure

The service infrastructure consists of a communication server accessible by two endpoints: an automatic API and a forum.

The API provides a common endpoint for U-space participants to exchange information on all available topics. It is used to send and receive data. We differ between the following modes of communication, which all have to be supported, as sharing information in the ecosystem may arise from different reasons. Participants may send data live, on-event, or on-request. Independent of the sending mode, participants may receive data on-subscription or on-request. Live updates are suitable for continuously collected data that might be relevant to others, such as the current mobile network quality of the data link. The information-generating participant initiates the communication. Furthermore, the connection to the communication server could be established once and kept alive during the flight to minimize technical data overhead. In contrast, on-event communication arises once a participant notices a difference from the current assumptions in the ecosystem or wants to reinforce known information. For example, an emergency landing site is known in the ecosystem and assumed to be available. Now, a participant has the ability to asses the status of the site and shares his assessment as currently blocked by farming equipment or confirmed available. In a manner similar to live updates, the information-gathering participant initiates the communication. However, a constant connection may not be advantageous. On-demand arises if another participant initiates a communication. Participant A knows of information participant B generates and has an interest in it. However, B does not continuously share the information as a live update. For example, a landing site may provide a video feed of itself that can be requested during landing. As a receiver of information, the agent may either subscribe to live updates on the topic or explicitly request information created in a specific time frame. These variants allow participants to balance their information needs, cooperation, and effort, such as data link usage.

The forum targets developers and UAS operators. It displays all available topics and their documentation. Furthermore, it allows them to create, modify, delete and discuss topics. It provides access and help to detailed information about the minimal service understanding and agreed standards.

Topics define the semantics and layout of exchanged information. We identified the following topic-specific details needed to facilitate a successful information exchange. They consist of semantics and further technical aspects. Semantics describe the expected content and its potential value to other participants. Typical to an internet forum, a header, a content description, and exchanged attributes are helpful. A header provides an overview that a description can specify. Attributes are needed to define the specific pieces of exchanged information. They cover the essence of the topic and its necessary context. For instance, to use the status of an emergency landing site, we must also know its geo-position. In technical aspects, the expected participation and reception communication mode and the data format per communication method have to be defined. Table 1 shows a specific example in the context of emergency landing sites that is further explained and discussed in Section 4.

3.2. Involved Parties

We define different roles of information providers that generate and share information, consumers that utilize information, and administrators that shape exchanged information. Involved parties are human participants and mechanical participants.

UAS and the service infrastructure are at the system's core. Furthermore, other agents, such as ground-based uncrewed vehicles or stationary sensor systems, such as automated landing sites, could be included as mechanical participants. All of them are expected to act as information providers. They should share relevant information they gather themselves on respective topics. Ideally, they share information on different abstraction levels ranging from raw data to aggregated information and leave the interpretation of relevance to information consumers. For example, an automated landing site might share its avilability status and simultaneously offers to share a live video feed. Hereby, the status is information on a higher level of abstraction as it is already processed and interpreted data. One could imagine that the landing can determine its status by aggregating various sensors, such as a camera with an object detection algorithm, laser bridges, or closed gate pressure sensors. However, the live video feed could also be useful for a consumer who might want to use it as a safety mechanism to ensure nothing is beneath. Moving participants are expected to act as information consumers. Depending on their level of autonomy, they might consume the information directly or indirectly. A participant with a high level of autonomy has the capability to make use of the information for its mission directly. On the other end, a participant with a lower level of autonomy consumes the information indirectly as a human operator influences him in the loop. The information could be displayed on a GCS and induce the operator to adapt the UASA's mission accordingly.

Human participants mainly serve the role of active participants as administrators through developers and operators who identify useful information for a given use case. However, there are scenarios imaginable in which humans also act as resourceful information providers. We suspect two possible groups: substitutes and bystanders. First, humans can serve as a substitute and specifically target an information need that currently cannot be produced automatically. Second, the general public is part of the U-space ecosystem and has safety needs that have to be considered and can emerge dynamically. For example, emergency sites or events with public gatherings are often zones that UAS need to avoid due to either their ground risk or data protection concerns. The possibility of communicating such information through bystanders would increase the safety of the whole ecosystem.

3.3. Minimal Service Understanding

TWICS is based on the U-space concept as it defines an ecosystem of UAS in a territorial demarcated area. Furthermore, U-space provides initial beneficial regulations and the air space assessments as described in Section 2. Derived from that basis, we formulate key aspects of a minimal service understanding that each participant has to fulfill to partake in the service. The service understanding is aimed at formulating minimal restrictions while equally ensuring the necessities for cooperation.

U-space regulations for USSPs [1, 2] already address key factors that are largely fundamental to the ecosystem and independent of the specific service or U-space implementation. The key factors apply likewise between established services, such as traffic information, and potentially useful shared information, such as local mobile network data link quality. In the following, we highlight needed key factors: data and privacy protection, security and data quality.

Data protection policies are needed as TWICS allows the distribution of information that can be deemed secret or private. Sufficient encryption of the communication channel and stored information is a fundamental technical aspect. An understanding of information relevance concerning data minimization is a key organizational policy aspect of TWICS. Although we want to foster an open exchange of information, not all information can be relevant. In some situations, data protection must be given priority. Especially if information can depict third parties that are not directly part of the ecosystem, such as an open camera feed depicting bystanders. Depending on the communication mode as described in Section 2, further specifications are possible. For example, live updates of a camera feed have a significantly higher impact on data protection than an on-event stream of a few seconds that is not permanently stored. The service should determine specifics based on the U-space assessment and provide them in an easy-access format in the forum.

Authorization and authentication are security measures needed for data and privacy protection. We argue that such a basic level of security is needed to exclude malicious actors and establish that information in the ecosystem is only created by participants of the ecosystem who adhere to a common service understanding.

Communication standards should also be further specified. All data formats should be based on a format that contains attributes with their expected values and data type. Furthermore, a timestamp created by the service of the time it reached the communication server should build a unified clock reference. Other timestamps are possible and useful for specific information. However, a unified timestamp of a central clock is required to avoid timing differences between systems or at least to be aware of them. A serverside filter based on attributes a participant can customize to their utility is another key aspect we identified as relevant.

A data quality and cooperation ethics policy is further needed. TWICS largely differs in the assurance of data quality from general USSP requirements. Due to its nature, it cannot provide a guarantee for the shared information. Participants themselves need to decide if they trust the information they have received from others. However, a basic level of quality is still achieved by a data quality policy that lays the foundations of cooperation. Prior mentioned communication standards, as well as authorization and authentication, also add to a basic level of data quality.

4. Discussion

The presented concept aims to enable cooperative behavior and collective awareness of future autonomous agents by providing a solid basis for developing additional communication services in a U-space ecosystem. We discuss the potential of this goal in the context of autonomy first and follow up with a general discussion based on an example.

4.1. Information Autonomy - A Conceptual View

The integration of an autonomous unmanned aircraft in airspace requires three broad aspects to be well understood and accounted for. Let us call these properties *information autonomy*, *decision autonomy* and *action autonomy*. Information autonomy refers to the degree to which the unmanned aircraft is independent of its operator to obtain information about its environment, including information on weather, traffic, obstacles, terrain, navigational aids and landing sites. Decision autonomy is the degree to which the unmanned aircraft is then able to decide the appropriate course of action, (e.g., change in flight plan, diversion to alternate landing site) in response to an event, e.g., a system failure, collision warning, weather front or blocked landing site. Finally, action autonomy is the degree to which the unmanned aircraft is allowed to execute the course of action it decided upon. For example, while the aircraft may have the capability to deliberate and decide what to do next, it may not be allowed to execute its plan without permission from its remote pilot. For an unmanned aircraft to be completely autonomous, it should be fully independent of its remote pilot in all three aspects. The level of decision autonomy, even when high, may still be brittle if the unmanned aircraft is programmed to react to different situations using robust procedures. The level of action autonomy depends on the integrity of the information and the decision-making processes as well as the onboard capabilities of the UAS to control its flight path, e.g., navigating along a flight path while avoiding traffic and obstacles, landing at different sites without intervention from a remote pilot. While the separation of the three aspects helps in the development of software modules and in the design of onboard capabilities to tackle different types of challenges, there is a high degree of correlation between the three properties. Without information autonomy, the UAS may not be able to react to external events in a timely manner by performing the correct decision-making and executing the appropriate remedial plan. Without decision autonomy, the UAS may possess information about traffic but is dependent on the remote pilot to command a traffic avoidance maneuver and a return to the nominal flight path after the maneuver. In a low fuel scenario, the UAS may possess information on where the landing site is and understand that it should land as soon as possible. However, without action autonomy, it may not be capable of navigating to that landing site while avoiding terrain. In this paper, we explored the first of the three aspects, namely information autonomy. In particular, we studied the possibility of using information gathered by other UAS that previously navigated the airspace through the establishment of an operator-agnostic information service, i.e., U-space TWICS. This may increase the level of collective intelligence in the U-space while reducing the dependence of an individual UAS to its remote pilot or operator.

4.2. Example Emergency Landing Sites

We discuss the following example and its implementation into our concept. Furthermore, we highlight assumptions of the concept with their potential pitfalls and evaluate advantages and disadvantages compared to alternative solutions.

We consider information about “Emergency Landing Sites” an example of information that is currently not actively dynamically used but could be useful in future scenarios. We assume an operational U-space in a rural, primarily wooded area with industry and commercial lots. It is established to develop and test concepts for automated delivery UAS. An operator wants to plan an optimal delivery route for their half-automated UAS between a pick-up and drop-off point. As a further optimization step, they want to make sure their UAS can land safely without damaging itself or others in case of an emergency or contingency. Their initial planning designates open fields, unpaved parking lots and glades as suitable sites. Based on the availability of a reachable landing site, they plan a route.

A possible solution to this problem would be to create a route that fulfils the goal with a high probability based on statistical data and supported by logical arguments. At each route point, a specific number of landing sites has to be available. One could argue open fields are often undisturbed, glades only seldom used by hikers and unpaved parking lots are empty if no major event is nearby. However, there is no possibility to know for sure until the UAS’s own sensors classify a landing site as unsuitable. In such a case the information is either not relevant for the UAS itself or it is too late. Suppose the UAS has to perform a contingency landing and chooses an open field randomly from previously defined options. In that case, there is a certain possibility that a farmer blocks it. As a consequence, the UAS would have to trigger a more serious behavior, potentially damaging itself to avoid hitting the farmer.

We want to exchange information and build collective awareness. Hereby, detecting a blocked landing site can be useful to other participants. Even shared information that a landing site is actually available increases safety. The information can then be used to plan a route with higher data quality as it is based on up-to-date information with a higher reliability. If there is a TWICS service established in the example U-space, a developer could first look into the forum and check if a topic of such content is already established. If it is, they will find all the needed information. Otherwise, they create the topic themselves. Table 1 provides a possible topic definition. All previously mentioned information is formalized in a possible format. Header and content describe the topic. Attributes define the availability as key information and the geo-position, an areal extent and a type as further context to interpret the suitability for a participant. The expected technical participation to the topic is “on-event” as they have to spot a landing site to create the information. Subscription allows other UAS to receive the information during their flight and tactically replan if necessary. Additionally, on-request provides a possibility to plan strategically based on the latest information without a requirement to be constantly subscribed. The data format is the same for all communication modes and it implements the attributes. Geo-position and areal extent are implemented as a circle with a center coordinated and a radius. Furthermore, it provides a basis for future extensions. For example, another user might operate a UAS that is suitable for landing on water. They can now use and contribute towards the topic by adding a “watersite” type while still assessing the already added types. In contrast to the previous solution, operators now know earlier if a site is blocked or they receive a confirmation that it is available.

A decentralized information organization has the advantage of a shared burden and effort to keep the data recent and available. However, it also depends heavily on a sufficient number of users willing to participate and adhere to the minimal service understanding.

The majority of concerns need to be addressed by surveying future use cases and their stakeholder in an implemented, experimental setting.

Table 1. Topic Example “Emergency Landing Site”.

Category	Descriptor	Value
Semantic	Header	Emergency Landing Site
Semantic	Content	Observations of possible landing sites and their availability that are not anticipated as primary landing spots but can be used in a case of emergency or contingency
Semantic	Attributes	Geo-position, areal extent, type, availability
Technical	Expected Participation	OnEvent (Information of a landing site collected)
Technical	Expected Reception	subscription, on request

Technical	Dataformat Participation / Reception	{
		CenterPosition: {
		Lat: float in degrees (WGS84)
		…Lon: float in degrees (WGS84)
		},
		ExtendRadius: float in meters
		type: enum of {field, parking lot, glade},
		availability: boolean {yes, no}
		}

5. Conclusion

We have presented a communication concept that aims to create a shared perception in the context of a defined U-space. Although development in this area is in an early stage, our concept could provide a useful basis for future extensions.

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