in case of a problem. He will then be in charge of making the right decisions regarding the trajectories allowing the UAV to reach a safe zone.

Summary of the invention

Embodiments of the present invention propose to improve the generation of automatic flight programs by limiting the need for human intervention during flight, with great flexibility in the determination of the flight path.

According to a first aspect, a method is proposed for modeling a three-dimensional environment by digital processing in order to establish pathways for unmanned aerial devices optimized according to different priorities, characterized in that it comprises the following digital processing steps:

(a) providing a three-dimensional model of volumes (PEXi) in which flight is prohibited,

(b) subdividing the model into individual elements (PVk),

(c) determining a center (Pk) for each individual element,

(d) establishing and memorizing a graph, the nodes (Pk, Ik) of which are formed by at least one portion of said centers, and are connected by branches,

(e) determining a priority among a set of priorities for a path to be followed by an unmanned aerial device, and

(f) weighing the branches of the graph by means of one or several weighing schemes according to the determined priority.

This method advantageously but optionally includes the following additional features, taken individually or in any combination that a person skilled in the art would consider to be technically compatible:

* the priorities include at least two priorities among an absolute distance priority, a travel time priority, an energy consumption priority and a risk priority.

* at least one of the weightings depends on a constraint affecting all the branches.

* said constraint comprises a constraint vector affecting all branches.

* the constraint vector is a wind vector, with each branch having a pair of weights associated with the direction of travel respectively, and each weight being distinctly subject to the wind vector.

* said weighting is such that different weights are assigned to the same branch depending on the direction of travel, so as to generate preferred directions of travel.

* said weighting is based on a mapping defining different levels of constraints depending on the location in a flight space.

* the constraint levels are included in a group that includes a maximum allowable speed constraint and a risk constraint.

* the constraint is able to take a value such that the corresponding zone becomes a no-fly zone.

* step (a) includes providing a three-dimensional model with volumes (PEXi) in which flight is physically impossible, and reprocessing this model with static safety margin data.

* step (a) comprises the subdivision of the three-dimensional model into horizontal slices (Txy), the projection of the volumes on a horizontal plane being the same throughout the thickness of each slice, and the implementation of a subdivision into individual elements in each horizontal plane.

* the subdivision is done by triangulation.

* the triangulation is a Delaunay triangulation.

* step (d) involves establishing graph branches between nodes located in adjacent horizontal planes using a distance minimization approach.

According to a second aspect, a method is proposed for determining by an unmanned aerial device a path between two points in a three-dimensional space modeled by a graph obtained by the modeling method as defined above, characterized in that it comprises the following steps:

- determining a priority for the route,

- taking into consideration or establishing a given graph corresponding to the determined priority, and

- defining the route, on board the device, by a best path computation in said given graph.

- determining an allowable trajectory deviation as a function of the relaxation factor, and

- applying a trajectory correction instruction only when an actual measured trajectory deviation exceeds the allowable trajectory deviation.

Advantageously but optionally, the relaxation factor is determined from at least one data item representative of one of the following pieces of information: current accuracy of a GPS unit installed on the device, wind, response of the device to the steering commands, size of the device, type of device.

According to a fourth aspect, a method for steering an unmanned aerial device is proposed, comprising the following steps:

- determining a path by the determination method defined above,

- measuring a dynamic characteristic of the device during the flight,

- dynamically determining a new path according to the evolution of said dynamic characteristic.

This method advantageously but optionally includes the following additional features, taken individually or in any combination that a person skilled in the art would consider to be technically compatible:

* said dynamic characteristic comprises at least one characteristic from the available energy on board and a behavioral anomaly.

* the graph includes nodes designating landing stations or zones, and the step of dynamically determining the new path takes into account the positions of the landing station or zone nodes.

* the step of dynamically determining the new path also takes into account the status (free, occupied) of the station or landing zone nodes.

* the method includes a modification of the priority in case of a behavioral anomaly.

According to a fifth aspect, there is provided an unmanned aerial device, wherein the unmanned aerial device includes digital processing and wireless communication circuits designed to implement all or part of any of the above methods.

According to a sixth aspect, there is provided a computer program, suitable for loading on board an unmanned aerial device, wherein the

computed program includes instructions suitable for implementing all or part of any of the above methods.

Brief description of the drawings

Other aspects, objectives and advantages of the present invention will become clearer from the following detailed description of preferred embodiments thereof, given by way of non-limiting example and made with reference to the appended drawings, in which:

- Figure 1 is a plan view of a simplified site on which a UAV must operate,
- Figure 2 is an elevation view of the simplified site in Figure 1,
- Figure 3 is a perspective view of the simplified site in Figures 1 and 2,
- Figure 4 is a view similar to Figure 1, showing safety zones surrounding no-fly zones,
- Figure 5 is a view similar to Figure 2, showing safety zones surrounding no-fly zones,
- Figure 6 is a plan view at a first altitude, illustrating a possible spatial breakdown of the simplified site at this altitude,
- Figure 7 is a plan view at a second altitude, illustrating a possible spatial breakdown of the simplified site at this altitude,
- Figure 8 is a plan view at a third altitude, illustrating a possible spatial breakdown of the simplified site at this altitude,
- Figure 9 is a plan view at a fourth altitude, illustrating a possible spatial breakdown of the simplified site at this altitude,
- Figure 10 illustrates a theoretical path via points of the spatial breakdown of Figure 6,
- Figure 11 shows a corrected path established from the points in Figure 10, and
- Figure 12 illustrates the overall architecture of a drone system suitable for implementing the invention.

Detailed description of preferred embodiments

Claims

1. A modeling method using digital processing of a three-dimensional environment in order to establish pathways for unmanned aerial devices optimized according to different priorities, characterized in that the method comprises the following digital processing steps:

(a) providing a three-dimensional model of volumes (PEXi) in which flight is prohibited,

(b) subdividing the model into individual elements (PVk),

(c) determining a center (Pk) for each individual element,

(d) establishing and memorizing a graph, the nodes (Pk, Ik) of which are formed by at least one portion of said centers, and are connected by branches,

(e) determining a priority among a set of priorities for a path to be followed by an unmanned aerial device, and

(f) weighing the branches of the graph by means of one or several weighing schemes according to the determined priority.

2. The method according to claim 1, wherein the priorities include at least two priorities from an absolute distance priority, a travel time priority, an energy consumption priority, and a risk priority.

3. The method according to one of claims 1 and 2, wherein at least one of the weighting schemes depends on a constraint affecting the set of branches.

4. The method according to claim 3, wherein said constraint comprises a constraint vector affecting all branches.

5. The method according to claim 4, wherein the constraint vector is a wind vector, each branch having a pair of weights associated respectively with the direction of travel and each weight being distinctly subject to the wind vector.

6. The method according to one of claims 1 and 2, wherein said weighting scheme is such that different weights are assigned to the same branch depending on the direction of travel, so as to generate preferred directions of travel.

7. The method according to one of claims 1 and 2, wherein said weighting scheme is based on a mapping defining different levels of constraints depending on the location in a flight space.

8. The method according to claim 7, wherein the constraint levels are included in a group comprising a maximum authorized speed constraint and a risk constraint.

9. The method according to claim 8, wherein the constraint is able to assume a value such that the corresponding zone becomes a no-fly zone.

10. The method according to one of claims 1-9, wherein step (a) comprises providing a three-dimensional model having volumes (PEXi) in which flight is physically impossible, and reprocessing this model with static safety margin data.

11. The method according to claim 10, wherein step (a) comprises subdividing the three-dimensional model into horizontal slices (Txy), the projection of the volumes onto a horizontal plane being the same throughout the thickness of each slice, and implementing a subdivision into individual elements in each horizontal plane.

12. The method according to claim 11, wherein the subdivision is performed by triangulation.

13. The method according to claim 12, wherein the triangulation is a Delaunay triangulation.

14. The method according to one of claims 11 to 13, wherein step (d) comprises establishing branches of the graph between nodes located in adjacent horizontal planes by a distance minimization approach.

15. A method for determining, by an unmanned aerial device, a path between two points in a three-dimensional space modeled by a graph obtained by the method according to one of claims 1 to 14, characterized in that it comprises the following steps:

- determining a priority for the route,
- taking into consideration or establishing a given graph corresponding to the determined priority, and
- defining the route, on board the device, by a best path computation in said given graph.

16. The method according to claim 15, wherein the step of weighting the branches of the graph is implemented by remotely receiving a starting graph with unweighted branches, and weighting, on board the device, said branches according to said at least one weighing scheme.

17. The method according to one of claims 15 and 16, which comprises, during flight, a step of updating the branch weights of at least a portion of the graph and a step of recomputing the best path in the graph.

18. The method according to claim 17, wherein the updating of the weights of the branches of the graph is performed according to a change in priority.

19. The method according to claim 17 or 18, wherein the updating of the weights of the branches of at least a portion of the graph is performed based

on receipt of modified weighting data for the weighting scheme corresponding to the current priority.

20. The method according to one of claims 15 to 19, wherein the step of updating the weights of the branches of the graph comprises generating prohibited branches based on a dynamically occurring prohibited zone.

21. The method according to claim 20, wherein the prohibited zone is determined by remote communication of the device with other equipment of which the position determines the prohibited zone.

22. The method according to claim 21, wherein the other equipment is another unmanned aerial device.

23. The method according to claim 22, wherein the prohibited zone is a prohibited altitude landing.

24. The method according to claim 23, wherein the other equipment is associated with a temporary site intervention.

25. The method according to one of claims 15 to 24, wherein the computation of the best path is performed according to an agility constraint of the device.

26. A method for steering an unmanned aerial device, comprising the following steps:

- determining a path by the method according to one of claims 15 to 25,
- applying at least one trajectory relaxation factor,
- determining an allowable trajectory deviation as a function of the relaxation factor, and

- applying a trajectory correction instruction only when an actual measured trajectory deviation exceeds the allowable trajectory deviation.

27. The method according to claim 26, wherein the relaxation factor is determined from at least one piece of data representative of one of the following pieces of information: current accuracy of a GPS unit installed on the device, wind, response of the device to steering commands, size of the device, type of device.

28. A method for steering an unmanned aerial device, comprising the following steps:

- determining a path by the method according to one of claims 15 to 25,
- measuring a dynamic characteristic of the device during the flight,
- dynamically determining a new path according to the evolution of said dynamic characteristic.

29. The method according to claim 28, wherein said dynamic characteristic comprises at least one characteristic from on-board available energy and a behavioral anomaly.

30. The method according to claim 28 or 29, wherein the graph comprises nodes designating landing stations or zones, and wherein the step of dynamically determining the new path takes into account the positions of the landing station or zone nodes.

31. The method according to claim 30, wherein the step of dynamically determining the new path also takes into account statuses (free, occupied) of station or landing zone nodes.

32. The method according to claim 29, which comprises modifying the priority in the event of a behavioral anomaly.

33. An unmanned aerial device, characterized in that it comprises digital processing and wireless communication circuits designed for the implementation in whole or in part of the method according to one of claims 1 to 32.

34. A computer program, suitable for being loaded on board an unmanned aerial device, characterized in that it comprises instructions suitable for implementing all or part of the method according to one of claims 1 to 32.