CLAIMS

1. A system for passive sensing of unmanned aircrafts (UAs) within a target volume using radio frequency (RF) signals transmitted by satellites and/or aerostats, comprising:

one or more passive RF sensor units, wherein each of the one or more passive RF sensor units is configured to:

a. produce one or more concurrent reception beams, wherein at least one of the one or more concurrent reception beams has a beam direction that matches a present location of an RF-transmitting satellite or aerostat (RTSA) and a beam width that matches an angular width of a forward scatter region, and wherein the RTSA is one of a satellite and an aerostat, which transmits RF signals;

b. receive RTSA resultant signals originating from one or more RTSAs, wherein the RTSA resultant signals are signals transmitted by the one or more RTSAs after traversing a medium between the one or more RTSAs and the one or more passive RF sensor units; and

c. process the received RTSA resultant signals to perform target detection and/or target location estimation based on the forward scatter effect.

2. A system according to claim 1, wherein the beam direction of at least one of the one or more concurrent reception beams is adjusted over time to match an RTSA trajectory.

3. A system according to claim 1, wherein one or more of the following configurations is employed for at least one of the one or more concurrent reception beams:

a. a reception beam with a beam direction that matches a present location of a specific RTSA, and additional beam characteristics that are tailored for the specific RTSA;

b. several reception beams designed to obtain monopulse measurements using RTSA resultant signals transmitted by a specific RTSA;

c. several reception beams designed to obtain interferometric direction-finding measurements using RTSA resultant signals transmitted by a specific RTSA;

d. a reception beam with beam characteristics determined so as to allow concurrent utilization of RTSA resultant signals transmitted by multiple RTSAs;

e. several reception beams designed to concurrently obtain monopulse measurements using RTSA resultant signals transmitted by multiple RTSAs; and

f. several reception beams designed to concurrently obtain interferometric direction-finding measurements using RTSA resultant signals transmitted by multiple RTSAs.

4. A system according to claim 1, wherein beam steering is performed mechanically and/or electronically, wherein the beam steering determines the beam direction for the one or more concurrent reception beams.

5. A system according to claim 1, wherein each of the one or more passive RF sensor units comprises one or more of the following:

a. an antenna module, used for receiving the RTSA resultant signals;

b. an RF module, applying analog-to-digital conversion to the RTSA resultant signals received by the antenna module;

c. a digital module, processing samples generated by the RF module;

d. a power supply;

e. a GNSS receiver;

f. an accurate clock; and

g. a communication module, which may be wired and/or wireless.

6. A system according to claim 5, wherein the RF module and/or the digital module further perform one or more of the following:

a. phase-shifting;

b. true-time-delay application;

c. gain control;

d. down-conversion;

e. band-pass filtering;

f. low-pass filtering;

g. matched filtering; and

h. beamforming.

7. A system according to claim 1, wherein each of the one or more passive RF sensor units is either stationary or mobile, and wherein each of the one or more passive RF sensor units is one of: ground-based, shipborne, and airborne.

8. A system according to claim 1, wherein each of the one or more passive RF sensor units further performs one or more of the following:

a. target location and/or velocity estimation;

b. target tracking;

c. target classification into one of several predefined categories;

d. identification of a target's specific type;

e. prediction and/or detection of events associated with UA safety and/or security;

f. gathering information required for target location and/or velocity estimation;

g. gathering information required for target classification into one of several predefined categories; and

h. gathering information required for identification of a target's specific type.

9. A system according to claim 1, wherein the system further comprises one or more multi-sensor analysis units, wherein each of the one or more multi-sensor analysis units receives and processes data from at least one of the one or more passive RF sensor units, and wherein each of the one or more multi-sensor analysis units performs one or more of the following:

a. target location and/or velocity estimation;

b. target tracking;

c. target classification into one of several predefined categories;

d. identification of a target's specific type;

e. prediction and/or detection of events associated with UA safety and/or security; and

f. control of at least one of the one or more passive RF sensor units to which it is connected.

10. A system according to claim 9, wherein the system further comprises a central analysis unit that receives and processes data from at least one of the one or more multi-sensor analysis units and/or data from at least one of the one or more passive RF sensor units, to provide UA situational surveillance for an entire target volume and optionally to control the one or more multi-sensor analysis units and/or the one or more passive RF sensor units to which it is connected, wherein the UA situational surveillance comprises one or more of the following:

a. target detection;

b. target tracking;

c. target classification;

d. target identification; and

e. prediction and/or detection of events associated with UA safety and/or security.

11. A system according to claim 1, wherein target detection for a given reception beam comprises one or more of the following:

a. defining one or more RTSA resultant signal attributes, computing values of the one or more RTSA resultant signal attributes for one or more time-swaths during a reception beam, and detecting deviations from expected values of the one or more RTSA resultant signal attributes that meet certain predefined criteria;

b. estimating a transmission resultant signal, and detecting differences between the received RTSA resultant signal and the estimated transmission resultant signal that meet certain predefined criteria, wherein the transmission resultant signal is the RTSA resultant signal after subtracting contributions of signals resulting from reflection and/or scattering from targets;

c. applying auto-correlation to the received RTSA resultant signal, and detecting deviations between an auto-correlation output and an auto-correlation output expected in the absence of targets, that meet certain predefined criteria;

d. estimating a transmission resultant signal, applying cross-correlation between the received RTSA resultant signal and the estimated transmission resultant signal, and detecting peaks in a cross-correlation output other than a peak corresponding to a zero time-delay that meet certain predefined criteria; and

e. estimating a transmission resultant signal, computing a difference between the received RTSA resultant signal and the estimated transmission resultant signal to obtain a resultant signal difference, computing a cross-correlation between the resultant signal difference and the estimated transmission resultant signal, and detecting peaks in a cross-correlation output that meet certain predefined criteria.

12. A system according to claim 1, wherein at least one of the one or more passive RF sensor units further comprises one or more sensors of another type, wherein each of the one or more sensors of another type is one of:

a. a radar;

b. an RF sensor monitoring the spectrum;

c. an acoustic sensor;

d. a video camera;

e. an electro-optical sensor;

f. an infrared sensor; and

g. an identification friend-or-foe system.

13. A system according to claim 1, wherein the system provides information to, and/or receives information from, a UA traffic management system.

14. A system according to claim 1, wherein the system provides real-time UA situational surveillance information to one or more UAs, wherein the real-time UA situational surveillance comprises one or more of the following:

a. target detection;

b. target tracking;

c. target classification;

d. target identification; and

e. prediction and/or detection of events associated with UA safety and/or security.

15. A method for passive sensing of unmanned aircrafts (UAs) within a target volume using radio frequency (RF) signals transmitted by satellites and/or aerostats, the method comprising:

receiving RF-transmitting satellite or aerostate (RTSA) resultant signals originating from one or more RTSAs using one or more passive RF sensor units, wherein each of the one or more passive RF sensor units employs one or more concurrent reception beams, wherein at least one of the one or more concurrent reception beams has a beam direction that matches a present location of one or more RTSAs and a beam width that matches an angular width of a forward scatter region, wherein each of the one or more RTSAs is one of a satellite and an aerostat, which transmits RF signals, and wherein the RTSA resultant signals are signals transmitted by the one or more RTSAs after traversing a medium between the one or more RTSAs and the one or more passive RF sensor units; and

processing the received RTSA resultant signals, wherein the processing further comprises performing target detection based on the forward scatter effect using one or more of the following:

a. applying auto-correlation to the received RTSA resultant signal, and detecting deviations between an auto-correlation output and an auto-correlation output expected in the absence of targets;

b. defining one or more RTSA resultant signal attributes, computing values of the one or more RTSA resultant signal attributes for one or more time-swaths during a reception beam, and detecting deviations from expected values of the one or more RTSA resultant signal attributes;

c. estimating a transmission resultant signal, and detecting differences between the received RTSA resultant signal and the estimated transmission resultant signal, wherein the transmission resultant signal is the RTSA resultant signal after subtracting contributions of signals resulting from reflection and/or scattering from targets;

d. estimating a transmission resultant signal, applying cross-correlation between the received RTSA resultant signal and the estimated transmission resultant signal, and detecting peaks in a cross-correlation output other than a peak corresponding to a zero time-delay; and

e. estimating a transmission resultant signal, computing a difference between the received RTSA resultant signal and the estimated transmission resultant signal to obtain a resultant signal difference, computing a cross-correlation between the resultant signal difference and the estimated transmission resultant signal, and detecting peaks in a cross-correlation output.

16. A method according to claim 15, wherein the estimating the transmission resultant signal comprises:

a. estimating a signal transmitted by an applicable RTSA;

b. estimating a signal interaction effect, the signal interaction effect being an effect of signal interaction with the medium and/or the terrain; and

c. applying the estimated signal interaction effect to the estimated signal transmitted by the applicable RTSA, to obtain the estimated transmission resultant signal.

17. A method according to claim 15, wherein the auto-correlation output expected in the absence of targets is derived from statistical analysis of an auto-correlation output obtained in the past.

18. A method according to claim 15, wherein the performing target detection further comprises a pre-processing step, wherein the pre-processing step comprises one or more of the following:

a. beamforming on reception; and

b. digital band-pass filtering whose central frequency and bandwidth are derived from a frequency range employed by a specific RTSA.

19. A method according to claim 15, wherein the processing the received RTSA resultant signals further comprises estimating a target's radar cross-section (RCS) at forward scatter by:

a. measuring a target-transmission power ratio based on outputs computed as part of the performing target detection, wherein the target-transmission power ratio is a power ratio between a target resultant signal and the transmission resultant signal, wherein the target resultant signal is a contribution of signal resulting from reflection and/or scattering from targets to the RTSA resultant signal; and

b. deriving the target's RCS at forward scatter from the target-transmission power ratio using the bi-static radar equation.

20. A method according to claim 15, wherein the processing the received RTSA resultant signals further comprises one or more of:

a. gathering information required for target location estimation; and

b. gathering information required for target velocity estimation;

wherein the gathering information required for target location estimation comprises one or more of the following:

a. bi-static range measurement based on outputs computed as part of the performing target detection;

b. monopulse measurement, providing an estimate of a spatial angle of a target with respect to the one or more passive RF sensor units; and

c. interferometric direction-finding measurements, providing an estimate of a spatial angle of a target with respect to the one or more passive RF sensor units; and

wherein the gathering information required for target velocity estimation comprises one or more of the following:

a. bi-static Doppler shift measurement; and

b. time-difference measurement, comprising measurement of a time difference between target detections in two reception beams, wherein the two reception beams have a similar or equal beam direction and a similar or equal start-time.

21. A method according to claim 20, wherein the processing the received RTSA resultant signals further comprises the target location estimation using one or more of the following:

a. combining the bi-static range measurement with the monopulse measurement and/or the interferometric direction-finding measurement obtained using one or more concurrent or essentially concurrent reception beams having similar beam directions; and

b. multilateration using bi-static range measurements and/or monopulse measurements and/or interferometric direction-finding measurements obtained using two or more concurrent or essentially concurrent reception beams, wherein the two or more concurrent or essentially concurrent reception beams may be associated with one or more of the one or more passive RF sensor units.

22. A method according to claim 20, wherein the processing the received RTSA resultant signals further comprises the target velocity estimation using one or more of the following:

a. combining two or more of the bi-static Doppler shift measurements obtained for two or more concurrent or essentially concurrent reception beams, wherein the two or more concurrent or essentially concurrent reception beams may be associated with one or more of the one or more passive RF sensor units;

b. combining two or more of the time-difference measurements obtained concurrently or essentially concurrently; and

c. combining one or more of the bi-static Doppler shift measurements and one or more of the time-difference measurements obtained concurrently or essentially concurrently.

23. A method according to claim 15, wherein the processing the received RTSA resultant signals further comprises target tracking, wherein the target tracking comprises:

a. target association comprising associating target detection outputs and/or target tracking outputs which are determined to correspond to the same physical target, and are obtained at different times and/or by different reception beams and/or by different passive RF sensor units; and

b. for each target, applying a tracking method to outputs of the target association.

24. A method according to claim 15, wherein the processing the received RTSA resultant signals further comprises target classification into one of several predefined categories and/or identification of a target's specific type.

25. A method according to claim 15, further comprising management of reception beams produced by the one or more passive RF sensor units, wherein the management of reception beams comprises at least one of:

a. determination of a number of reception beams used at any given time; and

b. determination of one or more parameters for at least one of the reception beams.

26. A method according to claim 15, wherein the processing the received RTSA resultant signals further comprises prediction and/or detection of events associated with UA safety and/or security, and wherein the prediction and/or detection of events associated with UA safety and/or security addresses one or more of the following types of events:

a. UAs that do not adhere to safety requirements and/or applicable regulations;

b. UAs that do not transmit remote identification information;

c. UAs that transmit remote identification information but whose remote identification information does not match outputs of passive sensing of the UAs; and

d. UAs that enter unauthorized airspace.

27. A system for passive sensing of unmanned aircrafts (UAs) within a target volume using radio frequency (RF) signals transmitted by satellites and/or aerostats, said system comprising one or more passive RF sensor units, wherein each of the one or more passive RF sensor units is configured to:

a. produce one or more concurrent reception beams;

b. receive RF-transmitting satellite or aerostat (RTSA) resultant signals originating from one or more RTSAs, wherein each of the one or more RTSAs is one of a satellite and an aerostat, which transmits RF signals, and wherein the RTSA resultant signals are signals transmitted by the one or more RTSAs after traversing a medium between the one or more RTSAs and the one or more passive RF sensor units; and

c. process the received RTSA resultant signals to perform target detection based on the forward scatter effect.

28. A method for passive sensing of unmanned aircrafts (UAs) within a target volume using radio frequency (RF) signals transmitted by satellites and/or aerostats, said method comprising:

receiving RF-transmitting satellite or aerostat (RTSA) resultant signals originating from one or more RTSAs using one or more passive RF sensor units, wherein each of the one or more

passive RF sensor units employs one or more concurrent reception beams, wherein each of the one or more RTSAs is one of a satellite and an aerostat, which transmits RF signals, and wherein the RTSA resultant signals are signals transmitted by the one or more RTSAs after traversing a medium between the one or more RTSAs and the one or more passive RF sensor units; and

processing the received RTSA resultant signals, wherein the processing further comprises performing target detection based on the forward scatter effect using one or more of the following:

a. applying auto-correlation to the received RTSA resultant signal, and detecting deviations between an auto-correlation output and an auto-correlation output expected in the absence of targets, that meet certain predefined criteria;

b. defining one or more RTSA resultant signal attributes, computing values of the one or more RTSA resultant signal attributes for one or more time-swaths during a reception beam, and detecting deviations from expected values of the one or more RTSA resultant signal attributes that meet certain predefined criteria;

c. estimating a transmission resultant signal, and detecting differences between the received RTSA resultant signal and the estimated transmission resultant signal that meet certain predefined criteria, wherein the transmission resultant signal is the RTSA resultant signal after subtracting contributions of signals resulting from reflection and/or scattering from targets;

d. estimating a transmission resultant signal, applying cross-correlation between the received RTSA resultant signal and the estimated transmission resultant signal, and detecting peaks in a cross-correlation output other than a peak corresponding to a zero time-delay that meet certain predefined criteria; and

e. estimating a transmission resultant signal, computing a difference between the received RTSA resultant signal and the estimated transmission resultant signal to obtain a resultant signal difference, computing a cross-correlation between the resultant signal difference and the estimated transmission resultant signal, and detecting peaks in a cross-correlation output that meet certain predefined criteria.