MULTI-ROTOR TONAL NOISE CONTROL FOR UAV

TECHNICAL FIELD

[0001] This disclosure relates generally to unmanned aerial vehicles (UAVs), and in particular, relates to noise control of UAVs.

BACKGROUND INFORMATION

[0002] An unmanned vehicle, which may also be referred to as an autonomous vehicle, is a vehicle capable of travel without a physically-present human operator. An unmanned vehicle may operate in a remote-control mode, in an autonomous mode, or in a partially autonomous mode.

[0003] When an unmanned vehicle operates in a remote-control mode, a pilot or driver that is at a remote location can control the unmanned vehicle via commands that are sent to the unmanned vehicle via a wireless link. When the unmanned vehicle operates in autonomous mode, the unmanned vehicle typically moves based on pre-programmed navigation waypoints, dynamic automation systems, or a combination of these. Further, some unmanned vehicles can operate in both a remote-control mode and an autonomous mode, and in some instances may do so simultaneously. For instance, a remote pilot or driver may wish to leave navigation to an autonomous system while manually performing another task, such as operating a mechanical system for picking up objects, as an example.

[0004] Various types of unmanned vehicles exist for various different environments. For instance, unmanned vehicles exist for operation in the air, on the ground, underwater, and in space. Unmanned aerial vehicles (UAVs) are becoming more popular in general. Their use over populated areas, such as suburban and urban localities, means that controlling the noise generated by these vehicles is increasingly important.

SUMMARY

[0004a] According to a first aspect of the present invention, there is provided an unmanned aerial vehicle (UAV), comprising:

a UAV body;

a plurality of rotor units mounted to the UAV body, each of the rotor units including a bladed rotor that rotates to generate thrust; and

a control system coupled to each of the rotor units to control rotation of the bladed rotor of each of the rotor units, wherein the control system includes a controller with logic that, when executed by the controller, will cause the UAV to perform operations including:

adjusting at least one of a rotation rate or a phase delay of at least one of the rotor units relative to another of the rotor units, wherein adjusting the at least one of the rotation rate or the phase delay causes a spread in tonal noises generated by the rotor units.,

wherein adjusting at least one of the rotation rate or the phase delay comprises offsetting phase delays of the rotor units relative to each other to offset phases of peak amplitudes of the tonal noises generated by different ones of the rotor units from each other,

wherein offsetting the phase delays of the rotor units relative to each other comprises:

determining a rotation period for one or more of the rotor units;

dividing the rotation period by a number N of the rotor units to generate a phase delay value; and

phase delaying each of the number N of the rotor units by a different integer multiple of the phase delay value.

[0004b] According to a second aspect of the present invention, there is provided a method of controlling tonal noises produced by an unmanned aerial vehicle (UAV), the method comprising:

generating thrust with a plurality of rotor units mounted to the UAV to propel the UAV into flight, each of the rotor units including a bladed rotor; and

adjusting at least one of a rotation rate or a phase delay of at least one of the rotor units relative to one or more others of the rotor units, wherein adjusting the at least one of the rotation rate or the phase delay causes a spread in the tonal noises generated by the rotor units,

wherein adjusting at least one of the rotation rate or the phase delay comprises offsetting phase delays of the rotor units relative to each other to offset phases of peak amplitudes of the tonal noises generated by different ones of the rotor units from each other,

wherein offsetting the phase delays of the rotor units relative to each other comprises:

determining a rotation period for one or more of the rotor units;

dividing the rotation period by a number N of the rotor units to generate a phase delay value; and

phase delaying each of the number N of the rotor units by a different integer multiple of the phase delay value

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Non-limiting and non-exhaustive embodiments of the invention are described with reference to the following figures, wherein like reference numerals refer to like parts throughout the various views unless otherwise specified. Not all instances of an element are necessarily labeled so as not to clutter the drawings where appropriate. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles being described.

CLAIMS

1. An unmanned aerial vehicle (UAV), comprising:

a UAV body;

a plurality of rotor units mounted to the UAV body, each of the rotor units including a bladed rotor that rotates to generate thrust; and

a control system coupled to each of the rotor units to control rotation of the bladed rotor of each of the rotor units, wherein the control system includes a controller with logic that, when executed by the controller, will cause the UAV to perform operations including:

adjusting at least one of a rotation rate or a phase delay of at least one of the rotor units relative to another of the rotor units, wherein adjusting the at least one of the rotation rate or the phase delay causes a spread in tonal noises generated by the rotor units,

wherein adjusting at least one of the rotation rate or the phase delay comprises offsetting phase delays of the rotor units relative to each other to offset phases of peak amplitudes of the tonal noises generated by different ones of the rotor units from each other,

wherein offsetting the phase delays of the rotor units relative to each other comprises:

determining a rotation period for one or more of the rotor units;

dividing the rotation period by a number N of the rotor units to generate a phase delay value; and

phase delaying each of the number N of the rotor units by a different integer multiple of the phase delay value.

2. The UAV of claim 1, wherein the rotation period for the one or more of the rotor units is determined by determining a revolution frequency for one or more of the rotor units.

3. The UAV of claim 1, wherein the number N comprises a total number of the rotor units mounted to the UAV body.

4. The UAV of claim 1, wherein offsetting the phase delays of the rotor units relative to each other further comprises:

grouping the plurality of rotor units into noise generating subgroups (i) based upon proximity of the rotor units to each other;

generating a phase delay value D(i) for each of the noise generating subgroups (i) based upon a number N(i) of the rotors in each of the noise generating subgroups (i); and

phase delaying each of the rotor units within a given one of the noise generating subgroups (i) relative to other ones of the rotor units within the given one of the noise generating subgroups (i) by a different integer multiple of the phase delay value D(i).

5. The UAV of claim 4, wherein the UAV body includes a wing assembly and first and second boom assemblies mounted to the wing assembly and wherein the rotor units are mounted to the first and second boom assemblies, wherein the rotor units mounted to the first boom assembly fore of the wing assembly comprise a first one of the noise generating subgroups (i), the rotor units mounted to the first boom assembly aft of the wing assembly comprise a second one of the noise generating subgroups (i), the rotor units mounted to the second boom assembly fore of the wing assembly comprise a third one of the noise generating subgroups (i), and the rotor units mounted to the second boom assembly aft of the wing assembly comprise a fourth one of the noise generating subgroups (i).

6. The UAV of claim 2, wherein offsetting the phase delays of the rotor units relative to each other further comprises:

updating the phase delay value in real-time based upon changes in the revolution frequency of the one or more of the rotor units.

7. The UAV of claim 2, wherein determining the revolution frequency for the one or more of the rotor units comprises monitoring one or both of a voltage or a current driving the one or more of the rotor units in real-time and wherein phase delaying each of the rotor units comprises adjusting a pulse width modulation of each of the rotor units in real-time.

8. The UAV of claim 1, wherein adjusting at least one of the rotation rate or the phase delay comprises varying rotation rates of the rotor units relative to each other to

spectrally spread out component frequencies of the tonal noises collectively generated by the rotor units.

9. The UAV of claim 8, wherein one or more of the rotor units have different physical geometries relative to each other such that different rotation rates for different ones of the rotor units produce a common amount of thrust.

10. The UAV of claim 9, wherein the different physical geometries includes differences in one or more of a diameter of the bladed rotor, a surface area of the bladed rotor, a pitch of the bladed rotor, or a number of blades on the bladed rotor.

11. The UAV of claim 8, wherein varying the rotation rates of the rotor units relative to each other comprises varying the rotation rates in groups of the rotor units to spectrally spread out the component frequencies of the tonal noises while maintaining flight stability.

12. The UAV of claim 8, wherein varying the rotation rates of the rotor units relative to each other to spectrally spread out the component frequencies of the tonal noises comprises introducing a gyroscopic wobble about a stabilized center of the UAV by dynamically modulating the rotation rates of different ones of the rotor units.

13. The UAV of claim 1, wherein the controller includes further logic that, when executed by the controller, will cause the UAV to perform additional operations including:

dynamically modulating the rotation rates of the rotor units to generate a melody with the tonal noises generated by the rotor units, wherein the melody comprises arranging the tonal noises to an acoustical beat;

associating the melody with a particular flight phase;

generating the melody with the rotor units while the UAV is operating in the particular flight phase; and producing different melodies for different flight phases.

14. The UAV of claim 13, wherein the particular flight phase comprises one of an arrival phase, a departure phase, or a transit phase.

15. The UAV of claim 1, wherein the controller includes further logic that, when executed by the controller, will cause the UAV to perform additional operations including:

generating chords with the tonal noises by varying the rotation rates between the rotor units.

16. A method of controlling tonal noises produced by an unmanned aerial vehicle (UAV), the method comprising:

generating thrust with a plurality of rotor units mounted to the UAV to propel the UAV into flight, each of the rotor units including a bladed rotor; and

adjusting at least one of a rotation rate or a phase delay of at least one of the rotor units relative to one or more others of the rotor units, wherein adjusting the at least one of the rotation rate or the phase delay causes a spread in the tonal noises generated by the rotor units,

wherein adjusting at least one of the rotation rate or the phase delay comprises offsetting phase delays of the rotor units relative to each other to offset phases of peak amplitudes of the tonal noises generated by different ones of the rotor units from each other,

wherein offsetting the phase delays of the rotor units relative to each other comprises:

determining a rotation period for one or more of the rotor units;

dividing the rotation period by a number N of the rotor units to generate a phase delay value; and

phase delaying each of the number N of the rotor units by a different integer multiple of the phase delay value.

17. The method of claim 16, wherein the rotation period for the one or more of the rotor units is determined by determining a revolution frequency for the one or more of the rotor units.

18. The method of claim 16, wherein offsetting the phase delays of the rotor units relative to each other further comprises:

grouping the plurality of rotor units into noise generating subgroups (i) based upon proximity of the rotor units to each other;

generating a phase delay value D(i) for each of the noise generating subgroups (i) based upon a number N(i) of the rotors in each of the noise generating subgroups (i); and

phase delaying each of the rotor units within a given one of the noise generating subgroups (i) relative to other ones of the rotor units within the given one of the noise generating subgroups (i) by a different integer multiple of the phase delay value D(i).

19. The method of claim 17, wherein offsetting the phase delays of the rotor units relative to each other further comprises:

updating the phase delay value in real-time based upon changes in the revolution frequency of the one or more of the rotor units.

20. The method of claim 16, wherein adjusting at least one of the rotation rate or the phase delay comprises varying rotation rates of the rotor units relative to each other to spectrally spread out component frequencies of the tonal noises collectively generated by the rotor units.

21. The method of claim 20, wherein one or more of the rotor units have different physical geometries relative to each other such that different rotation rates for different ones of the rotor units produce a common amount of thrust.

22. The method of claim 20, wherein varying the rotation rates of the rotor units relative to each other comprises varying the rotation rates in groups of the rotor units to spectrally spread out the component frequencies of the tonal noises while maintain flight stability.

23. The method of claim 20, wherein varying the rotation rates of the rotor units relative to each other comprises varying the rotation rates of the rotor units relative to each other to generate an interference pattern perceived as an acoustical beat.

24. The method of claim 16, further comprising:

dynamically modulating the rotation rates of the rotor units to generate a melody with the tonal noises generated by the rotor units, wherein the melody comprises arranging the tonal noises to an acoustical beat;

associating the melody with a particular flight phase;

generating the melody with the rotor units while the UAV is operating in the particular flight phase; and

producing different melodies for different flight phases.