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(72) Inventors:
• **JØRGENSEN, Morten Skov**
1100 Copenhagen K (DK)
• **HOLSTEN, Fredrik**
1100 Copenhagen K (DK)
• **SKOU, Jesper**
1100 Copenhagen K (DK)
• **ØSTERGAARD, Ronni Winkler**
1100 Copenhagen K (DK)

(71) Applicant: **Skypuzzler ApS**
1100 Copenhagen K (DK)

(74) Representative: **Nordic Patent Service A/S**
Bredgade 30
1260 Copenhagen K (DK)

(54) **TACTICAL DECONFLICTION OF UNMANNED AERIAL VEHICLES**

(57) A method and system for tactical deconfliction of aerial vehicles based on detecting possible conflicts (5) between aerial vehicles and additional objects (4) in a deconfliction space (2); determining a minimum distance parameter (6) for interfering aerial vehicles in a possible conflict (5) based on the interfering types of aerial vehicles and data quality (10) of the obtained flight data (8) and the environmental data (9) describing the additional

objects (4); and calculating an alternative flight path (7) for interfering aerial vehicles based on the minimum distance parameter (6). The alternative flight path calculation can further take into account priority levels (23) assigned to the aerial vehicles, and can be optimized for a global variable (17) based on unit variables (18) derived from calculated flight path deviations of each individual aerial vehicle.

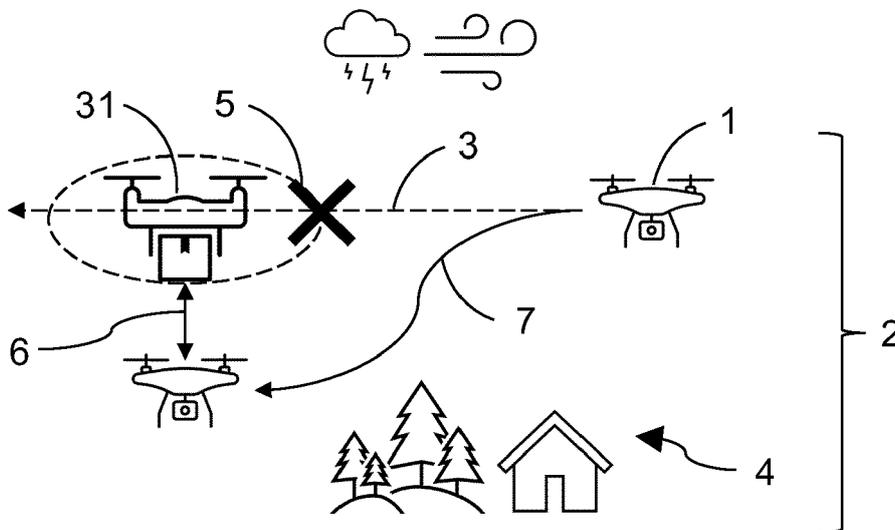


FIG. 1

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DescriptionTECHNICAL FIELD

[0001] The disclosure relates to tactical deconfliction of unmanned aerial vehicles (UAVs), and more particularly systems and methods for navigating a plurality of UAVs in a deconfliction space in a manner that reliably avoids collisions even in complex situations.

BACKGROUND

[0002] The number of unmanned aerial vehicles (UAVs) in airspaces is steeply increasing, which results in a growing need for measures to be implemented in order to avoid collisions and disruptions of the air traffic.

[0003] Existing solutions include support systems for the remote controller of an UAV situated on the ground or the provision of autonomous detect and avoid capabilities on board the UAVs, which work even if the link between the UAV and the remote controller is (temporarily) broken. Detect and avoid systems generally include cooperative detect and avoid (CDA) systems, based on actively emitted signals by the cooperative systems (e. g. transponder, FLARM, ADS-B out) situated on other aircraft, as well as non-cooperative detect and avoid (NCDA) systems, allowing for the detection of aircraft (and other airborne objects) that do not actively emit signals from cooperative systems.

[0004] EP 2 187 371 B1 (Saab AB) relates to collision avoidance systems and in particular to the determination of escape maneuvers in such systems. It is especially suitable for aerial vehicles with low maneuverability. A corresponding system receives navigational data regarding an intruding aerial vehicle and the own aircraft. A plurality of pre-simulated escape trajectories are stored, and at least a subset thereof is compared with a presumed trajectory of the intruding aerial vehicle in order to select one of the pre-simulated escape trajectories.

[0005] GB 2 450 987 B (EADS Deutschland GmbH) relates to a detect and avoid system using available on-board sensors (such as TCAS, radar, IR sensors and optical sensors) in order to make for itself an image of the surrounding airspace. The situation thus established is analyzed for imminent conflicts, i. e. collisions, TCAS violations or airspace violations. If a problem is detected, a hierarchical search for avoidance options is started, wherein the avoidance routes as far as possible comply with statutory air traffic regulations.

[0006] However, such existing solutions have serious limitations when it comes to navigating complex situations involving a plurality of UAVs flying Beyond Visual Line of Sight (BVLOS), and today's Air Traffic Management (ATM) systems can not manage this task without a dedicated air traffic control solution for UAVs, such as an Automated Tactical Deconfliction system that would be capable of continuous deconfliction of a large number of

UAVs in an airspace. This impedes growth of the UAV industry, and results in more and more flights being restricted to segregated areas or corridors only allowing one operator to fly at the time.

SUMMARY

[0007] According to a first aspect, there is provided a computer-implemented method for deconfliction of unmanned aerial vehicles, UAVs, the method comprising the steps of obtaining flight data of a plurality of UAVs in a deconfliction space, the flight data comprising at least UAV type and flight path of the plurality of UAVs within the deconfliction space; obtaining environmental data comprising information on additional objects within the deconfliction space; determining data quality of the obtained flight data and the environmental data; determining possible conflicts between the plurality of UAVs, other airspace users and additional objects or obstacles based on vertical and horizontal interference of the obtained flight paths; determining a minimum distance parameter for interfering UAVs in a possible conflict based on the interfering UAV types and the data quality of the obtained flight data and the environmental data; and calculating an alternative flight path for interfering UAVs based at least on the obtained flight path and the minimum distance parameter.

[0008] The methods and systems according to the first and second aspect disclosed herein enable automatic initiation of tactical deconfliction manoeuvres, to prevent mid-air collisions between UAVs and/or other airspace users, weather conditions, no-fly zones, obstacles, or objects, both with and without input from an operator. The methods and systems can provide tactical deconfliction for UAVs without extra cost to install additional hardware on the aerial vehicles as it is based on software-to-software communication between installed flight control software on the UAVs and the disclosed computer-implemented method either directly or through the respective Unmanned traffic Management (UTM) or UAV fleet management systems.

[0009] In a possible implementation form of the first aspect determining the minimum distance parameter is at least partially based on maneuvering ability of the UAVs in a possible conflict based on their individual UAV types, such as a fixed-wing UAV having a larger turning radius than multi-rotors, or that payload size and speed of the UAVs will affect turning and climb/descent ability.

[0010] In a possible implementation form of the first aspect the obtained flight data comprises current position data, and determining the minimum distance parameter is at least partially based on a positioning parameter related to the precision and veracity of the current position data of each UAV based on the positioning system such GPS, GNSS, Baidu, Galileo, RTK, 5G, ADS-B, included in each UAV.

[0011] In a possible implementation form of the first

aspect determining the minimum distance parameter is at least partially based on an environmental parameter related to the precision and veracity of the obtained environmental data based on the method of obtaining the environmental data, such as how updated, how granular, or how accurate the data is about environmental objects.

[0012] In a possible implementation form of the first aspect the obtained environmental data comprises weather data, such as wind formations or rain, and determining the minimum distance parameter is at least partially based on weather parameter related to the veracity of obtained weather data.

[0013] In an embodiment determining the minimum distance parameter is further based on a safety buffer parameter defining a minimum time interval between different UAVs and other aerial vehicles occupying the same space within the deconfliction space, with their respective safety zones.

[0014] In a possible implementation form of the first aspect calculating the alternative flight path for the plurality of UAVs is further based on a global variable, wherein a unit variable is defined for each UAV in a possible conflict based on a possible alternative flight path with respect to the obtained flight path, and wherein the method optimizes for a global variable that is a sum of all unit variables from UAVs in the deconfliction space.

[0015] In a possible implementation form of the first aspect the global variable is a distance variable, wherein each unit variable is calculated based on flight path deviation of an UAV in a possible conflict from its obtained flight path, and wherein the global variable is optimized so that the sum of deviations of all UAVs in the deconfliction space is kept at a minimum or maximum.

[0016] In a possible implementation form of the first aspect the global variable is a time-of-flight variable wherein each unit variable is calculated based on time-of-flight of an alternative flight path, and wherein the global variable is optimized so that the sum of time-of-flights of all UAVs in the deconfliction space is kept at a minimum or maximum.

[0017] In a possible implementation form of the first aspect the global variable is an energy consumption variable wherein each unit variable is calculated based on energy consumption of an UAV when taking an alternative flight path, and wherein the global variable is optimized so that the sum of energy consumption of all UAVs in the deconfliction space is kept at a minimum.

[0018] In an embodiment the energy consumption of an UAV is calculated based on a set of energy consumption parameters such as:

- UAV type, such as multi-rotor, fixed-wing, single-rotor, and hybrid vertical take-off and landing (VTOL), wherein different UAV types require different amount of energy for certain movements;
- payload, such as weight or typology affecting energy consumption;

- weather, such as headwind increasing energy consumption;
- temperature, such as extreme temperatures affecting lifespan of batteries.

[0019] In a possible implementation form of the first aspect the global variable is a price variable wherein each unit variable is calculated based on fees need to be paid by an UAV when taking an alternative flight path, and wherein the global variable is optimized so that the sum of fees to be paid by all UAVs in the deconfliction space is kept at a minimum or maximum.

[0020] In a possible implementation form of the first aspect the flight data comprises a priority level assigned to the plurality of UAVs within the deconfliction space, wherein calculating the alternative flight path for the plurality of UAVs takes into account these priority levels so that a priority UAV of the highest priority level, such as emergency UAVs, can keep to their current flight path or to an optimized flight path, and an alternative flight path is calculated for the remaining conflicting UAVs according to the global variable.

[0021] In an embodiment the obtained flight data comprises at least one of:

- UAV type defining type of the UAV such as multi-rotor, fixed-wing, single-rotor, and hybrid vertical take-off and landing (VTOL), and its battery status;
- planned flight path defining a pre-flight state of departure point, route waypoints and destination point;
- payload defining type of cargo and its weight;
- priority level defining a priority UAV such as medical, police, or UAV low on battery;
- current position based on UAV tracking;
- current flight path defining in-flight state with updates with respect to the planned flight path;
- altitude defining both actual altitude and planned altitude according to planned flight path;
- speed defining both actual speed and planned speed according to planned flight path.

[0022] In an embodiment the obtained environmental data comprises spatial information of the deconfliction space defining position and geometry of physical and/or virtual additional objects such as GEO zones, static and dynamic obstacles and objects, and topological levels.

[0023] In an embodiment the obtained environmental data further comprises tracking information regarding the actual position of all UAVs and other aircraft via on-board devices such as Remote ID, transponders, and on-ground sensors such as radars, RF and other technologies.

[0024] In a possible implementation form of the first aspect the obtained environmental data further comprises a ruleset defining local flight regulations and deconfliction rules, and wherein this ruleset is integrated in the method for at least one of:

- determining the minimum distance parameter,
- determining possible conflicts, or
- calculating the alternative flight path.

[0025] In a possible implementation form of the first aspect the flight data and environmental data is obtained from an Unmanned Traffic Management, UTM system, or an UAV fleet management system; wherein the UTM system comprises infrastructure and a set of procedures designed to manage and monitor the operations of a plurality of UAVs in the deconfliction space, and wherein the UAV fleet management system is configured to manage and monitor a select fleet of UAVs from the plurality of UAVs.

[0026] In an embodiment the calculated alternative flight path is provided to the UTM system or UAV fleet management system.

[0027] In an embodiment the UTM system is configured to ensure safe and efficient integration of UAVs into an existing deconfliction space, coordinate their movements and prevent collisions by enabling the control and tracking of UAVs, facilitating communication between multiple UAVs and other aerial vehicles such as manned aircraft via Air Traffic Management, ATM systems, and providing information to operators about airspace conditions, regulations, and restrictions.

[0028] In an embodiment the UAV fleet management system is primarily configured to handle the operational aspects of UAV fleets, such as planning, scheduling, monitoring, and controlling multiple UAVs to achieve specific objectives.

[0029] In an embodiment flight data and environmental data is further obtained from an Air Traffic Management, ATM system, wherein the obtained flight data further comprises type and flight path of a plurality of aircrafts within a horizontally and/or vertically enlarged deconfliction space managed by the ATM system, wherein the obtained environmental data comprises information on additional objects within the enlarged deconfliction space, and wherein determining possible conflicts further takes into account aircrafts within the enlarged deconfliction space.

[0030] In an embodiment flight data and environmental data is further obtained from a Space Traffic Management, STM system, wherein the obtained flight data comprises type and flight path of a plurality of spacecrafts within a horizontally and/or vertically enlarged deconfliction space managed by the STM system, wherein the obtained environmental data comprises information on additional objects within the enlarged deconfliction space, and wherein determining possible conflicts further takes into account spacecrafts within the enlarged deconfliction space.

[0031] In an embodiment the obtained flight data comprises type and flight path of a plurality of aerial vehicles within a deconfliction space, the aerial vehicles comprising at least one of plurality of UAVs managed by a UTM system, aircrafts managed by an ATM system, or space-

crafts managed by an STM system; and the method comprises determining possible conflicts between the plurality of aerial vehicles and additional objects based on vertical and horizontal interference of the obtained flight paths; determining a minimum distance parameter for interfering aerial vehicles in a possible conflict based on the types of interfering aerial vehicles and the data quality of the obtained flight data and the environmental data; and calculating an alternative flight path for interfering aerial vehicles based at least on the obtained flight path and the minimum distance parameter.

[0032] In an embodiment the method comprises determining flight path changes for any of the plurality of UAVs where a conflict has been determined, based on the obtained flight path and the calculated alternative flight path, the flight path changes comprising at least one of:

- waypoints (GPS, GNSS etc.),
- heading adjustments,
- altitude adjustments, or
- speed adjustments.

[0033] In a possible implementation form of the first aspect the method comprises determining a flight control signal for any of the plurality of UAVs where a conflict has been determined, based on the alternative flight path or flight path changes determined based on the obtained flight path and the calculated alternative flight path, the flight control signal comprising at least one of:

- waypoints (GPS, GNSS etc.),
- heading adjustments,
- altitude adjustments, or
- speed adjustments.

[0034] According to a second aspect, there is provided a computer-implemented deconfliction system for of unmanned aerial vehicles, UAVs, the system comprising an input unit configured for obtaining flight data and environmental data of a deconfliction space, the flight data comprising at least UAV type and flight path of a plurality of UAVs within the deconfliction space, and the environmental data comprising information on additional objects within the deconfliction space; a processor unit configured for determining data quality of the obtained flight data and the environmental data; determining possible conflicts between the plurality of UAVs and additional objects based on vertical and horizontal interference of the obtained flight paths; determining a minimum distance parameter for interfering UAVs in a possible conflict based on the interfering UAV types and the data quality of the obtained flight data and the environmental data; and calculating an alternative flight path for interfering UAVs based at least on the minimum distance parameter; and an output unit configured for outputting a flight control signal for interfering UAVs based on their respective calculated alternative flight path.

[0035] These and other aspects will be apparent from and the embodiment(s) described below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0036] In the following detailed portion of the present disclosure, the aspects, embodiments and implementations will be explained in more detail with reference to the example embodiments shown in the drawings, in which:

Fig. 1 shows a schematic non-exclusive cross-sectional representation of tactical deconfliction of UAVs in a deconfliction space in accordance with an example of the disclosure;

Fig. 2 shows a flow diagram of a hybrid method for tactical deconfliction of UAVs in a deconfliction space using an existing UTM system in accordance with an example of the disclosure;

Fig. 3 shows a flow diagram of determining a minimum distance parameter from obtained flight data and environmental data in accordance with an example of the disclosure;

Fig. 4 shows a flow diagram of calculating alternative flight paths using a global variable and taking into account UAV priority levels in accordance with an example of the disclosure;

Fig. 5 shows a flow diagram of a tactical deconfliction system using an input module and an output module arranged in communication with an existing UTM system in accordance with an example of the disclosure; and

Figs. 6A to 6D illustrate schematic non-exclusive cross-sectional representations of tactical deconfliction of UAVs in deconfliction spaces in accordance with exemplary embodiments of the disclosure.

DETAILED DESCRIPTION

[0037] Presently disclosed methods and systems are configured for automatic initiation of tactical deconfliction manoeuvre, to prevent mid-air collisions between UAVs 1 and other airspace users 30, weather conditions, no-fly zones 32, obstacles, or additional objects 4, both with and without input from an operator. Such methods and systems provide tactical deconfliction to aerial vehicles such as unmanned aerial vehicles (UAVs) via Unmanned Traffic Management (UTM) systems or UAV fleet management systems, manned aircraft via Air Traffic Management (ATM) systems, and space vehicles via Space Traffic Management (STM) systems, without extra cost to install additional hardware on the aerial vehicles as it is based on software-to-software (SW-to-SW) communication between installed flight control software on the aerial

vehicles and the computer-implemented method either directly or involving the above mentioned systems.

[0038] In the following detailed description, numerous specific details are set forth by way of examples in order to provide a thorough understanding of the relevant disclosure. However, it should be apparent to those skilled in the art that the present disclosure may be practiced without such details. In other instances, well known methods, procedures, systems, components, and/or circuitry have been described at a relatively high-level, without detail, in order to avoid unnecessarily obscuring aspects of the present disclosure.

[0039] In the descriptions of the individual figures below, steps and features that are the same or similar to corresponding steps and features previously described or shown herein are denoted by the same reference numeral as previously used for simplicity.

[0040] Fig. 1 schematically illustrates a non-exclusive scenario of two conflicting UAVs 1 and 31 in the deconfliction space 2 (airspace 3D model), and a high-level picture of the operation of the computer-implemented method according to the present disclosure for detecting conflicts 5 and tactical deconflict the UAVs 1 and 31 to avoid mid-air collision and infringement with obstacles or additional objects 4 and weather conditions in the deconfliction space 2 by providing an alternative flight path 7 for the interfering UAV 1 based on a calculated energy consumption of the UAVs alternative flight path prioritizing UAV 31 and minimum distance parameter 6 to be respected between the interfering UAVs 1 and 31.

[0041] Fig. 2 shows an overview flowchart of the main steps of a method for tactical deconfliction of UAVs 1 in a deconfliction space 2 using an existing UTM system 12 in accordance the disclosure. The environment as described with respect to Fig. 1 is defined by environmental data 9 as non-exclusively listed below, wherein the UAVs 1 in the deconfliction space 2 are defined using flight data 8 comprising at least UAV type 11 and flight path 3 (further flight data options also listed below). This environmental data 9 and flight data 8 can be obtained from a UTM system 12 or an UAV fleet management system. The method transforms all this input into a 3D data model of the deconfliction space 2 to detect possible conflicts 5 based on vertical and horizontal interference of other UAVs 1, airspace users 30, obstacles, or additional objects 4, weather or violation of geo-zones 32 as defined in the deconfliction space 2.

[0042] The flight data 8 as described above may include: UAV type 11 (multi-rotor, fixed-wing, single-rotor, and hybrid vertical take-off and landing (VTOL), battery status), planned flight path (pre-flight - departure point, route waypoints and destination point), payload (type of cargo and weight), priority level 23 (medical, police, low on battery, etc.), current position (based on UAV tracking), current flight path 3 (in-flight - updates vs. planned flight path), altitude (actual and planned altitude according to planned flight plan), speed (actual and planned speed according to planned flight path).

[0043] The environmental data 9 may include: a ruleset defining flight regulations (rules, regulations, and operational concepts), deconfliction rules (defined separation rules and minima's), spatial information of the deconfliction space 2 defining position and geometry of physical and/or virtual additional objects 4 such as GEO zones 32 (static and dynamic no-fly zones, nature zones etc.), static and dynamic obstacles and objects, topological levels, tracking (actual position of all UAVs and airspace users via on-board devices as Remote ID, transponders, ADS-B, GPS, GNSS etc. and on-ground sensors as radars, RF and other technologies), weather (local weather as wind, rain, thunderstorms, etc.).

[0044] The method then determines a minimum distance parameter 6 for interfering UAVs 1 in a possible conflict 5 based on the interfering UAV types 11 and the data quality 10 (precision and veracity) of the obtained flight data 8 and the environmental data 9 and calculates an alternative flight path 7 for the interfering UAVs 1 using the calculated minimum distance parameter 6, as will be explained below in detail. The calculated alternative flight paths 7 are communicated to the UTM system 12 or UAV fleet management system, and the interfering UAVs 1 receive flight path changes 24 or a flight control signal 25 to modify their flight path, which can further be based on differences in their priority level 23 also defined in the flight data 8, as will be explained below. In the illustrated example, a priority UAV 31 with a higher priority level 23 can continue on its flight path 3 while an UAV 1 with lower priority level 23 adheres to its received alternative flight path 7 to respect the calculated minimum distance parameter 6 from priority UAV 31 and avoid collision.

[0045] The received ruleset defining flight regulations and deconfliction rules also can be integrated in the method for the determining of the minimum distance parameter 6, determining of possible conflicts 5, and/or calculating the alternative flight path 7.

[0046] Fig. 3 shows a flow diagram of the sub-task of determining a minimum distance parameter 6 from obtained flight data 8 and environmental data 9 in accordance with the disclosure.

[0047] The minimum distance parameter 6 is determined on one hand based on data quality 10 (precision and veracity) of any or all of the following parameters: positioning parameter 14 of the current position based on the positioning system (GPS, GNSS, Baidu, Galileo, RTK, 5G, ADS-B etc., local coordinate system) included in each UAVs and other airspace users, which has influence on the precision of the position, as well as timing precision; environmental parameter 15 based on how updated, how granular, and how accurate the received environmental data 9 is as non-exclusively listed above; weather parameter 16 based on the method of obtaining weather and accuracy in forecasts and actual weather data received; and optionally also a safety buffer parameter which determines the minimum time between aerial vehicles occupying the same space with their respective safety zones.

[0048] On the other hand, the minimum distance parameter 6 calculation further takes into account the manoeuvring ability 13 of the interfered and/or interfering UAVs 1 based on individual UAV types 11 extracted from the received flight data 8 (fixed-wing has a larger turning radius than multi-rotors, payload size and speed of the UAVs will affect turning and climb/descent ability).

[0049] Fig. 4 shows an overview flowchart of a subsequent step of calculating alternative flight paths 7 in accordance with an example of the disclosure.

[0050] In this example, calculating the alternative flight path 7 for the plurality of UAVs 1 is based on a global variable 17. First, a unit variable 18 is defined for each UAV 1 based on a possible alternative flight path 7 with respect to the received current flight path 3 and positioning, and the method then optimizes for a global variable 17 that is a sum of all unit variables 18 from UAVs 1 in the deconfliction space 2. These unit variables 18 can be defined in a dynamic way and include, but non-exclusively: a distance variable 19 which tries to optimize (min. or max.) the overall flight length of all UAVs 1 compared to their original path; time-of-flight variable 20 (ToF) which tries to optimize the time of flights for all UAVs 1; energy consumption (green) variable 21 which, based on the UAVs definitions such as UAV type 11 (multi-rotor, fixed-wing, single-rotor, and hybrid vertical take-off and landing (VTOL), wherein different UAV types require different amount of energy for certain movements), payload (such as weight or typology affecting energy consumption), weather (such as headwind increasing energy consumption), or temperature (such as extreme temperatures affecting lifespan of batteries) tries to optimize the amount of energy consumed; and/or price variable 22 which prioritises certain UAVs 1 depending on the subscription that the company, owning the UAV, has decided on.

[0051] Lastly, the method further takes into account a global priority based on individual priority levels 23 as mentioned before, wherein priority UAVs 31 such as emergency UAVs enjoy global priority over all other UAVs 1 and this (these) UAVs path will be optimized under any one or a combination of the above-mentioned variables.

[0052] Fig. 5 shows a flowchart of a tactical deconfliction system 26 for UAVs 1 according to an example of the disclosure, configured to execute a method as describe above. The deconfliction system 26 includes an input unit 27 and an output unit 29 arranged in communication with an existing UTM system 12, or an UAV fleet management system, or directly to the UAV flight control software according to the present disclosure.

[0053] A UTM system 12 comprises infrastructure and a set of procedures designed to manage and monitor the operations of UAVs 1 in the deconfliction space 2, configured to ensure safe and efficient integration of UAVs 1 into an existing deconfliction space 2, coordinate their movements and prevent collisions by enabling the control and tracking of UAVs 1, facilitating communication between multiple UAVs 1 and manned aircraft 30 via Air

Traffic Management (ATM) systems, and providing information to operators about airspace conditions, regulations, and restrictions.

[0054] A UAV fleet management system on the other hand is configured to focus explicitly on managing and optimising a select fleet of UAVs from said plurality of UAVs 1. In this sense, the UAV fleet management system is primarily configured to handle the operational aspects of UAV fleets, such as planning, scheduling, monitoring, and controlling multiple UAVs 1 to achieve specific objectives.

[0055] In further possible examples, instead or in addition to the above described UTM system 12 or an UAV fleet management system, flight data 8 and environmental data 9 is further obtained from an Air Traffic Management (ATM) system and/or a Space Traffic Management (STM) system, wherein the obtained flight data 8 comprises classification, a current position and a current flight path 3 of a plurality of aircrafts 30 and/or spacecrafts within a horizontally and/or vertically enlarged deconfliction space 2, and wherein the obtained environmental data 9 comprises information on additional objects 4 within the enlarged deconfliction space 2.

[0056] The input unit 27 is configured to obtain flight data 8 and environmental data 9 of a deconfliction space 2 from the UTM system 12 (or UAV fleet management system, the flight data 8 comprising at least UAV type 11 and flight path 3 of a plurality of UAVs 1 within the deconfliction space 2, and the environmental data 9 comprising information on additional objects 4 within the deconfliction space 2 as described before.

[0057] The deconfliction system 26 further includes a processor unit 28 configured for determining data quality 10 of the obtained flight data 8 and the environmental data 9 and to determine possible conflicts 5 between the plurality of UAVs 1 and additional objects 4 based on vertical and horizontal interference of the obtained flight paths 3 as also described above with respect to Fig. 2. The processor unit 28 is further configured for determining a minimum distance parameter 6 for interfering UAVs 1 in a possible conflict 5 based on the interfering UAV types 11 and the data quality 10 of the obtained flight data 8 and the environmental data 9 as described above with respect to Fig. 3; and for calculating an alternative flight path 7 for interfering UAVs 1 based at least on the minimum distance parameter 6 as described above with respect to Fig. 4.

[0058] In the illustrated example the processor unit 28 is further configured for determining flight path changes 24 for any of the plurality of UAVs 1 where a conflict 5 has been determined, based on the obtained flight path 3 and the calculated alternative flight path 7, the flight path changes 24 according to formats that conform with data that UAVs can parse. These can be in the form of waypoints based on the positioning system used. Low level adjustments of the UAVs movement vector (altitude, heading, and/or speed) will be an alternative way of controlling the UAVs. This data will be communicated

either to the UTM system, or UAV fleet management system or directly to the UAVs flight control software.

[0059] In the final step, the output unit 29 is configured for outputting a flight control signal 25 to the UTM system 12 (alternatively to the UAV fleet management system or directly to the UAVs flight control software) for the flight control software of interfering UAVs 1 based on their respective calculated alternative flight path 7 and/or the flight path changes 24 determined based on the obtained flight path 3 and the calculated alternative flight path 7. Similar to the determined flight path changes 24, flight control signal 25 can also comprise waypoints (GPS, GNSS etc.), heading adjustments, altitude adjustments, and/or speed adjustments. This SW-to-SW communication involves a two-way data communication; sending flight path changes 24 and/or a flight control signal 25 and receiving acknowledgement with a read-back of the received flight path changes 24 and/or a flight control signal 25, followed by an execution of the instruction by the UAV(s) 1 receiving the data.

[0060] Figs. 6A to 6D illustrate schematic non-exclusive scenarios of applying the above described tactical deconfliction system and method for deconflicting UAVs 1 in a deconfliction space 2 which may include all types of UAVs 1 (multi-rotor, fixed-wing, single-rotor, and hybrid vertical take-off and landing (VTOL)) with other airspace users 30, weather conditions, no-fly zones 32, obstacles, or objects 4, where a UTM system 12 is installed to manage UAV traffic in general or a UAV fleet management system to manage a fleet of UAVs 1 for a single or several operators. The illustrated scenarios are variants of the scenario depicted in Fig. 1, wherein some features have been removed for better clarity but are to be understood as implicitly included as described above with respect to Fig. 1, wherein the same deconfliction methods apply as described with respect to Figs. 2 to 5 unless otherwise indicated.

[0061] In the illustrated Scenario 1 in Fig. 6A, the computer-implemented method determines a possible conflict 5 based on the UAV's current flight path 3 received as input data from flight data 8 and the environmental data 9, as an activated dynamic geo-zone 32 interferes with the UAVs flight path 3 creating a conflict 5. A deconfliction situation module determines a positioning parameter of the UAV's current position and timing precision to the dynamic geo-zone 32 based on the UAV's positioning system and the environmental data 9 parameters based on how updated, how granular, and how accurate the data received (flight data 8 and the environmental data 9) is. A holistic algorithm calculates an alternative flight path 7 for the UAV 1 based on a unit variable 18 with respect to the received current flight path 3, current position, and planned flight path where the method optimizes for a global variable 17 that is a sum of all unit variables 18 in the deconfliction space 2. In scenario 1 the method involves only one unit variable 18 as the UAV's calculated alternative flight path 7 does not involve other units in the deconfliction space 2. Based

on a distance variable 19, a time-of-flight variable 20 (ToF) and an energy consumption variable 21 (price variable 22 and priority level 23 are excluded in this scenario), the method calculates the UAV's alternative flight path 7 to be a turn (heading adjustment) to circumnavigate the dynamic geo-zone 32 from a certain positioning point with a calculated turning rate based on the UAV type 11 and payload, manoeuvring ability 13 and a minimum distance parameter 6, as it creates the shortest distance equal to shortest ToF and the lowest energy consuming flight path to avoid the dynamic geo-zone 32 and resume navigation towards the planned flight path and destination when clear of the interfering dynamic geo-zone 32. Flight path changes 24 (updated flight data) determine the new waypoints for the UAV 1 to avoid the conflict 5 with the dynamic geo-zone 32 and resume navigation to the planned flight path and destination. These data are communicated back to the UTM system 12 or UAV fleet management system as updated data to the flight data 8. The flight path changes 24 are communicated to the UAV's flight control software in a flight control signal 25 (output) and involves all parties involved, which means in scenario 1 the UAV 1 (operator) and the UTM system 12 or UAV fleet management system and the computer-implemented method.

[0062] In the illustrated Scenario 2 in Fig. 6B, the computer-implemented method determines a possible conflict 5 based on the UAV's current flight path 3 received as input data from flight data 8 and the environmental data 9 including flight regulations and tracking information, as an aircraft 30 (helicopter) is tracked and interferes with the UAV's flight path 3. A deconfliction situation module determines a positioning parameter of the UAV's current position and timing precision to the helicopter based on the UAV's positioning system and the tracking (all airspace users) parameter based on how updated, how granular, and how accurate the data received (flight data 8 and the environmental data 9) is. A holistic algorithm calculates an alternative flight path 7 for the UAV 1 based on a unit variable 18 with respect to the received current flight paths 3 (UAV 1 and helicopter 30), positioning parameters (UAV 1 and helicopter 30) and planned flight path (UAV), wherein the method optimizes for a global variable 17 that is a sum of all unit variables 18 in the deconfliction space 2. In scenario 2 the method involves only one unit variable 17 as the UAV's calculated alternative flight path 7 does not involve other units in the deconfliction space 2 as the helicopter is a human flown vehicle (unless communicating with the UTM system 12 or other systems including the computer-implemented method according to the present disclosure). Based on a distance variable 19, a time-of-flight variable 20 (ToF), an energy consumption variable, and priority level 23 (price variable 22 is excluded in this scenario), the method calculates the UAV's alternative flight path 7 to be a descent (altitude adjustment) to avoid the conflict as the human flown helicopter 30 has priority according to flight regulations, and is executed from a certain position-

ing point with a calculated descent rate based on the UAV type 11 and payload, manoeuvring ability 13 and a minimum distance parameter 6, as it creates the lowest energy consuming flight path 7 to avoid the helicopter 30 and resume navigation towards the planned flight path (altitude) and destination when clear of the helicopter 30.

[0063] The calculated level (altitude adjustment) for the UAV 1 to descent to is based on the environmental data 9 in the 3D model where a crane (additional object 4) and a no-fly zone (Geo-zone 32) as vertical parameters define the minimum altitude adjustment to avoid interfering with the alternative flight path 7. The flight path changes 24 (updated flight data) determines the altitude adjustment for the UAV 1 to avoid the conflict with the helicopter 30, potential conflict with the object (crane) 4 and no-fly zone 32, and resume navigation to the planned flight path and destination. These data are communicated back to the UTM 12 or UAV fleet management system as updated data to the flight data 8. The flight path changes 24 are communicated to the UAV's flight control software in a flight control signal 25 (output) and involves all parties involved, which means in scenario 2 the UAV 1 (operator) and the UTM system 12 or UAV fleet management system and the computer-implemented method.

[0064] In the illustrated Scenario 3 in Fig. 6C, which is similar to the scenario depicted in Fig. 1, the computer-implemented method determines a possible conflict 5 based on the UAVs current flight paths 3 and altitude received as input data from flight data 8 and the environmental data 9, and deconfliction rules, as two UAVs 1 interferes each other's flight paths 3 in the same altitude and not separated according to the deconfliction rules in the deconfliction space 2. A deconfliction situation module determines a positioning parameter of the UAV's current position and timing precision to each other based on the UAVs positioning systems and the environmental data 9; deconfliction rules according to separation minima in the deconfliction space 2; weather (thunderstorm and heavy wind) in the higher part of the deconfliction space 2, besides additional objects 4 (house) and topological levels (hills with trees) based on how updated, how granular, and how accurate the data received is. A holistic algorithm calculates an alternative flight path 7 for the UAVs 1 based on a unit variable 18 with respect to the received current flight paths 3, positioning parameters and planned flight paths wherein the method optimizes for a global variable 17 that is a sum of all unit variables 18 in the deconfliction space 2. In scenario 3 the method involves two unit's (UAV 1 and UAV 2) variables as the UAVs calculated alternative flight paths 7 does not involve other units in the deconfliction space 2. Based on a distance variable 19, a time-of-flight variable 20 (ToF) and an energy consumption variable 21 (price variable 22 and priority level 23 are excluded in this scenario), the method calculates the UAVs alternative flight paths 7 to be a turn for UAV 2 (heading adjustment) to avoid the conflict as the UAV 1 is calculated to have a higher energy consumption due to UAV type 11 and payload, besides

weather, obstacles and topological levels restrict UAV 2 to execute a climb or descent. The heading adjustment of UAV 2 is executed from a certain positioning point with a calculated turn rate based on the UAV type 11 and payload, as it creates the lowest energy consuming flight path to avoid the conflict 5 between the two UAVs and resume navigation towards the planned flight path and destination when both UAVs are clear of the conflict 5. The calculated turn (heading adjustment) for UAV 2 is based on the environmental data 9 in the 3D model where the weather, object and topological levels vertical parameters define the minimum and maximum altitude adjustment not suitable to avoid interfering with the alternative flight path 7. The flight path changes 24 (updated flight data) determines the heading adjustment for UAV 2 to avoid the conflict with UAV 1, potential conflict with weather, additional objects 4 (house) and topological levels (hills with trees), and resume navigation to the planned flight path and destination. These data are communicated back to the UTM system 12 or UAV fleet management system as updated data to the flight data 8. The flight path changes 24 are communicated to the UAV's flight control software in a flight control signal 25 (output) and involves all parties involved, which means in scenario 3 the UAVs (operators) and the UTM 12 or UAV fleet management system and the computer-implemented method.

[0065] In the illustrated Scenario 4 in Fig. 6D, the computer-implemented method determines a possible conflict 5 based on the UAVs current flight paths 3, speed and altitude received as input data from the flight data 8 and the environmental data 9, and deconfliction rules, as three UAVs interfere each other's flight path 3 in the same altitude and not separated according to the deconfliction rules in the deconfliction space 2. A deconfliction situation module determines a positioning parameter of the UAV's current position and timing precision to each other based on the UAVs positioning systems and the environmental data 9; deconfliction rules according to separation minima in the deconfliction space 2, Geo-zone 32 (no-fly zone) and topological levels (mountains) based on how updated, how granular, and how accurate the environmental parameter 15 received is. A holistic algorithm calculates an alternative flight path 7 for the UAVs 1 based on a unit variable 18 with respect to the received current flight paths 3, positioning parameters and planned flight paths wherein the method optimizes for a global variable 17 that is a sum of all unit variables 18 in the deconfliction space 2. In scenario 4 the method involves three unit's (UAV 1, UAV 2 and UAV 3) variables 18 as the UAVs calculated alternative flight paths 7 does not involve other units in the deconfliction space 2. Based on a distance variable 19, a time-of-flight variable 20 (ToF), an energy consumption variable 21, a price variable 22 and priority levels 23, the method calculates the UAVs alternative flight paths 7 to be a climb for UAV 2 (altitude adjustment) and a turn for UAV 3 (heading adjustment) to avoid the conflict as the UAV 1 is a priority

UAV 31 (medicine and paid for priority flight as a private company according to the price variable 22 and priority levels 23). The calculation includes UAV type 11, payload and priority level 23, besides deconfliction rules, Geo-zones 32, topological levels, and weather not restricting UAV 2 to execute a climb (altitude adjustment) due to conflict with UAV 3 and accepted a climb (altitude adjustment) due to non-restricting weather. The turn (heading adjustment) of UAV 3 is based on a restriction to climb (altitude adjustment) due to deconfliction rules with UAV 2 and a restriction to descent (altitude adjustment) due to conflict with Geo-zone 32 (No-fly zone) and topological levels 4 (mountain). The climb (altitude adjustment) of UAV 2 is executed from a certain positioning point with a calculated climb rate based on the UAV type 11, payload, manoeuvring ability 13 and a minimum distance parameter 6, and the turn (heading adjustment) of UAV 3 is executed from a certain positioning point with a calculated turn rate based on the UAV type 11, payload, manoeuvring ability 13 and a minimum distance parameter 6 as it creates the lowest energy consuming flight path to avoid the conflict 5 between the three UAVs and resume navigation towards the planned flight path and destination when all UAVs are clear of the conflict. The calculated climb (altitude adjustment) for UAV 2 is based on the environmental data 9 in the 3D model where the weather parameter 16 defines the climb (altitude adjustment) suitable to avoid interfering with the alternative flight path 7. The calculated turn (heading adjustment) for UAV 3 is based on the environmental data 9 in the 3D model where the Geo-zone 32 (no-fly zone) and topological levels 4 (mountain) vertical parameters defines the minimum and maximum altitude adjustment not suitable to avoid interfering with the alternative flight path 7. The flight path changes 24 (updated flight data) determines the climb (altitude adjustment) for UAV 2 and turn (heading adjustment) for UAV 3 to avoid the conflict between the three UAVs, potential conflict with Geo-zone 32 (no-fly zone) and topological levels 4 (mountain), and resume navigation to the planned flight path and destination. These data are communicated back to the UTM system 12 or UAV fleet management system as updated data to the flight data 8. The flight path changes 24 are communicated to the UAV's flight control software in a flight control signal 25 (output) and involves all parties involved, which means in scenario 4 the UAVs (operators) and the UTM 12 or UAV fleet management system and the computer-implemented method.

[0066] The various aspects and implementations have been described in conjunction with various embodiments herein. However, other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed subject-matter, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor or other unit may fulfill the functions of several items

recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measured cannot be used to advantage. A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication or satellite systems.

[0067] The reference signs used in the claims shall not be construed as limiting the scope.

Claims

1. A computer-implemented method for deconfliction of unmanned aerial vehicles, UAVs (1), the method comprising:

obtaining flight data (8) of a plurality of UAVs (1) in a deconfliction space (2), the flight data (8) comprising at least UAV type (11) and flight path (3) of the plurality of UAVs (1) within the deconfliction space (2);

obtaining environmental data (9) comprising information on additional objects (4) within the deconfliction space (2);

determining data quality (10) of the obtained flight data (8) and the environmental data (9);
determining possible conflicts (5) between the plurality of UAVs (1) and additional objects (4) based on vertical and horizontal interference of the obtained flight paths (3);

determining a minimum distance parameter (6) for interfering UAVs (1) in a possible conflict (5) based on the interfering UAV types (11) and the data quality (10) of the obtained flight data (8) and the environmental data (9); and

calculating an alternative flight path (7) for interfering UAVs (1) based at least on the obtained flight path (3) and the minimum distance parameter (6).

2. A method according to claim 1, wherein determining the minimum distance parameter (6) is at least partially based on maneuvering ability (13) of the UAVs (1) in a possible conflict (5) based on their individual UAV types (11), such as a fixed-wing UAV having a larger turning radius than multi-rotors, or that payload size and speed of the UAVs (1) will affect turning and climb/descent ability.

3. A method according to any preceding claim, wherein the obtained flight data (8) comprises current position data, and determining the minimum distance parameter (6) is at least partially based on a positioning parameter (14) related to the precision and

veracity of the current position data of each UAV (1) based on the positioning system such as GPS, GNSS, Baidu, Galileo, RTK, 5G, ADS-B, included in each UAV (1).

4. A method according to any preceding claim, wherein determining the minimum distance parameter (6) is at least partially based on an environmental parameter (15) related to the precision and veracity of the obtained environmental data (9) based on the method of obtaining the environmental data (9), such as how updated, how granular, or how accurate the data is about environmental objects.

5. A method according to any preceding claim, wherein the obtained environmental data (9) comprises weather data, such as wind formations or rain, and determining the minimum distance parameter (6) is at least partially based on weather parameter (16) related to the veracity of obtained weather data.

6. A method according to any preceding claim, wherein calculating the alternative flight path (7) for the plurality of UAVs (1) is further based on a global variable (17), wherein a unit variable (18) is defined for each UAV (1) in a possible conflict (5) based on a possible alternative flight path (7) with respect to the obtained flight path (3), and wherein the method optimizes for a global variable (17) that is a sum of all unit variables (18) from UAVs (1) in the deconfliction space (2).

7. A method according to claim 6, wherein the global variable (17) is a distance variable (19), wherein each unit variable (18) is calculated based on flight path deviation of an UAV (1) in a possible conflict (5) from its obtained flight path (3), and wherein the global variable (17) is optimized so that the sum of deviations of all UAVs (1) in the deconfliction space (2) is kept at a minimum or maximum.

8. A method according to claim 6, wherein the global variable (17) is a time-of-flight variable (20) wherein each unit variable (18) is calculated based on time-of-flight of an alternative flight path (7), and wherein the global variable (17) is optimized so that the sum of time-of-flights of all UAVs (1) in the deconfliction space (2) is kept at a minimum or maximum.

9. A method according to claim 6, wherein the global variable (17) is an energy consumption variable (21) wherein each unit variable (18) is calculated based on energy consumption of an UAV (1) when taking an alternative flight path (7), and wherein the global variable (17) is optimized so that the sum of energy consumption of all UAVs (1) in the deconfliction space (2) is kept at a minimum.

10. A method according to any preceding claim, wherein

the flight data (8) comprises a priority level (23) assigned to the plurality of UAVs (1) within the deconfliction space (2), wherein calculating the alternative flight path (7) for the plurality of UAVs (1) takes into account these priority levels (23) so that a priority UAV (31) of the highest priority level (23), such as emergency UAVs, can keep to their current flight path (3) or to an optimized flight path, and an alternative flight path (7) is calculated for the remaining conflicting UAVs (1) according to the global variable (17).

11. A method according to any preceding claim, wherein the flight data (8) and environmental data (9) is obtained from an Unmanned Traffic Management, UTM system (12), or an UAV fleet management system; wherein the UTM system (12) comprises infrastructure and a set of procedures configured to manage and monitor operations of said plurality of UAVs (1) in the deconfliction space (2), and wherein the UAV fleet management system is configured to manage and monitor operations of a select fleet of UAVs from said plurality of UAVs (1); and wherein the calculated alternative flight path (7) is provided to said UTM system (12) or UAV fleet management system in return.

12. A computer-implemented method for aircraft deconfliction, the method comprising:

obtaining, from an Air Traffic Management, ATM system, flight data (8) of a plurality of aircrafts (30) in a deconfliction space (2), the flight data (8) comprising at least type and flight path (3) of the plurality of aircrafts (30) within the deconfliction space (2);
 obtaining environmental data (9) comprising information on additional objects (4) within the deconfliction space (2);
 determining data quality (10) of the obtained flight data (8) and the environmental data (9);
 determining possible conflicts (5) between the plurality of aircrafts (30) and additional objects (4) based on vertical and horizontal interference of the obtained flight paths (3);
 determining a minimum distance parameter (6) for interfering aircrafts (30) in a possible conflict (5) based on the types of interfering aircrafts (30) and the data quality (10) of the obtained flight data (8) and the environmental data (9);
 calculating an alternative flight path (7) for interfering aircrafts (30) based at least on the obtained flight path (3) and the minimum distance parameter (6); and
 providing said calculated alternative flight path (7) to said ATM system.

13. A computer-implemented method for spacecraft de-

confliction, the method comprising:

obtaining, from a Space Traffic Management, STM system, flight data (8) of a plurality of spacecrafts in a deconfliction space (2), the flight data (8) comprising at least type and flight path (3) of the plurality of spacecrafts within the deconfliction space (2);
 obtaining environmental data (9) comprising information on additional objects (4) within the deconfliction space (2);
 determining data quality (10) of the obtained flight data (8) and the environmental data (9);
 determining possible conflicts (5) between the plurality of spacecrafts and additional objects (4) based on vertical and horizontal interference of the obtained flight paths (3);
 determining a minimum distance parameter (6) for interfering spacecrafts in a possible conflict (5) based on the types of interfering spacecrafts and the data quality (10) of the obtained flight data (8) and the environmental data (9);
 calculating an alternative flight path (7) for interfering spacecrafts based at least on the obtained flight path (3) and the minimum distance parameter (6); and
 providing said calculated alternative flight path (7) to said STM system.

14. A method according to any preceding claim, wherein the method comprises determining a flight control signal (25) for any of the plurality of UAVs (1), aircrafts (30), or spacecrafts where a conflict (5) has been determined, based on the calculated alternative flight path (7) or flight path changes (24) determined based on the obtained flight path (3) and the calculated alternative flight path (7), the flight control signal (25) comprising at least one of:

- waypoints (GPS, GNSS etc.),
- heading adjustments,
- altitude adjustments, or
- speed adjustments.

15. A computer-implemented deconfliction system (26) for aerial vehicles, the system comprising:

an input unit (27) configured for obtaining flight data (8) and environmental data (9) of a deconfliction space (2), the flight data (8) comprising at least type and flight path (3) of a plurality of aerial vehicles within the deconfliction space (2), and the environmental data (9) comprising information on additional objects (4) within the deconfliction space (2);
 a processor unit (28) configured for:

determining data quality (10) of the ob-

tained flight data (8) and the environmental data (9);
determining possible conflicts (5) between the plurality of aerial vehicles and additional objects (4) based on vertical and horizontal interference of the obtained flight paths (3);
determining a minimum distance parameter (6) for interfering aerial vehicles in a possible conflict (5) based on the interfering types of aerial vehicles and the data quality (10) of the obtained flight data (8) and the environmental data (9); and
calculating an alternative flight path (7) for interfering aerial vehicles based at least on the minimum distance parameter (6); and

an output unit (29) configured for outputting a flight control signal (25) for interfering aerial vehicles based on their respective calculated alternative flight path (7).

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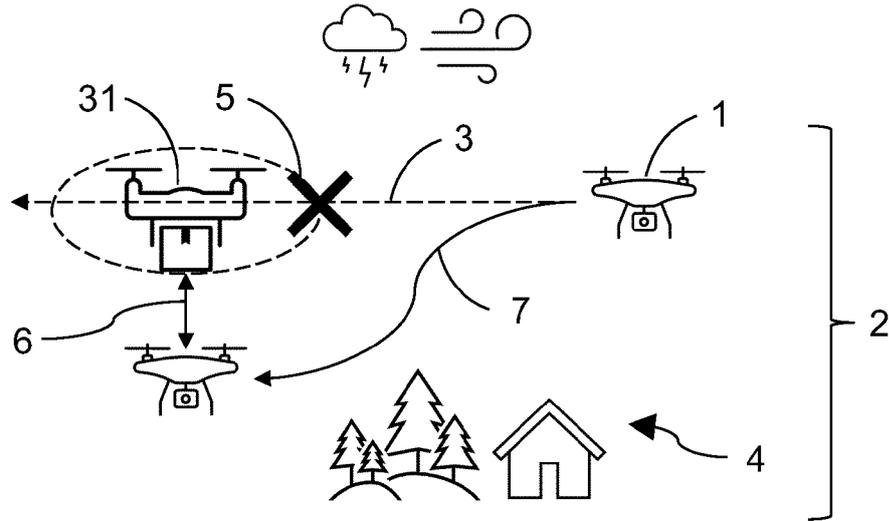


FIG. 1

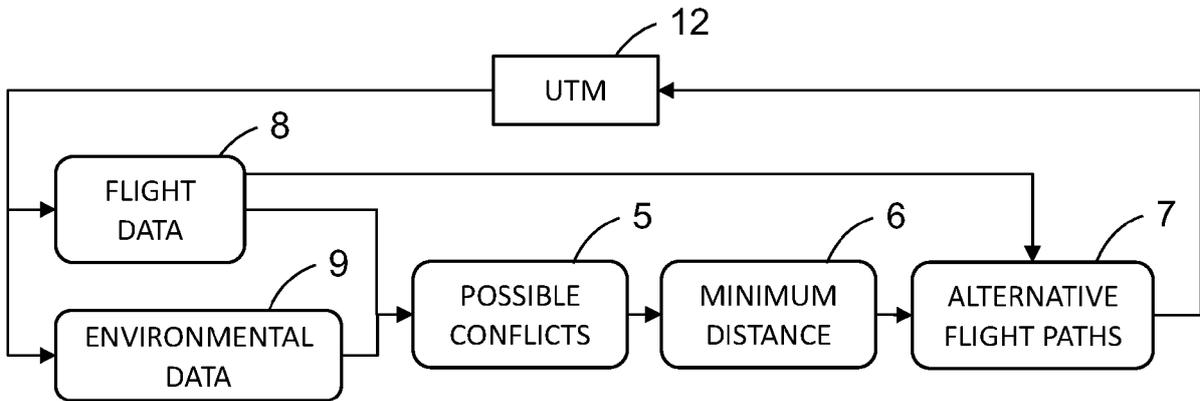


FIG. 2

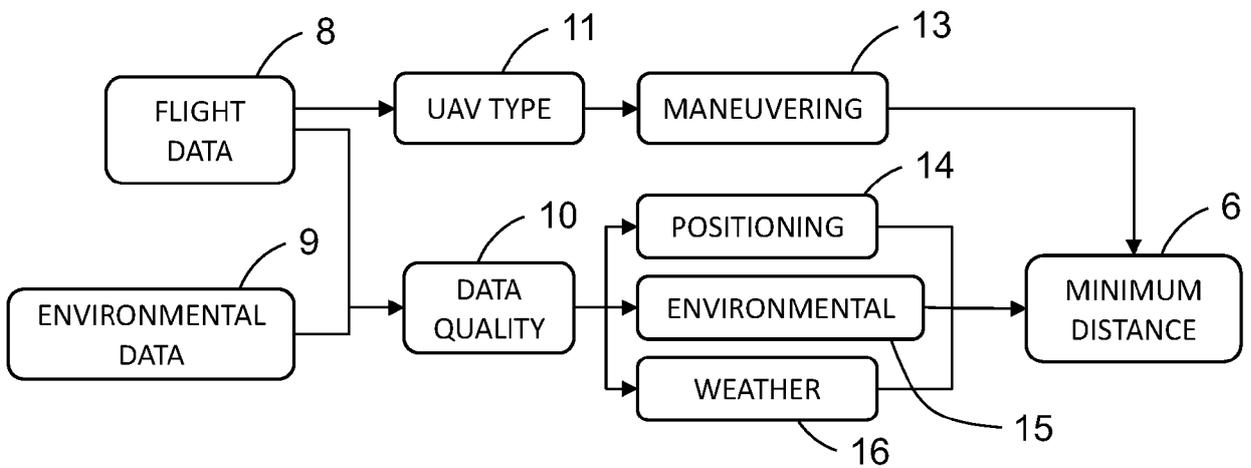


FIG. 3

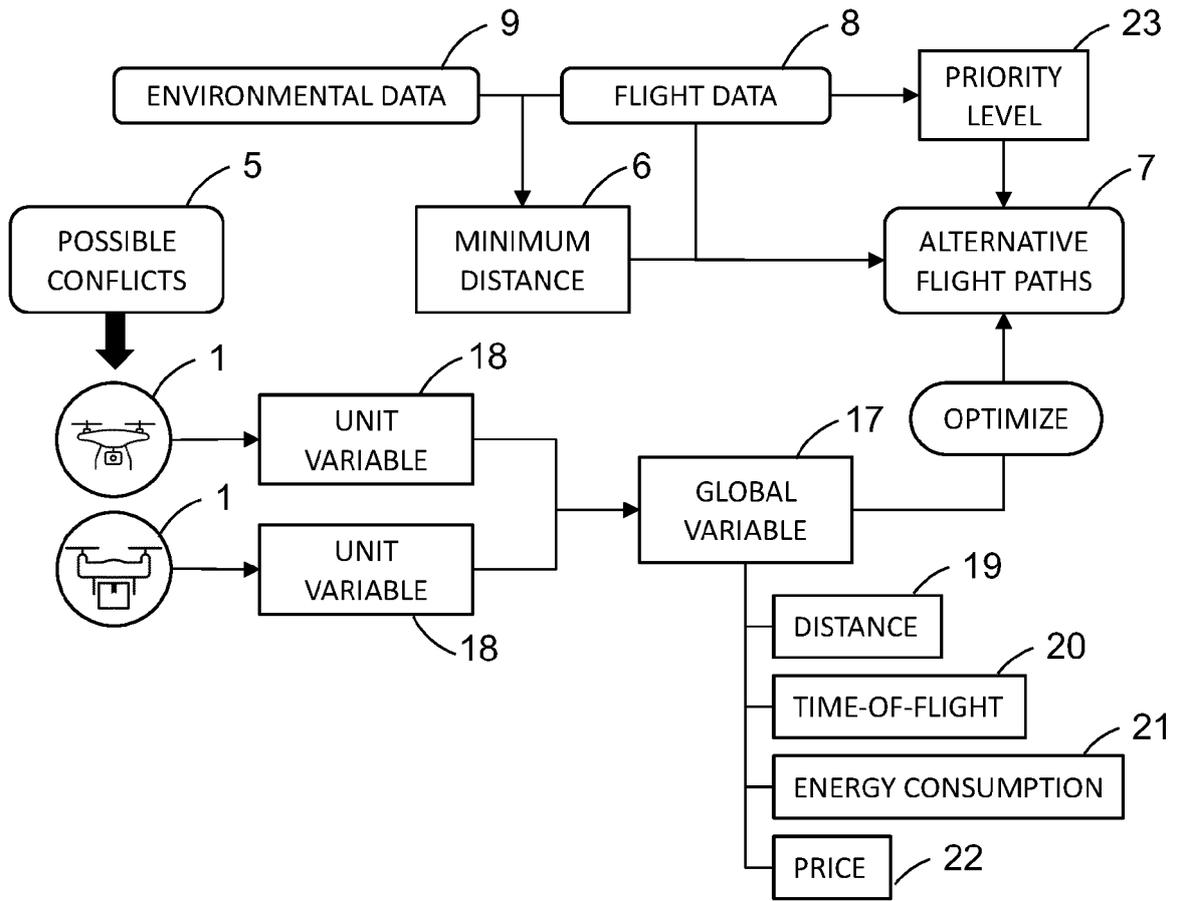


FIG. 4

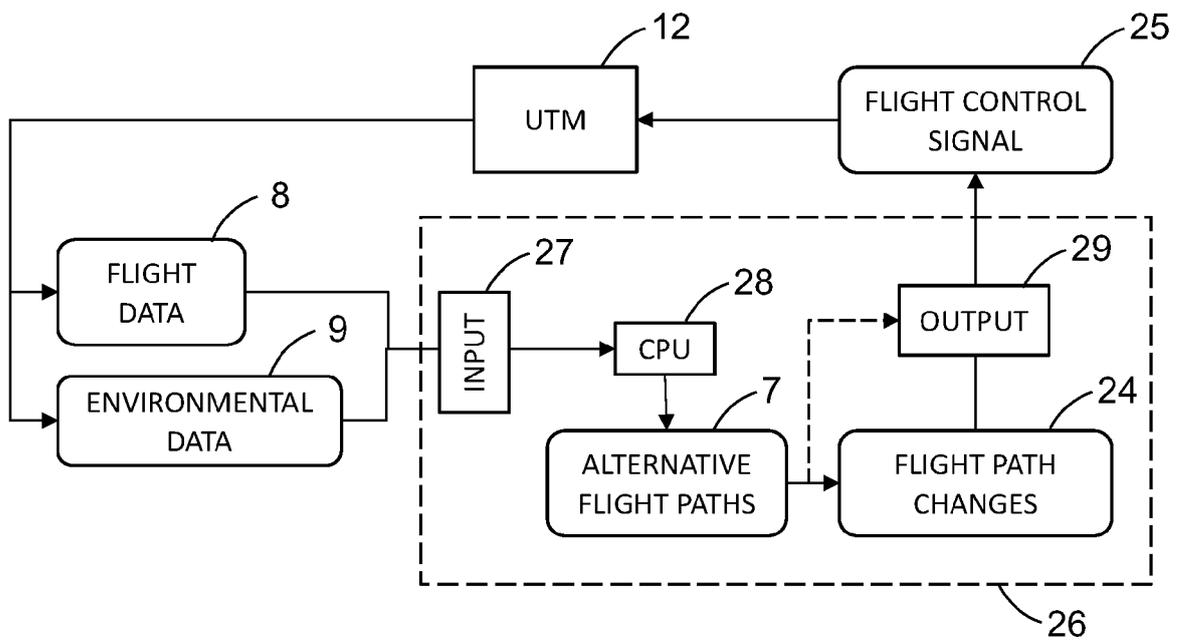


FIG. 5

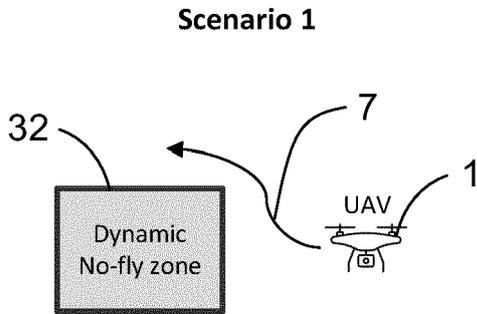


FIG. 6A

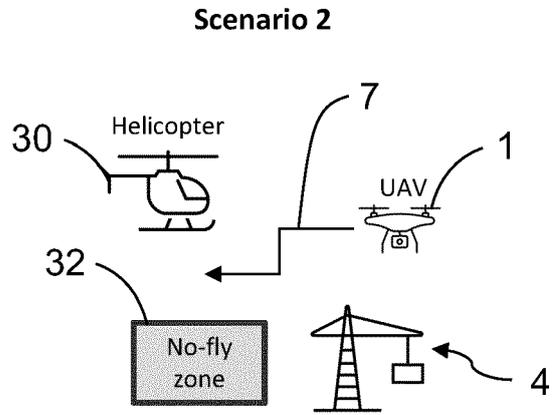


FIG. 6B

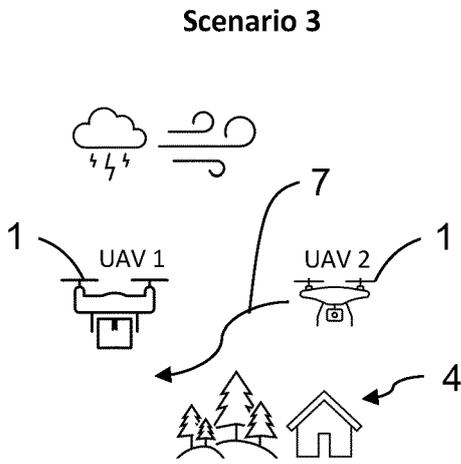


FIG. 6C

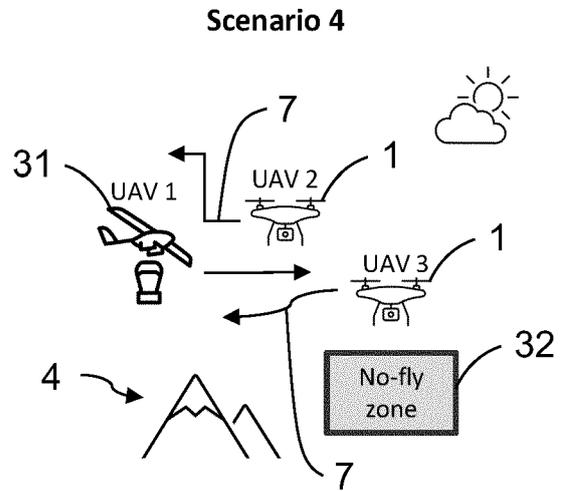


FIG. 6D



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Application Number

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A	<p>US 2012/191332 A1 (SAWHILL BRUCE K [US] ET AL) 26 July 2012 (2012-07-26)</p> <p>* abstract; figures *</p> <p>* paragraphs [0006], [0024], [0035] - [0045], [0099] - [0101], [0150] - [0163], [0205], [0206], [0337] - [0347] *</p> <p>-----</p>	1-15	<p>TECHNICAL FIELDS SEARCHED (IPC)</p> <p>G08G</p>
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The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
The Hague		2 December 2023	Roost, Joseph
CATEGORY OF CITED DOCUMENTS		<p>T : theory or principle underlying the invention</p> <p>E : earlier patent document, but published on, or after the filing date</p> <p>D : document cited in the application</p> <p>L : document cited for other reasons</p> <p>.....</p> <p>& : member of the same patent family, corresponding document</p>	
<p>X : particularly relevant if taken alone</p> <p>Y : particularly relevant if combined with another document of the same category</p> <p>A : technological background</p> <p>O : non-written disclosure</p> <p>P : intermediate document</p>			

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