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(54) **UNMANNED VEHICLE RECOGNITION AND THREAT MANAGEMENT**

(71) Applicant: **Digital Global Systems, Inc.**, Tysons Corner, VA (US)

(72) Inventors: **David William Kleinbeck**, Lees Summit, MO (US); **Armando Montalvo**, Winter Garden, FL (US)

(73) Assignee: **Digital Global Systems, Inc.**, Tysons Corner, VA (US)

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(63) Continuation of application No. 18/985,777, filed on Dec. 18, 2024, now Pat. No. 12,307,905, which is a continuation of application No. 18/789,011, filed on Jul. 30, 2024, now Pat. No. 12,243,431, which is a continuation of application No. 18/785,936, filed on Jul. 26, 2024, now Pat. No. 12,205,477, which is a continuation-in-part of application No. 18/775,710, filed on Jul. 17, 2024, now Pat. No. 12,183,213, which is a continuation-in-part of application No. 18/428,606, filed on Jan. 31, 2024, now Pat. No. 12,266,272, which is a continuation of application No. 18/374,376, filed on Sep. 28, 2023, now Pat. No. 11,893,893, which is a continuation of application No. 18/142,904, filed on May 3, 2023, now Pat. No. 11,783,712, which is a continuation of application No. 17/991,348, filed on Nov. 21, 2022, now Pat. No. 11,645,921, which is a continuation of application No. 17/735,615, filed on May 3, 2022, now Pat. No. 11,521,498, which is a continuation of application No. 17/190,048, filed on Mar. 2, 2021, now Pat. No. 11,328,609, which is a continuation of application No. 16/732,811, filed on Jan. 2, 2020, now Pat. No. 10,943,493, which is a continuation of application No. 16/275,575, filed on Feb. 14, 2019, now Pat. No. 10,529,241, which is a continuation-in-part of application No. 16/274,933, filed on Feb. 13, 2019, now Pat. No. 10,498,951, which is a continuation-in-part of application No. 16/180,690, filed on Nov. 5, 2018, now Pat. No. 10,459,020, which is a continuation-in-part of application No. 15/412,982, filed on Jan. 23, 2017, now Pat. No. 10,122,479.

(60) Provisional application No. 62/722,420, filed on Aug. 24, 2018, provisional application No. 62/632,276, filed on Feb. 19, 2018, provisional application No. 62/632,276, filed on Feb. 19, 2018.

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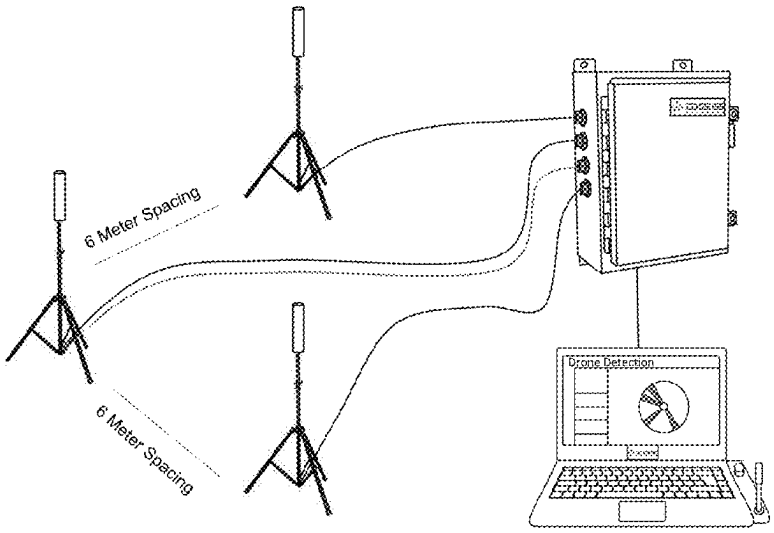
G08G 5/57	(2025.01)

(52) **U.S. Cl.**

CPC ***G08G 5/22*** (2025.01); ***G01S 3/043*** (2013.01); ***G01S 3/046*** (2013.01); ***G01S 3/46*** (2013.01); ***G06N 3/08*** (2013.01); ***G06N 7/01*** (2023.01); ***G08G 5/55*** (2025.01); ***G08G 5/57*** (2025.01)

(57) **ABSTRACT**

Systems and methods for automated unmanned aerial vehicle recognition. A multiplicity of receivers captures RF data and transmits the RF data to at least one node device. The at least one node device comprises a signal processing engine, a detection engine, a classification engine, and a direction finding engine. The at least one node device is configured with an artificial intelligence algorithm. The detection engine and classification engine are trained to detect and classify signals from unmanned vehicles and their controllers based on processed data from the signal processing engine. The direction finding engine is operable to provide lines of bearing for detected unmanned vehicles.



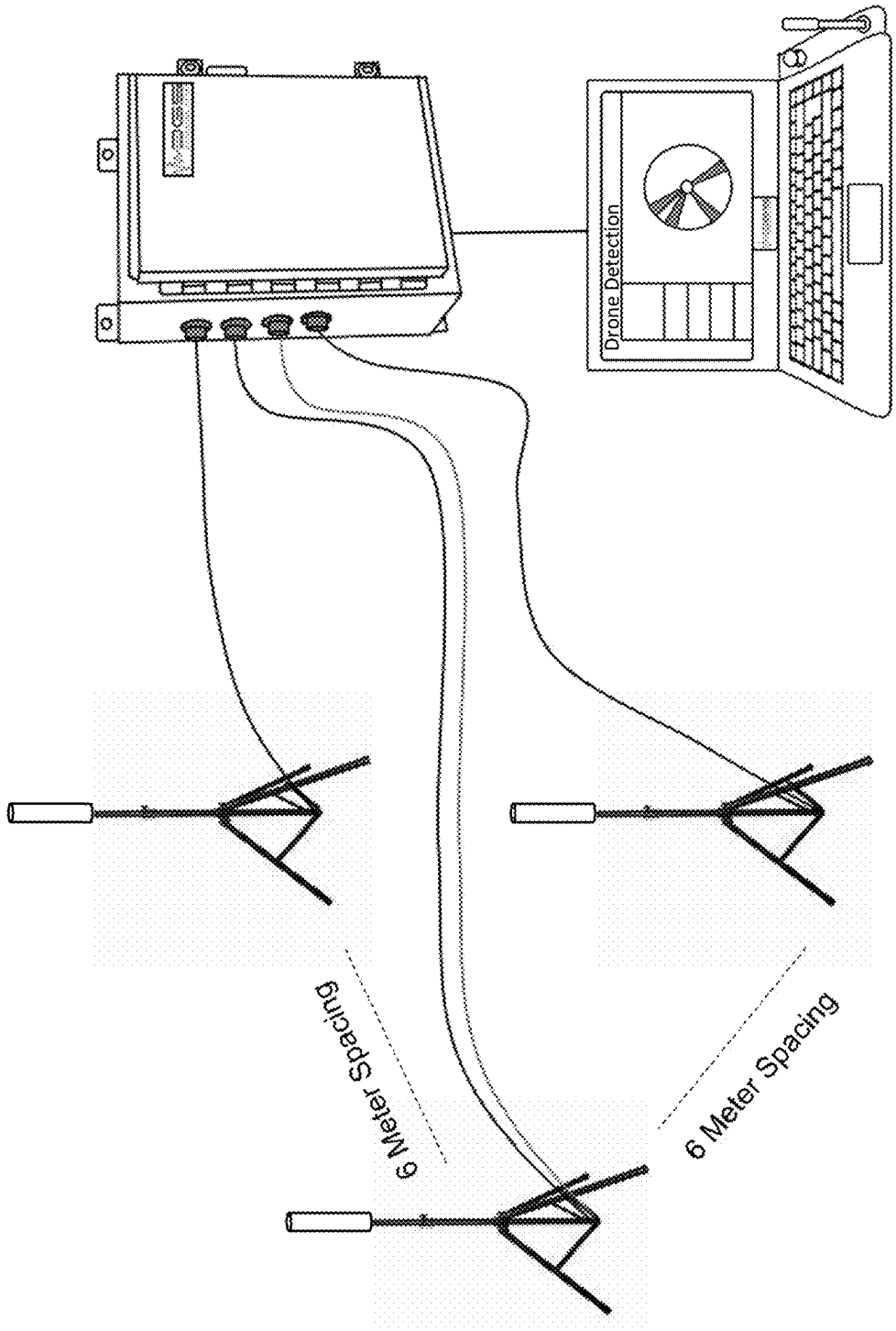


FIG. 1

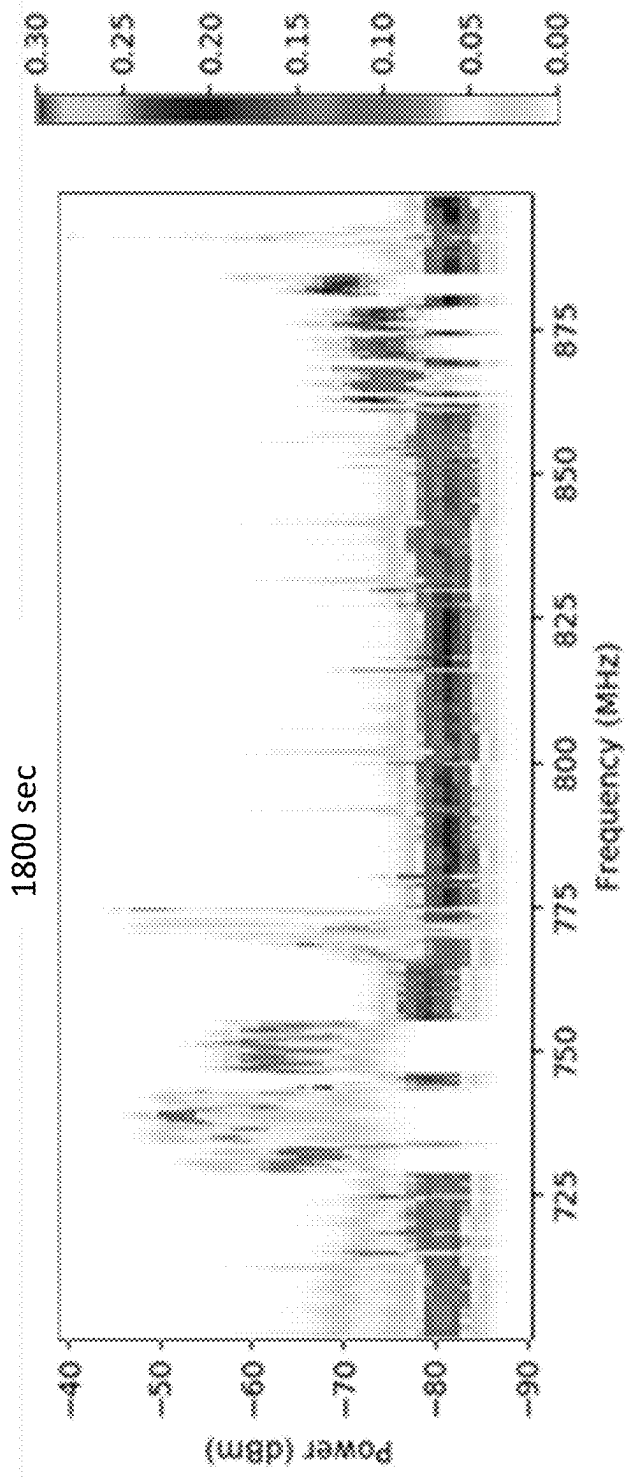

1800 sec
Power (dBm)
-40
-50
-60
-70
-80
-90
725
750
775
800
825
850
875
Frequency (MHz)
0.30
0.25
0.20
0.15
0.10
0.05
0.00

FIG. 2

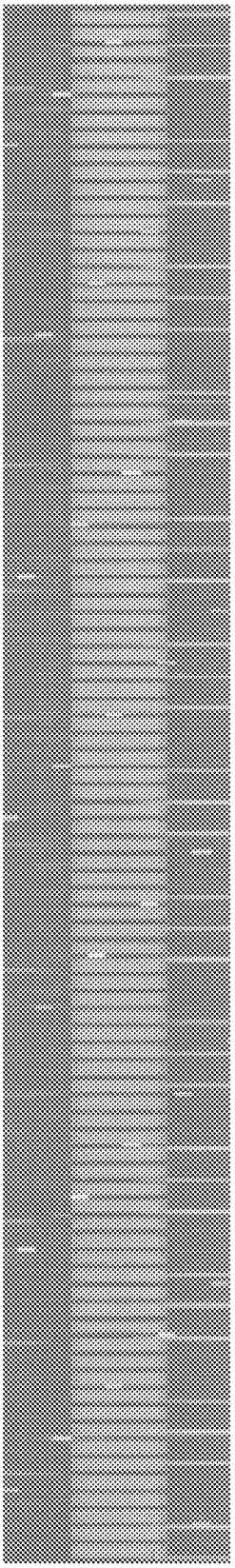


FIG. 3

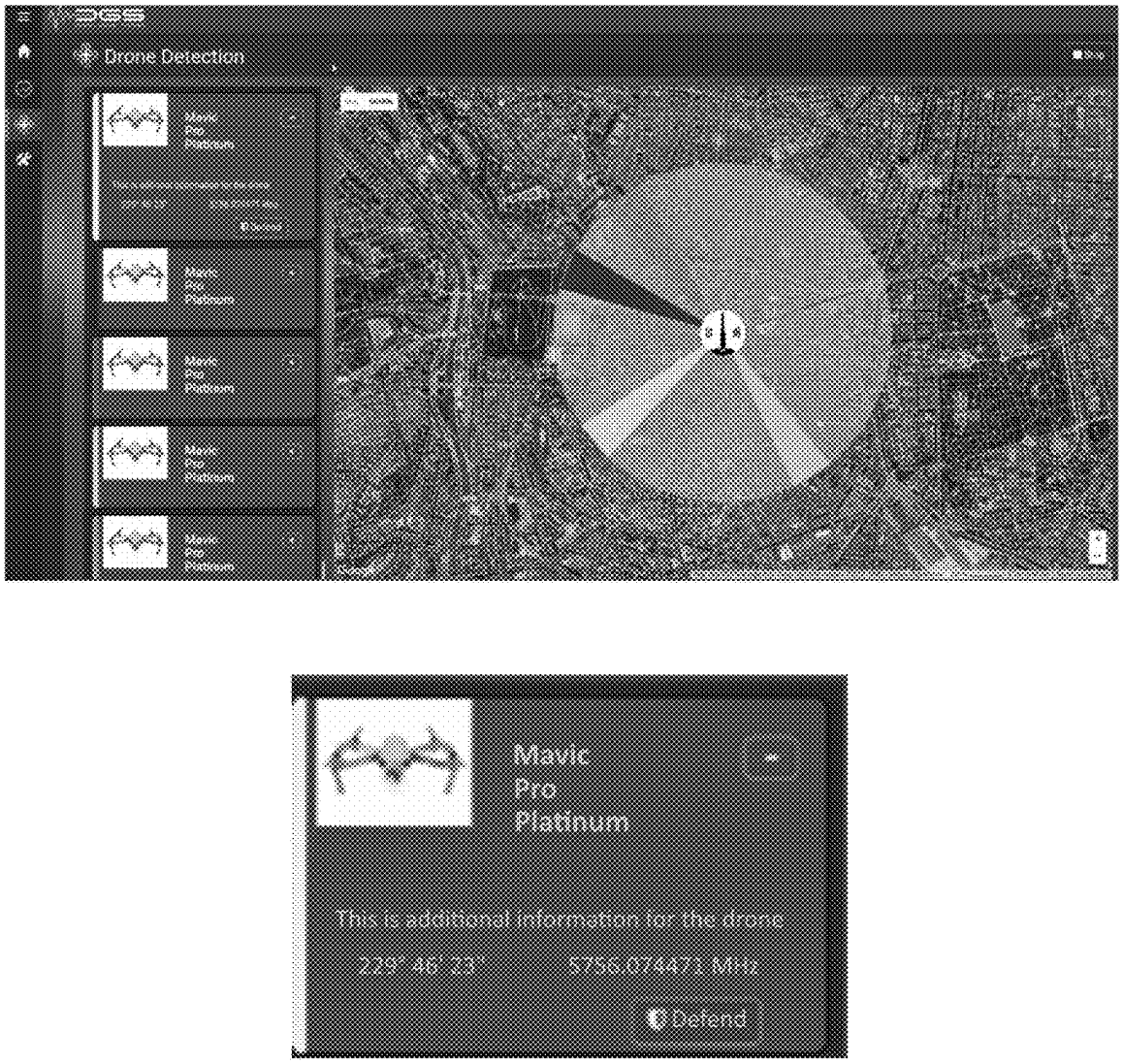

Drone Detection
Mavic
Pro
Platinum
This is additional information for the drone
229° 46' 23"
5736.074471 MHz
Defend

FIG. 4

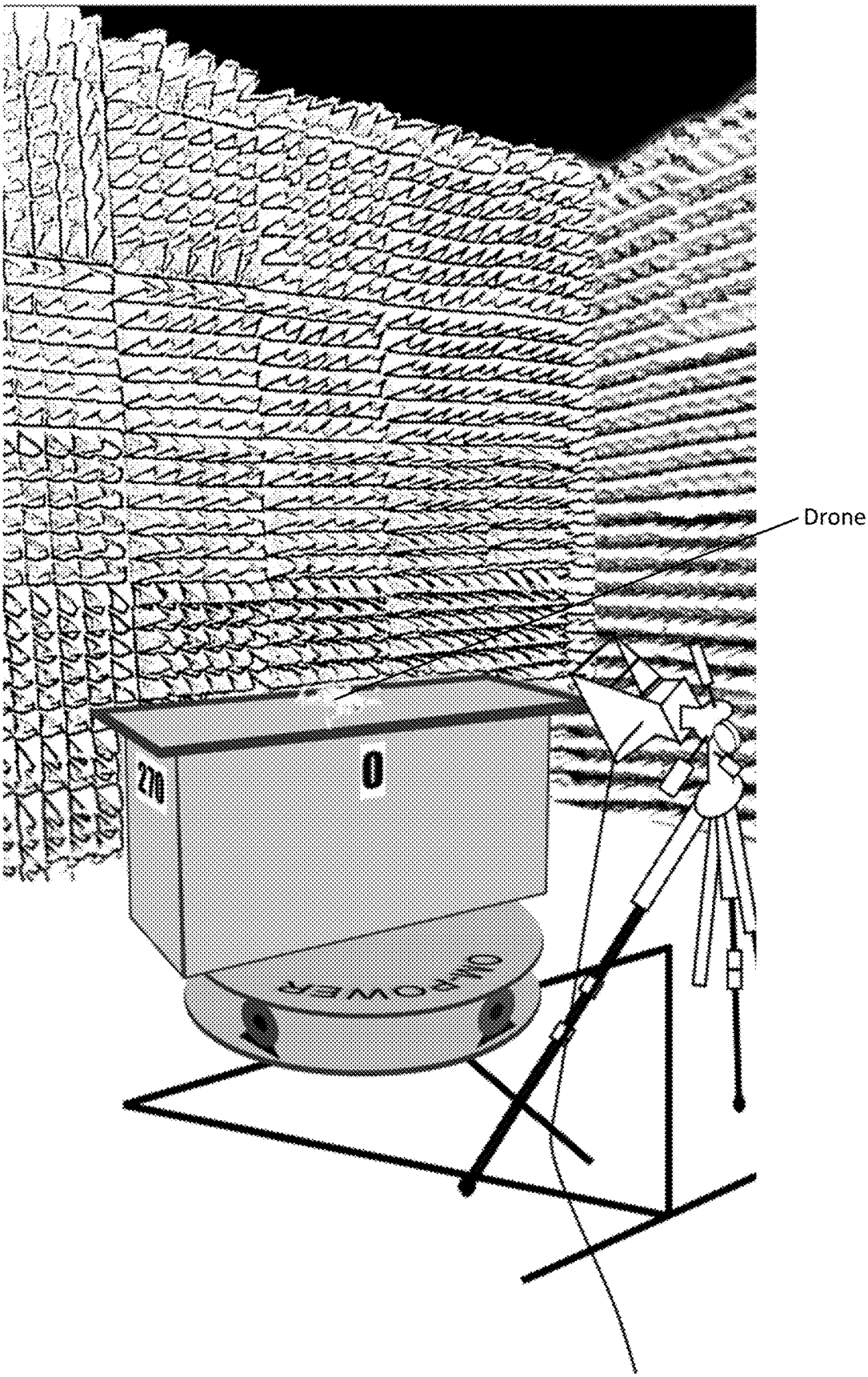


FIG. 5

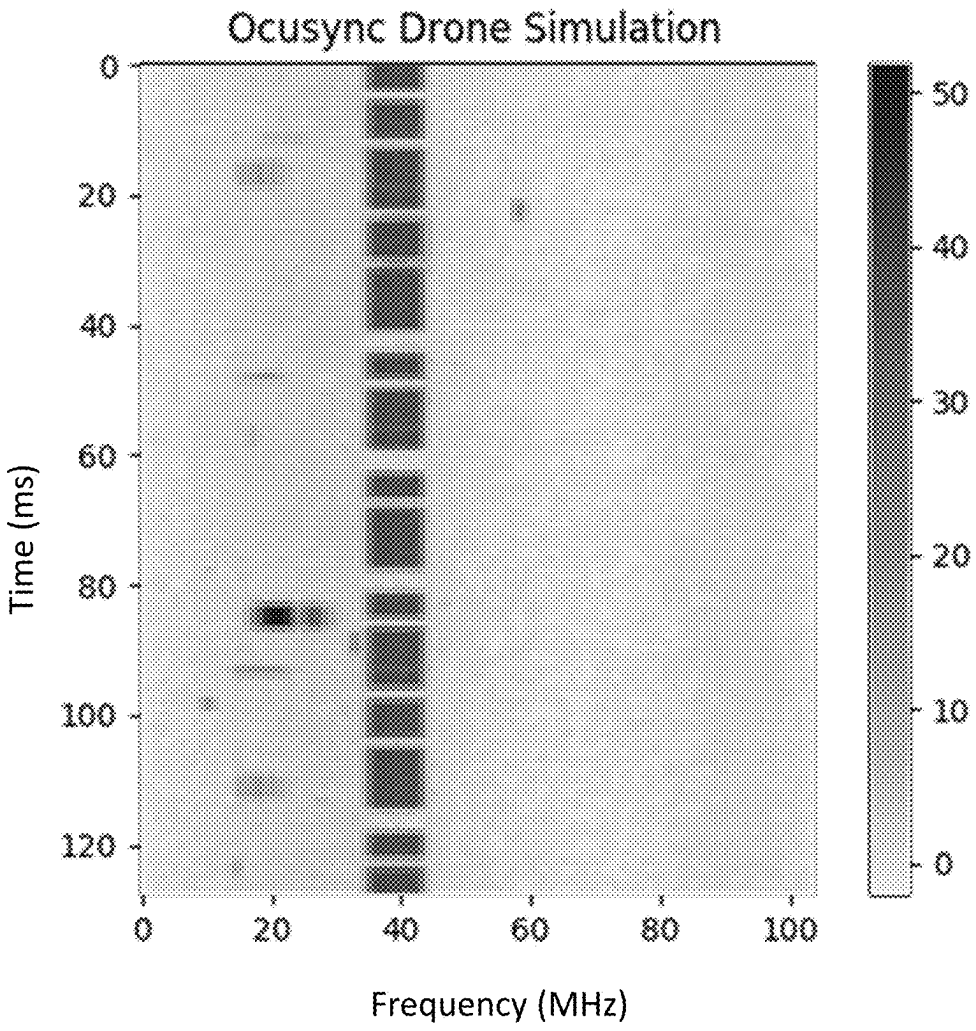

Ocusync Drone Simulation
Time (ms)
0
20
40
60
80
100
120
Frequency (MHz)
0
20
40
60
80
100
50
40
30
20
10
0

FIG. 6

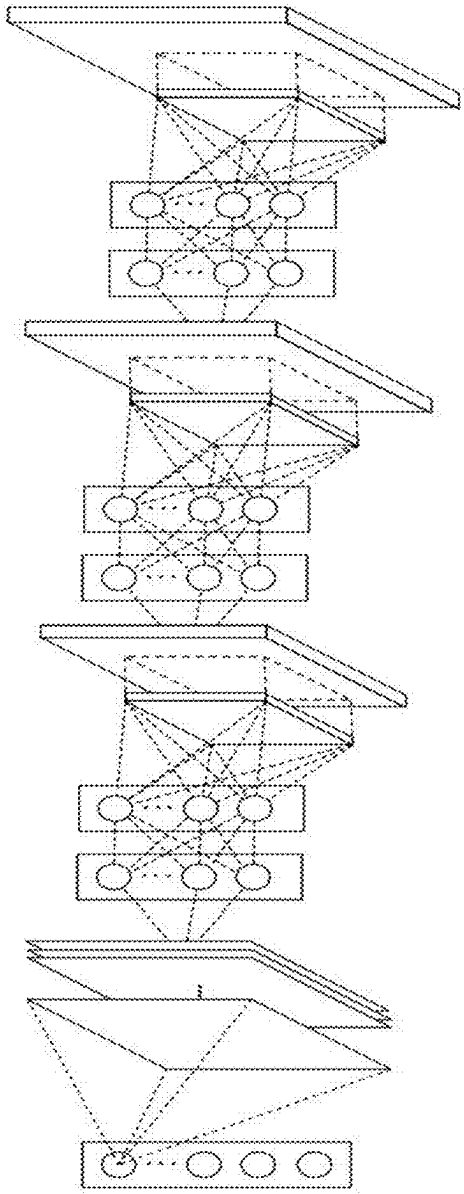


FIG. 7

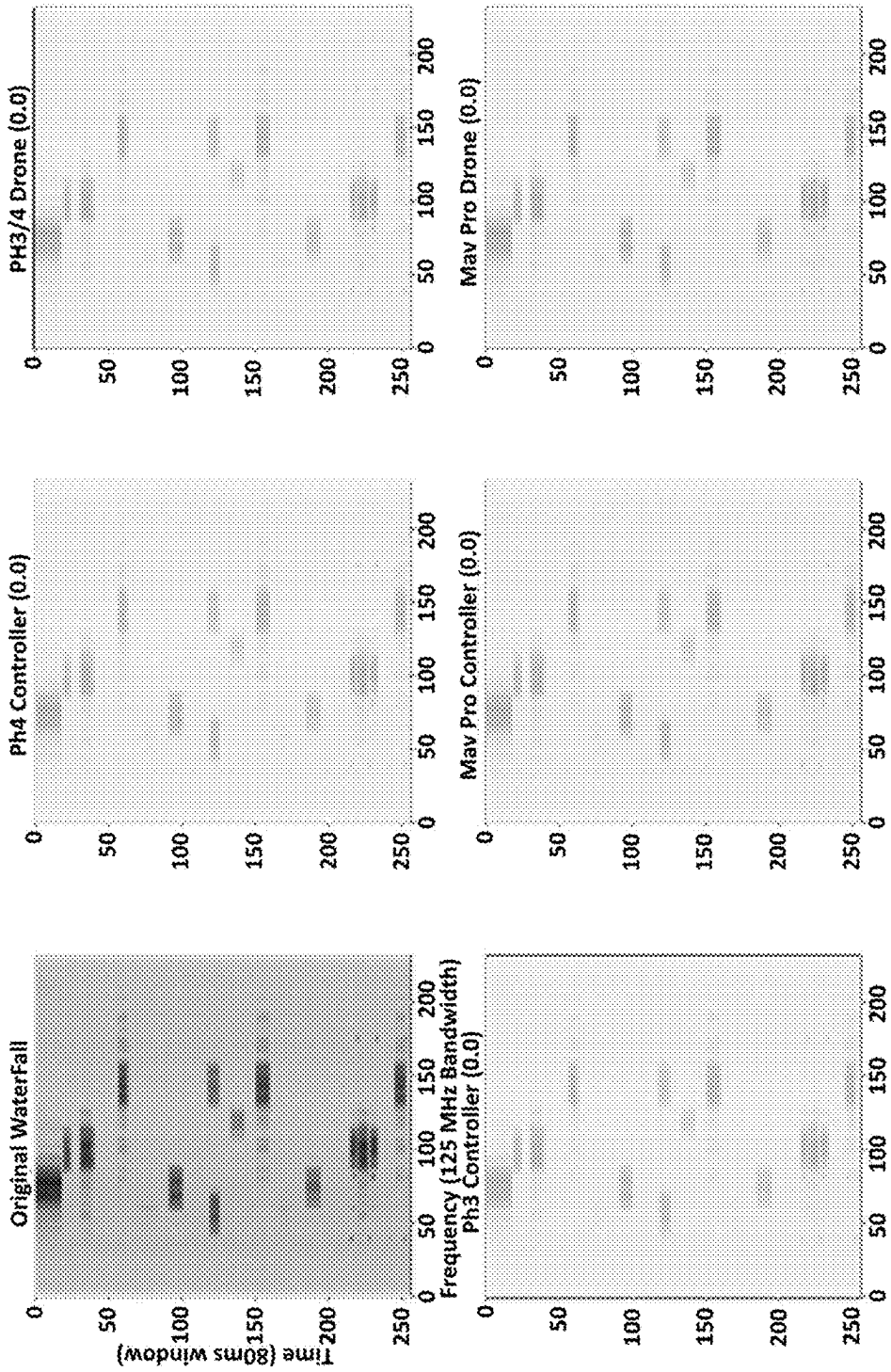

Original WaterFall
Time (80ms window)
Frequency (125 MHz Bandwidth)
Ph3 Controller (0.0)
Ph4 Controller (0.0)
Mav Pro Controller (0.0)
PH3/4 Drone (0.0)
Mav Pro Drone (0.0)
0
50
100
150
200
250

FIG. 8

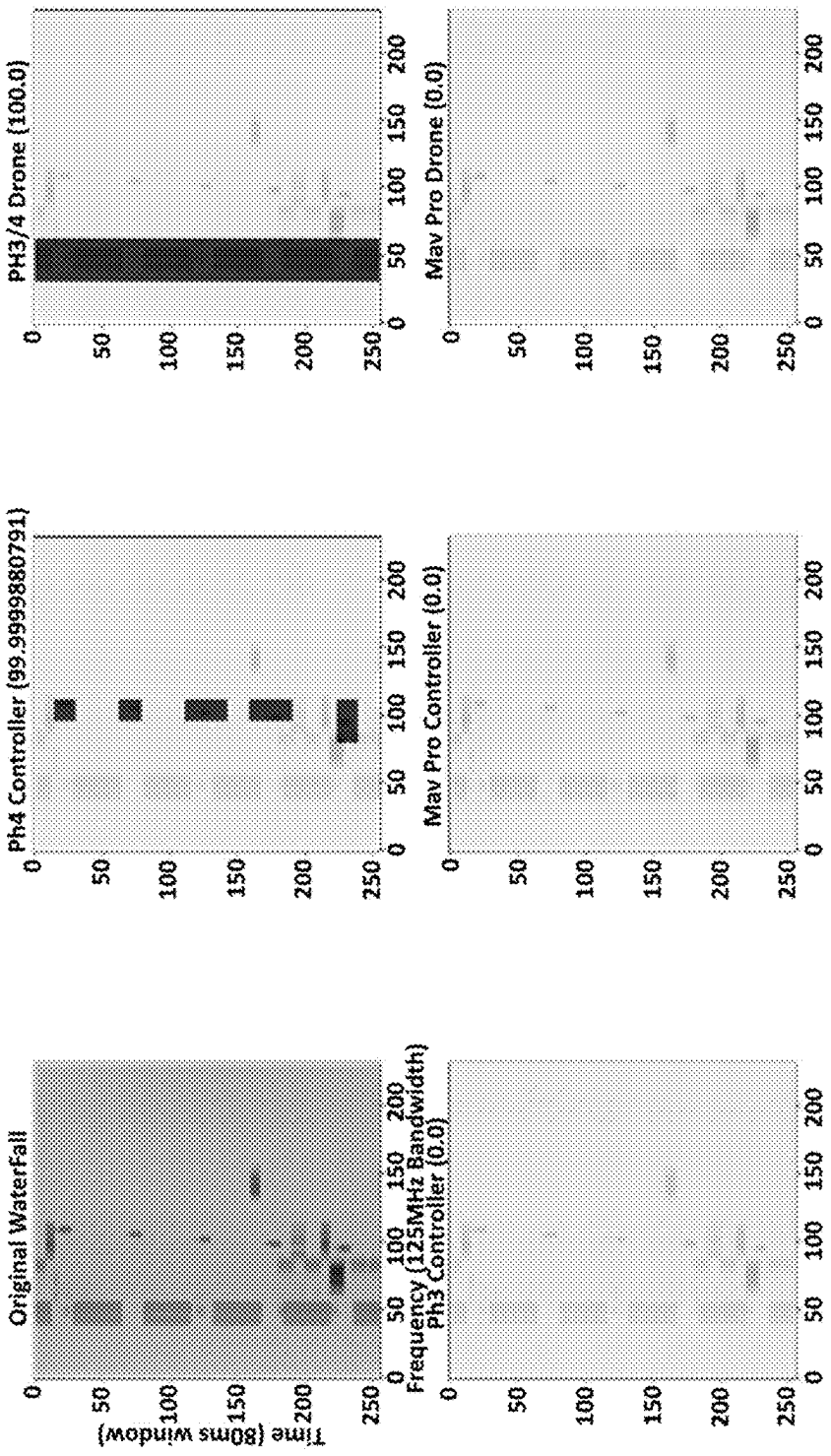

Original WaterFall
Time (80ms window)
Frequency (125MHz Bandwidth)
Ph3 Controller (0.0)
Ph4 Controller (99.99998807 91)
Mav Pro Controller (0.0)
PH3/4 Drone (100.0)
Mav Pro Drone (0.0)
0
50
100
150
200
250

FIG. 9

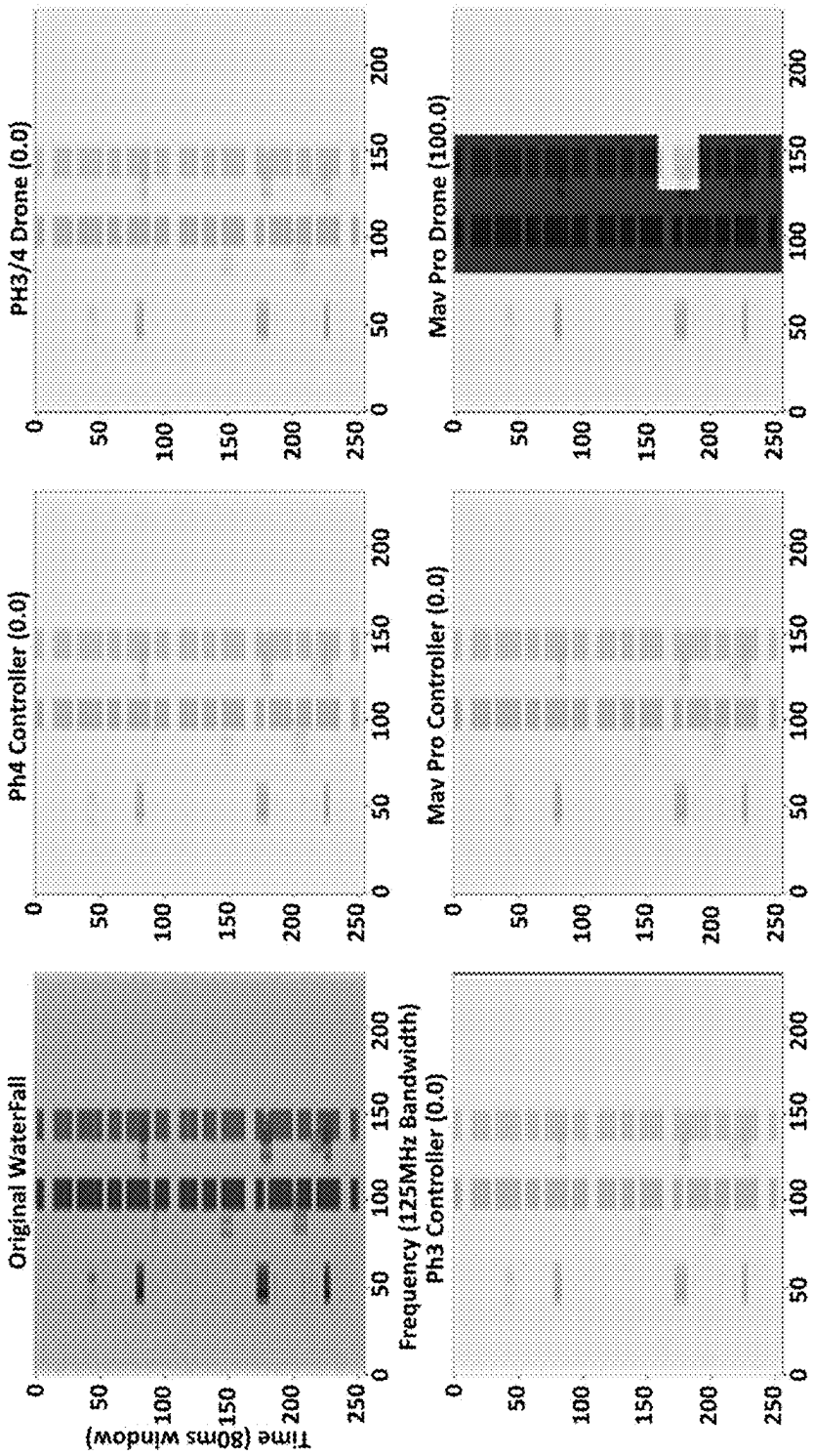

Original WaterFall
Ph4 Controller (0.0)
PH3/4 Drone (0.0)
Ph3 Controller (0.0)
Mav Pro Controller (0.0)
Mav Pro Drone (100.0)
Time (80ms window)
Frequency (125MHz Bandwidth)
0
50
100
150
200
250

FIG. 10

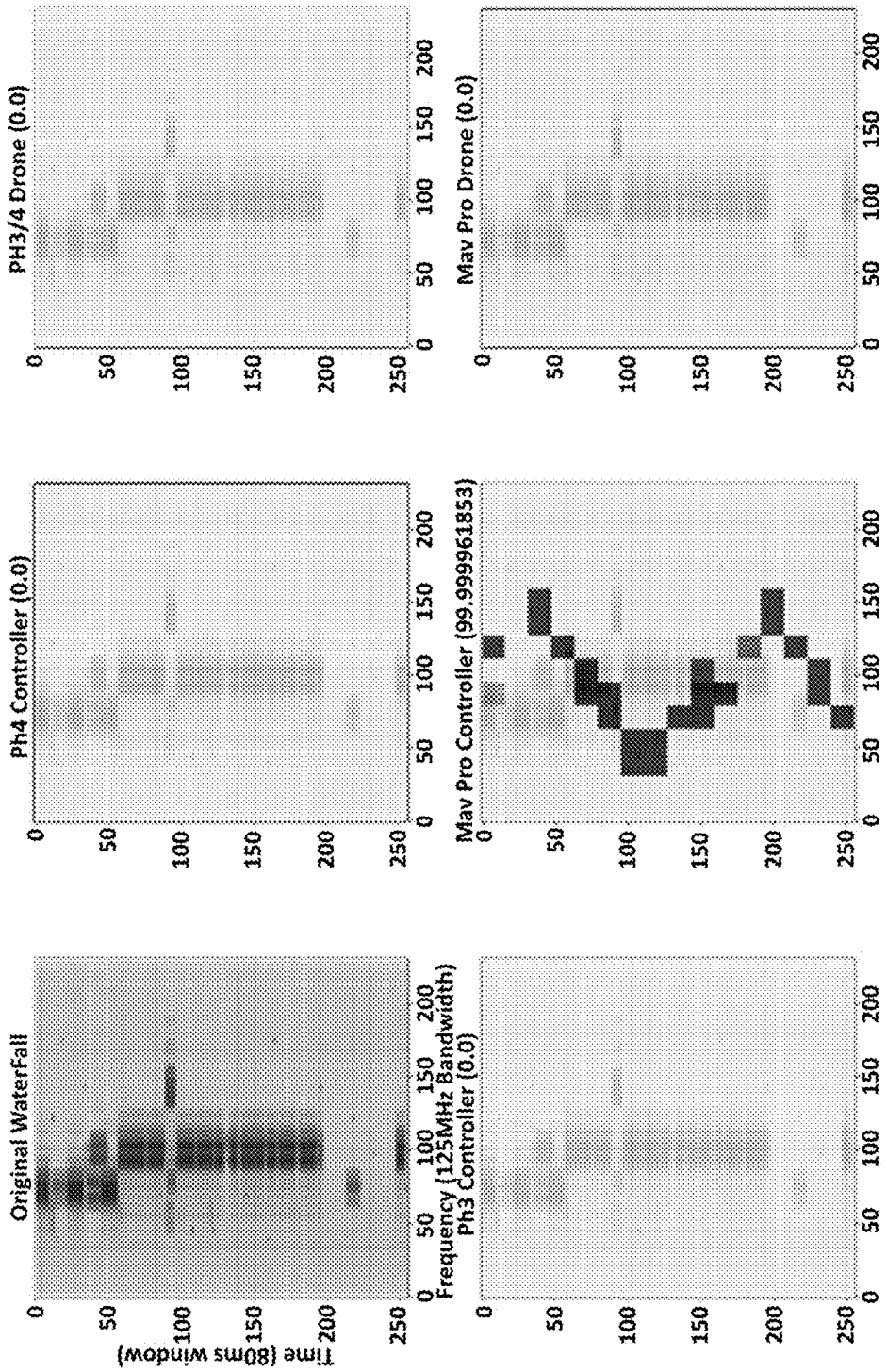

Original WaterFall
Time (80ms window)
Frequency (125MHz Bandwidth)
Ph3 Controller (0.0)
Ph4 Controller (0.0)
Mav Pro Controller (99.999961853)
PH3/4 Drone (0.0)
Mav Pro Drone (0.0)
0
50
100
150
200
250

FIG. 11

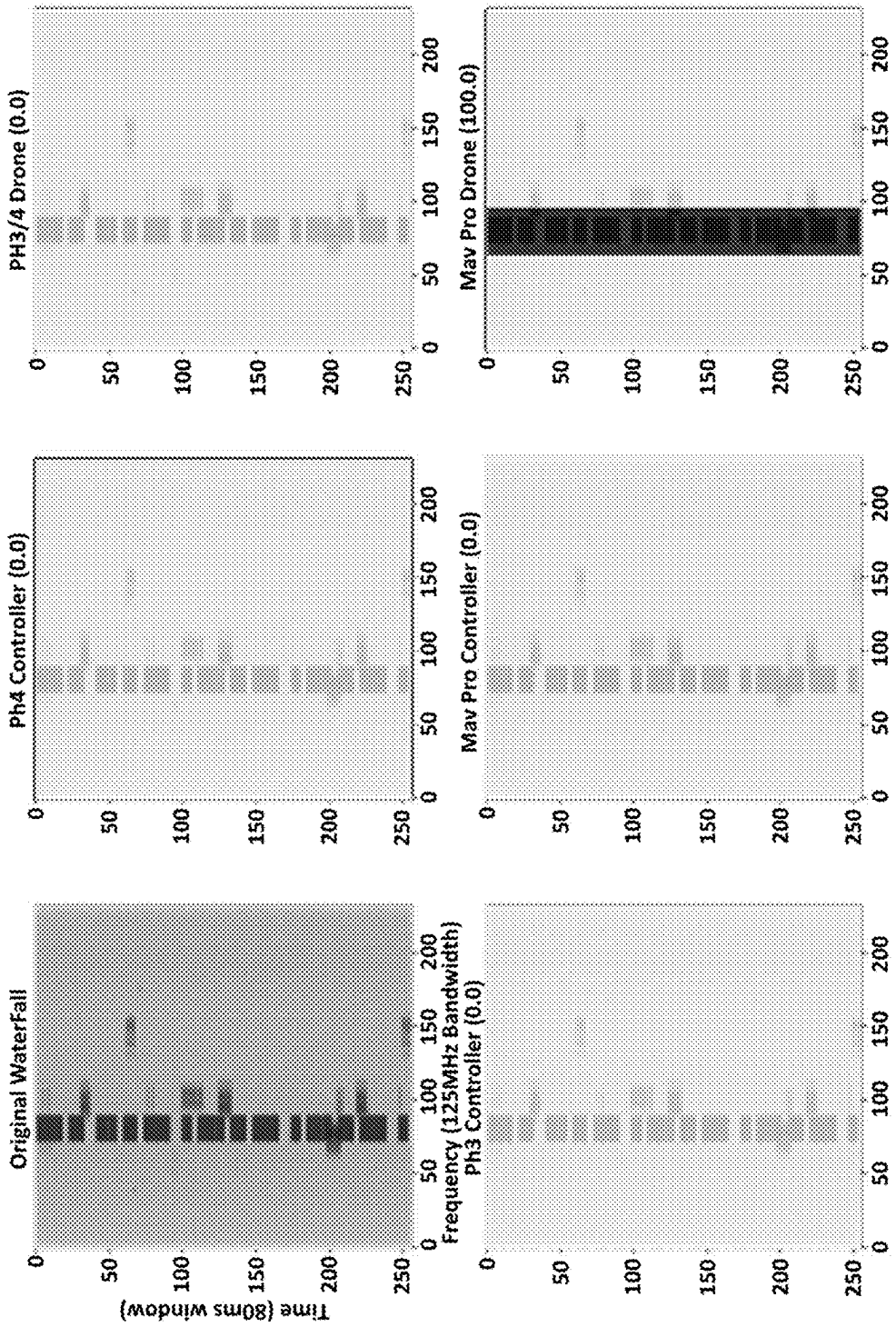

Original WaterFall
Ph4 Controller (0.0)
PH3/4 Drone (0.0)
Ph3 Controller (0.0)
Mav Pro Controller (0.0)
Mav Pro Drone (100.0)
Time (80ms window)
Frequency (125MHz Bandwidth)
0
50
100
150
200
250

FIG. 12

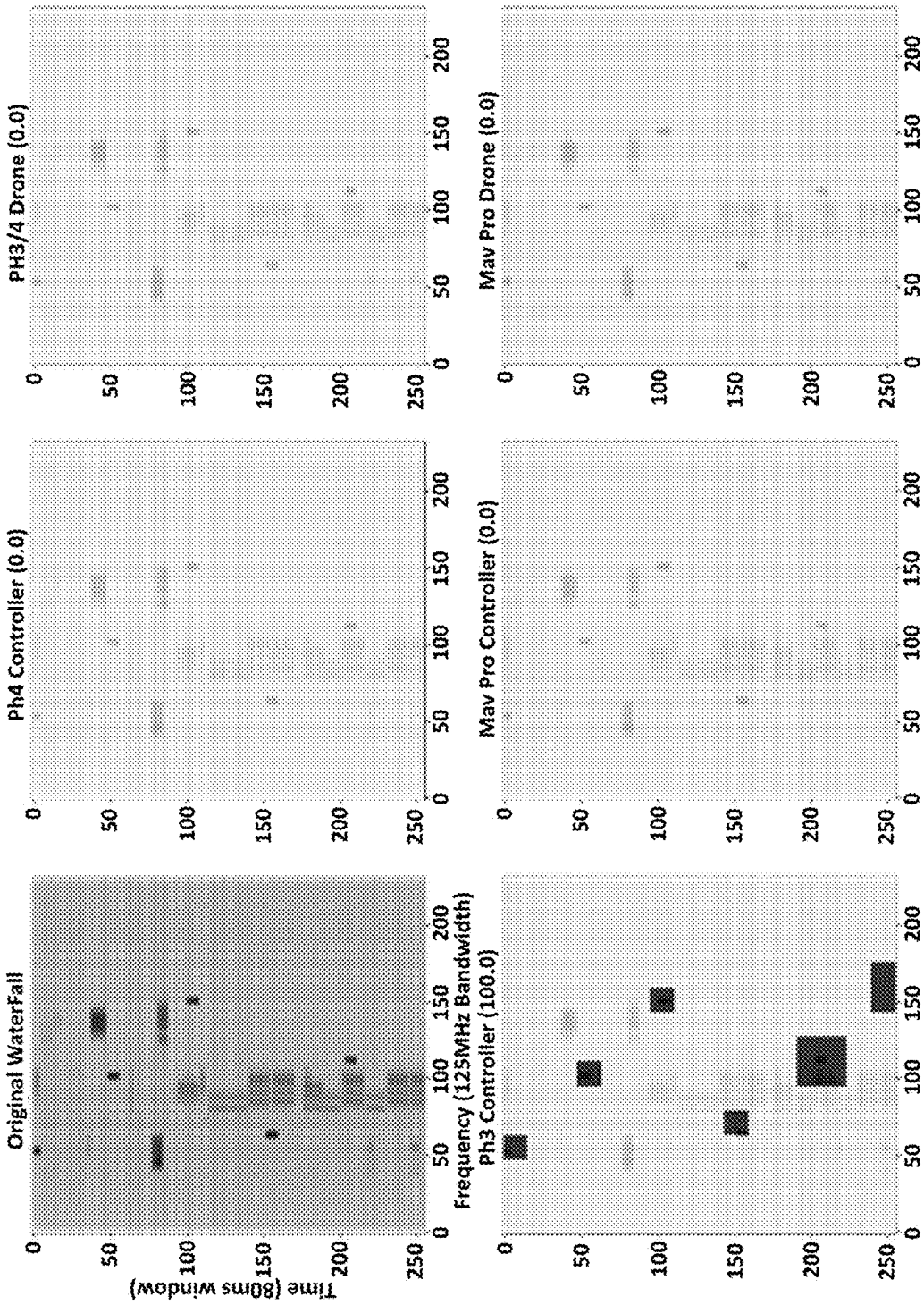

Original WaterFall
Ph4 Controller (0.0)
PH3/4 Drone (0.0)
Ph3 Controller (100.0)
Mav Pro Controller (0.0)
Mav Pro Drone (0.0)
Time (80ms window)
Frequency (125MHz Bandwidth)
0
50
100
150
200
250

FIG. 13

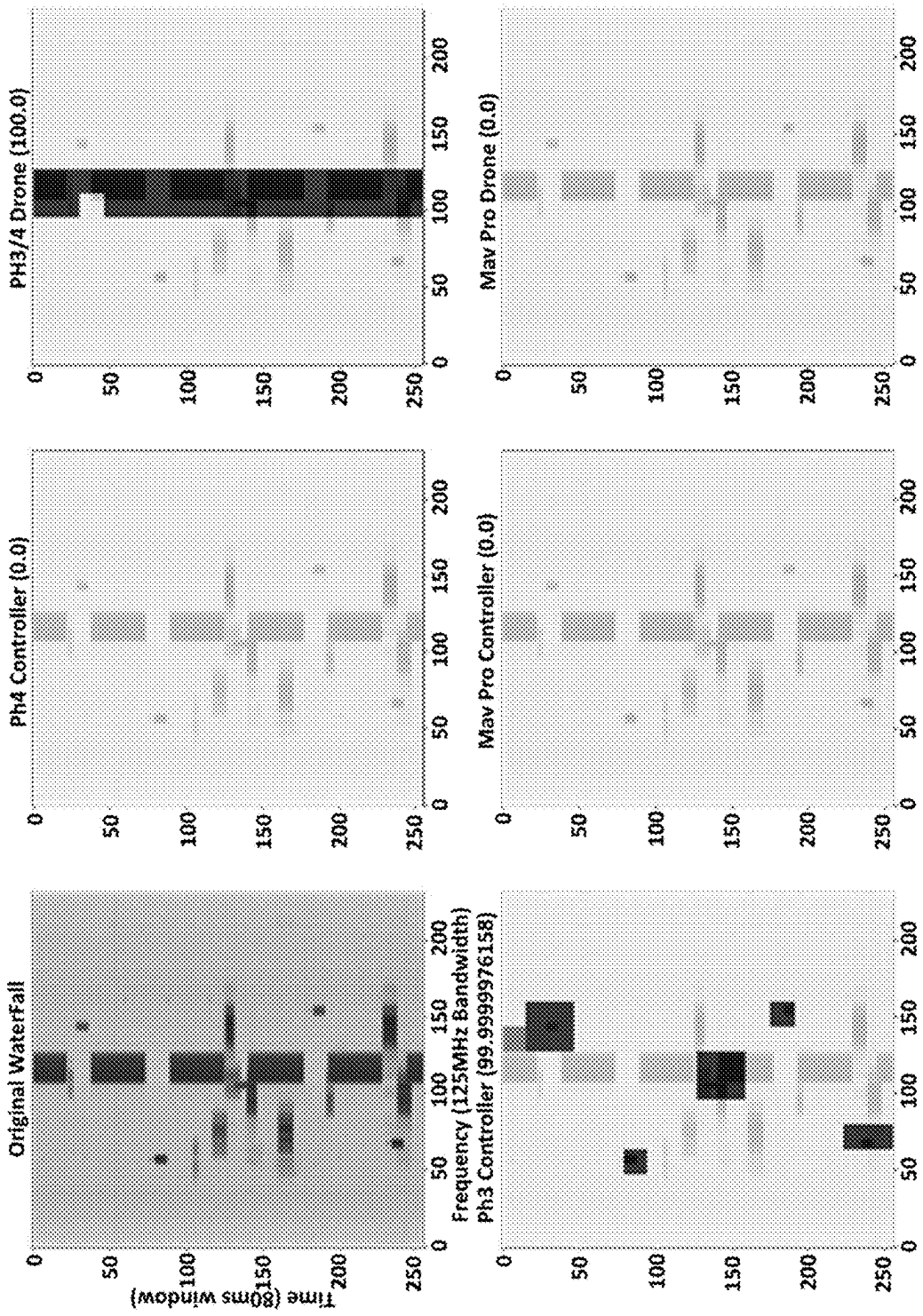

Original Waterfall
Ph4 Controller (0.0)
PH3/4 Drone (100.0)
Ph3 Controller (99.999976158)
Mav Pro Controller (0.0)
Mav Pro Drone (0.0)
Time (80ms window)
Frequency (125MHz Bandwidth)
0
50
100
150
200
250

FIG. 14

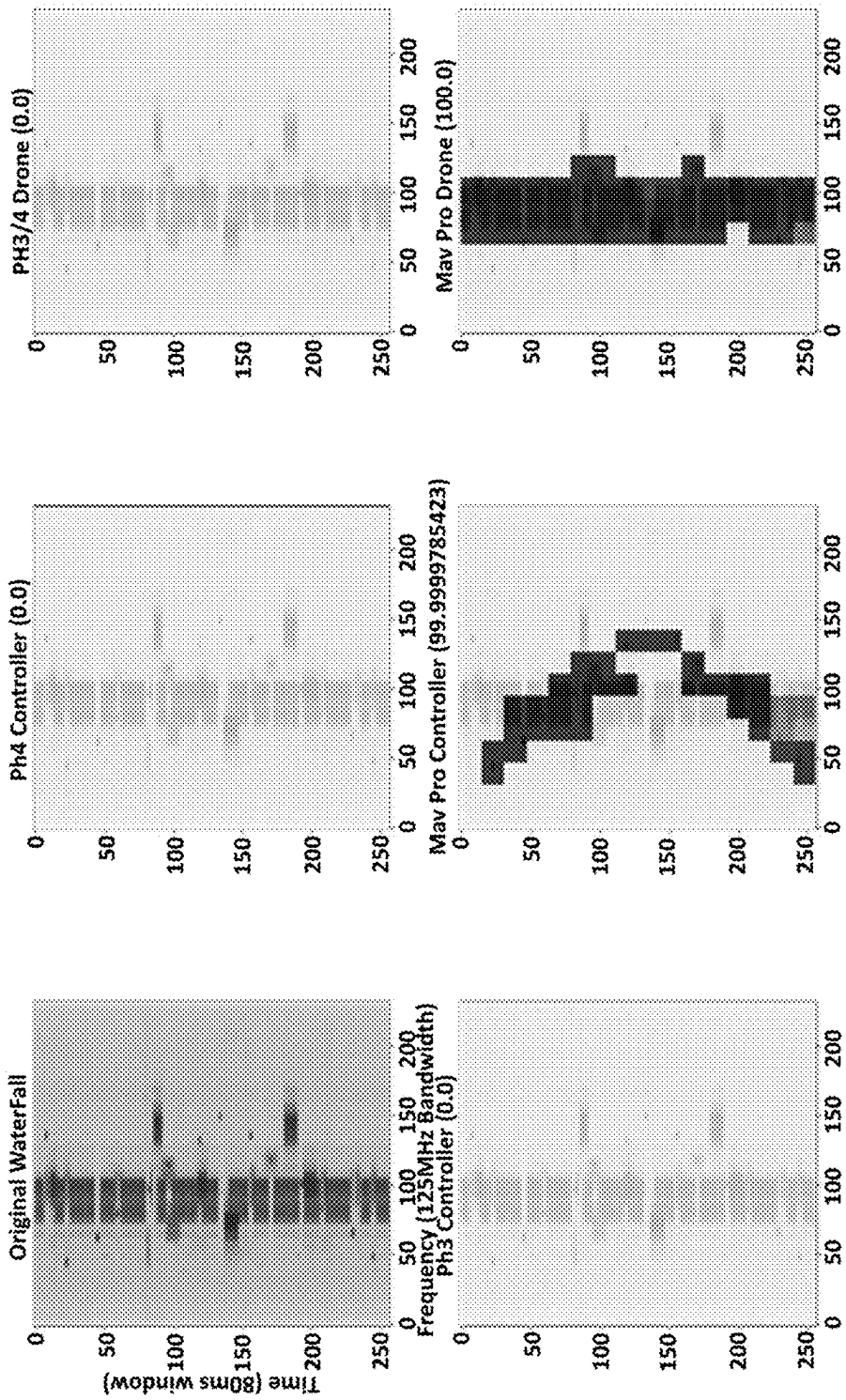

Original WaterFall
Time (80ms window)
Frequency (125MHz Bandwidth)
Ph3 Controller (0.0)
Ph4 Controller (0.0)
Mav Pro Controller (99.99997854 23)
PH3/4 Drone (0.0)
Mav Pro Drone (100.0)
0
50
100
150
200
250

FIG. 15

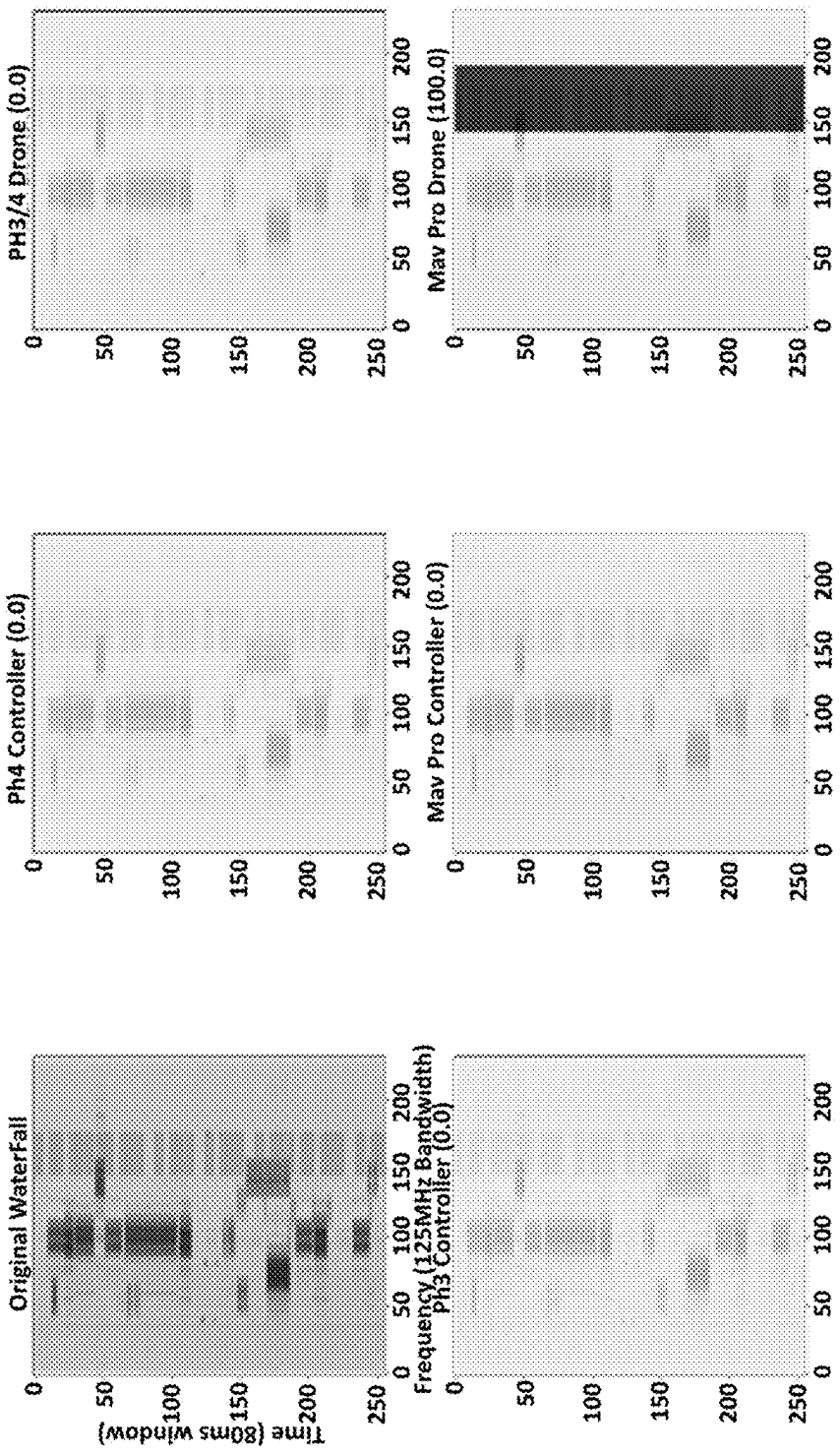

Original WaterFall
Time (80ms window)
Frequency (125MHz Bandwidth)
Ph3 Controller (0.0)
Ph4 Controller (0.0)
Mav Pro Controller (0.0)
PH3/4 Drone (0.0)
Mav Pro Drone (100.0)
0
50
100
150
200
250

FIG. 16

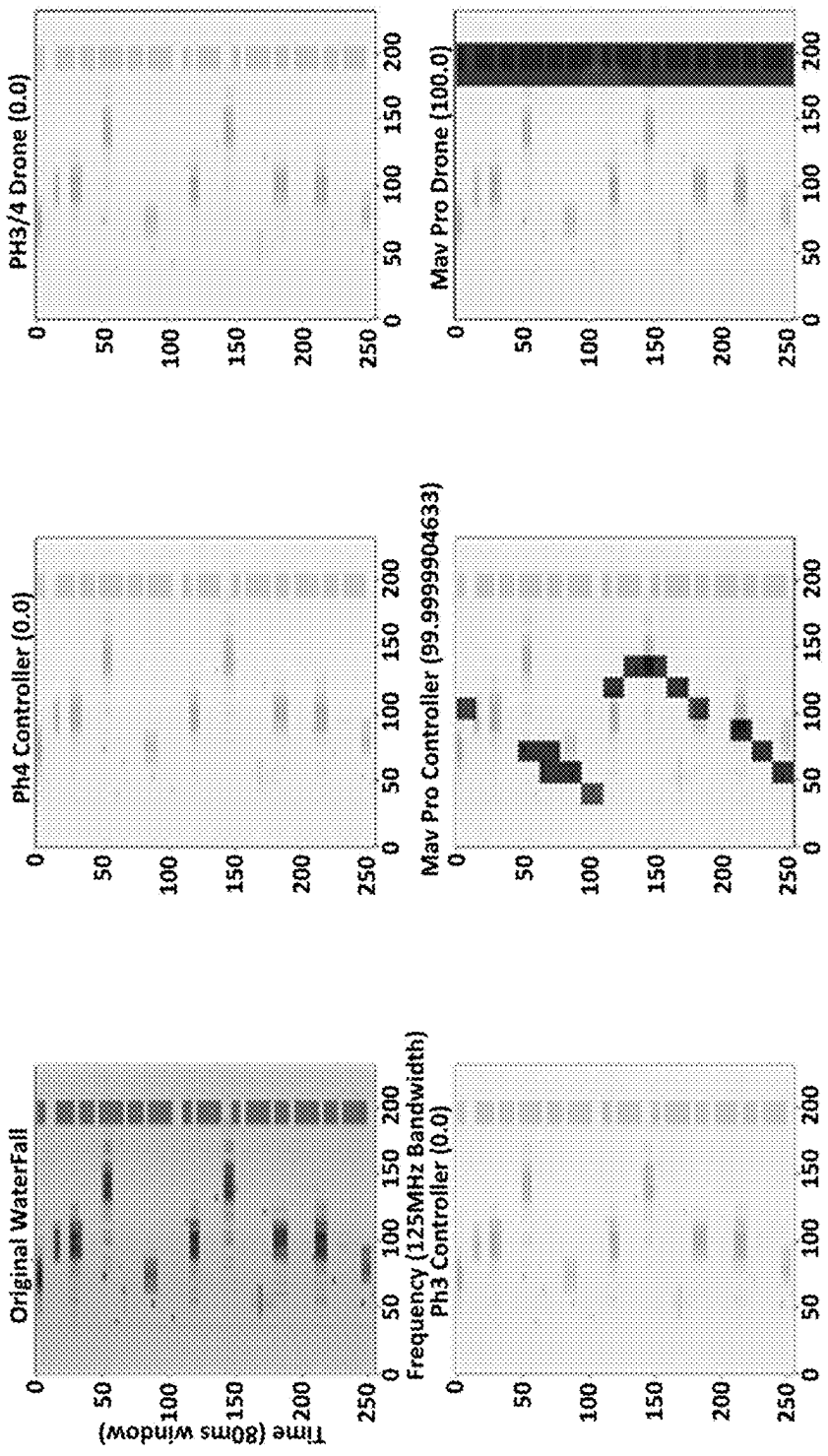

Original WaterFall
Time (80ms window)
Frequency (125MHz Bandwidth)
Ph3 Controller (0.0)
Ph4 Controller (0.0)
Mav Pro Controller (99.9999904633)
PH3/4 Drone (0.0)
Mav Pro Drone (100.0)
0
50
100
150
200
250

FIG. 17

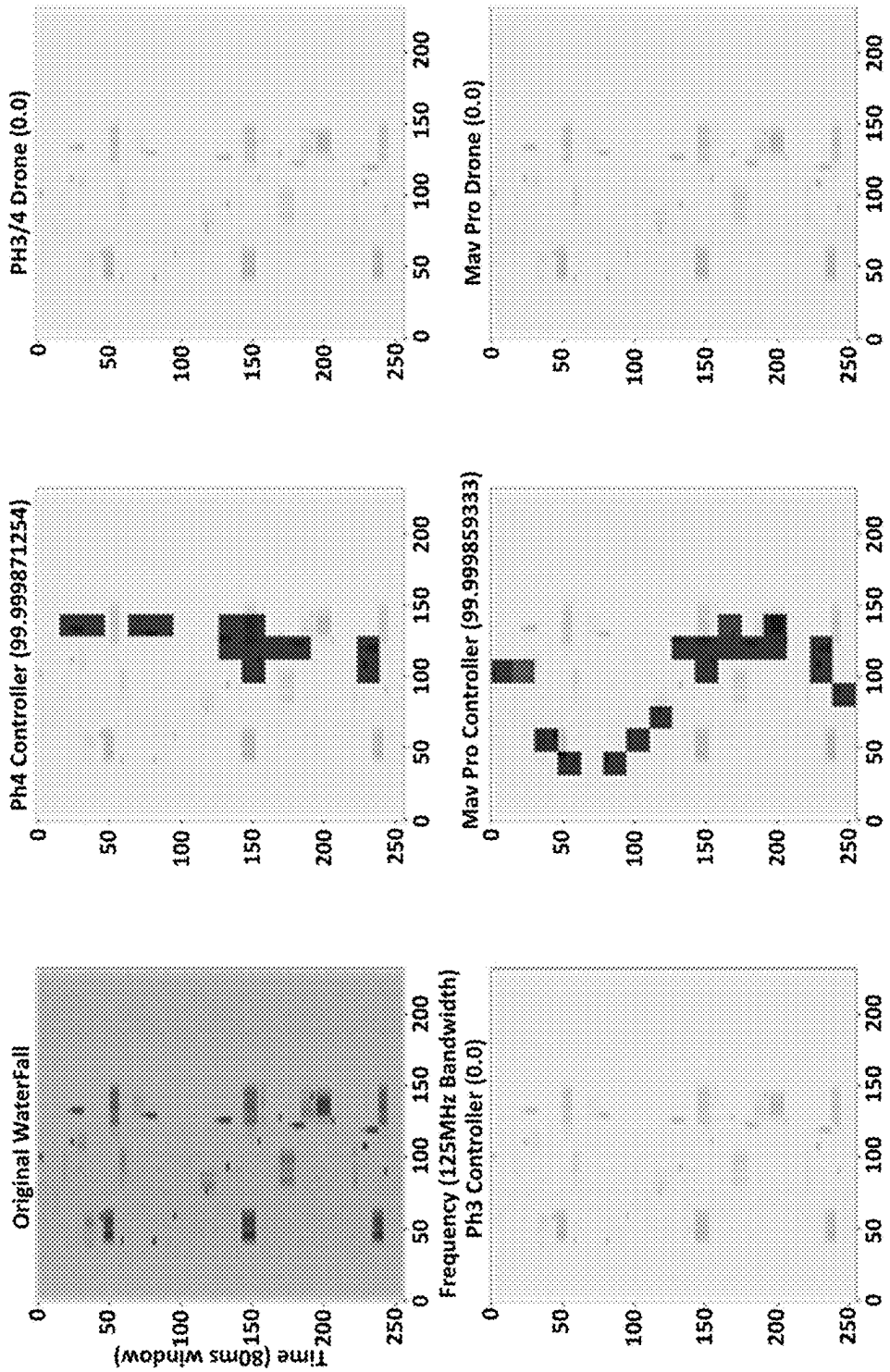

Original WaterFall
Time (80ms window)
Ph4 Controller (99.999871254)
Frequency (125MHz Bandwidth)
Ph3 Controller (0.0)
Mav Pro Controller (99.999859333)
PH3/4 Drone (0.0)
Mav Pro Drone (0.0)
0
50
100
150
200
250

FIG. 18

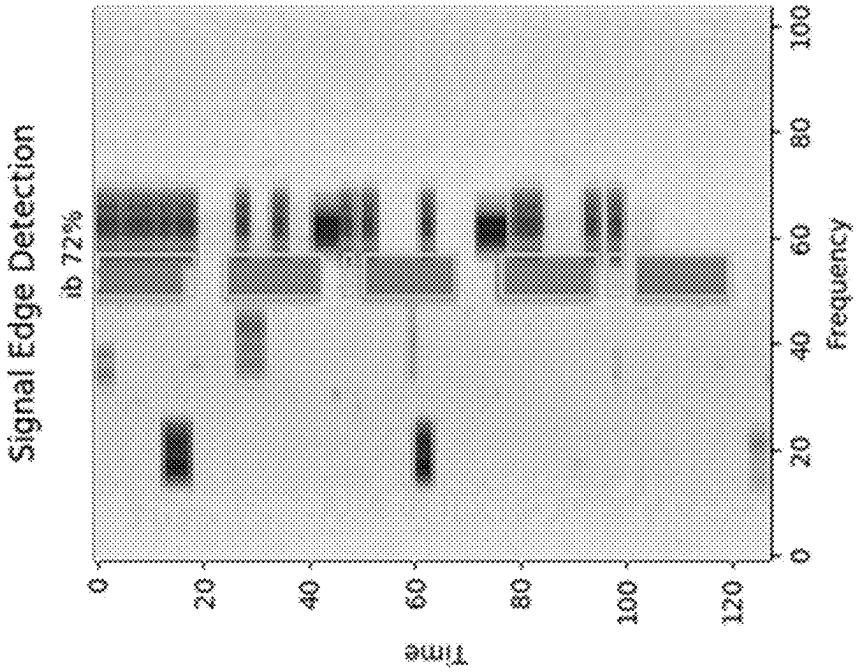

Signal Edge Detection
ib 72%
Time
0
20
40
60
80
100
120
Frequency
0
20
40
60
80
100

FIG. 19

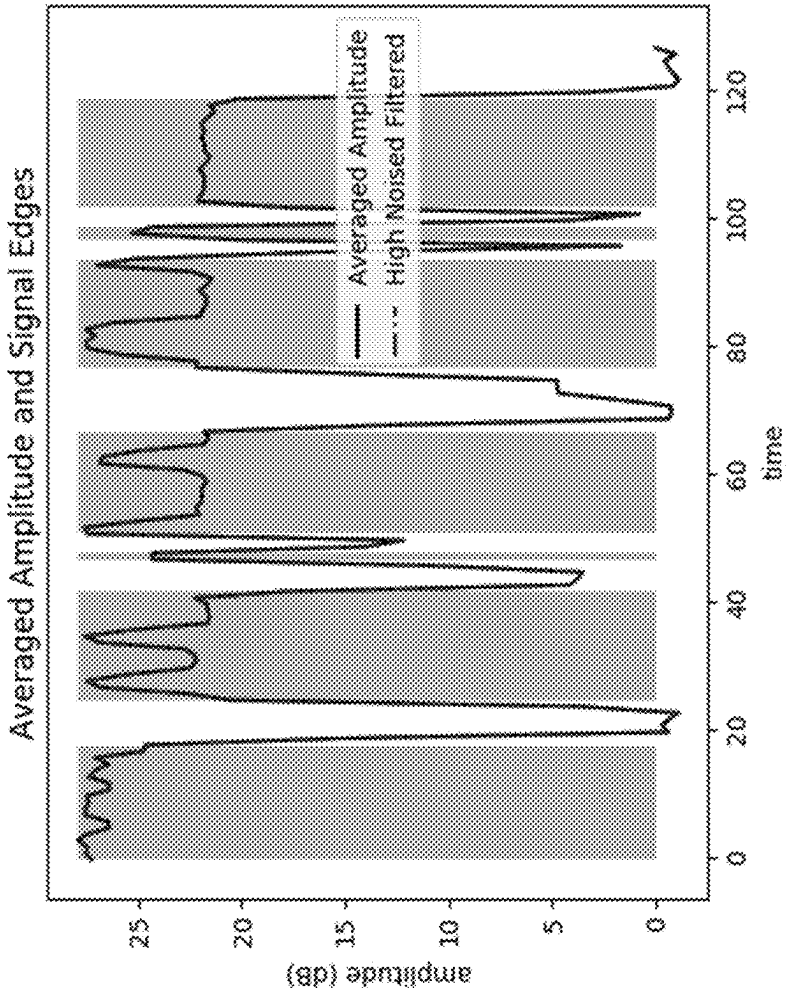

Averaged Amplitude and Signal Edges
Averaged Amplitude
High Noised Filtered
amplitude (dB)
25
20
15
10
5
0
0
20
40
60
80
100
120
time

FIG. 20

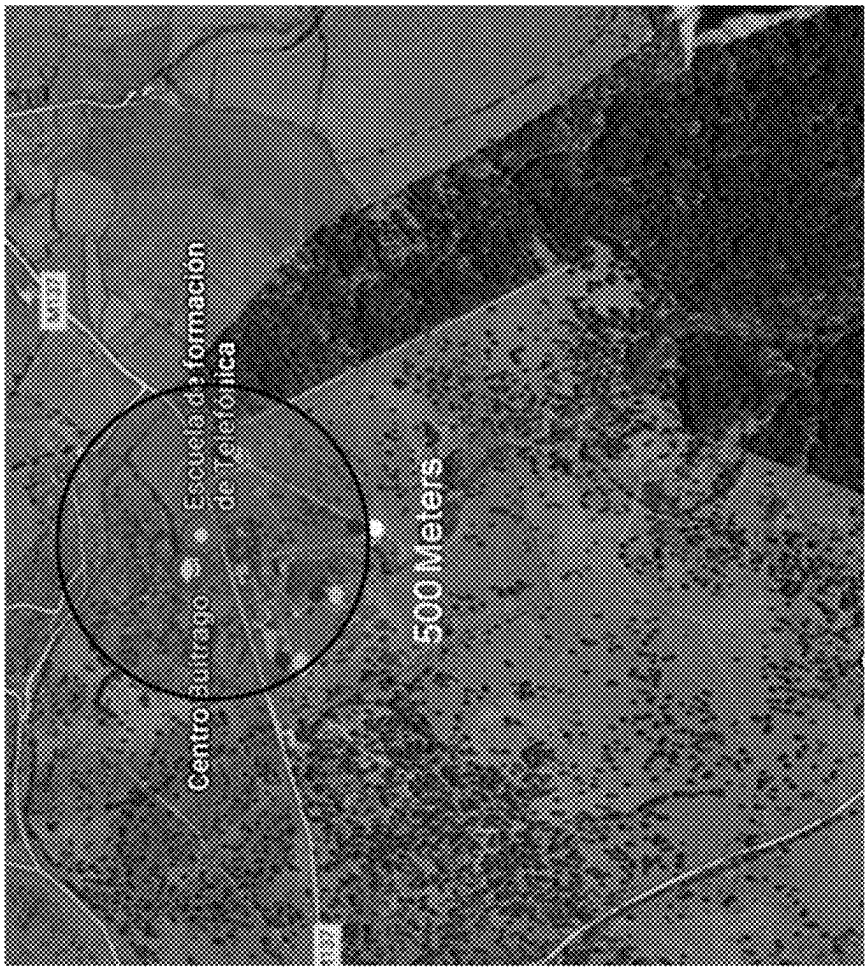

Centro Buitrago
Escuela de formación de Telefónica
500 Meters

FIG. 21

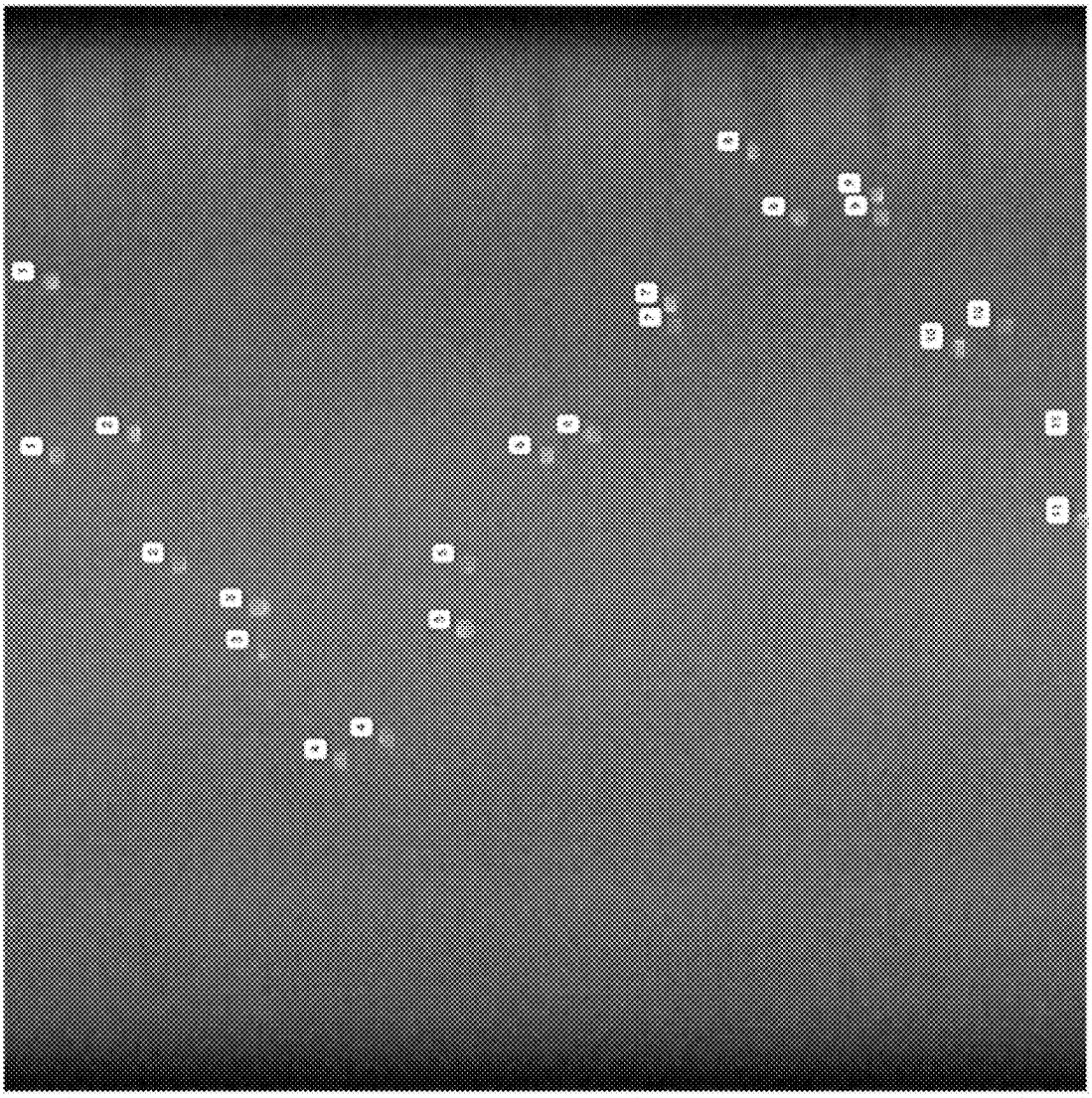


FIG. 22

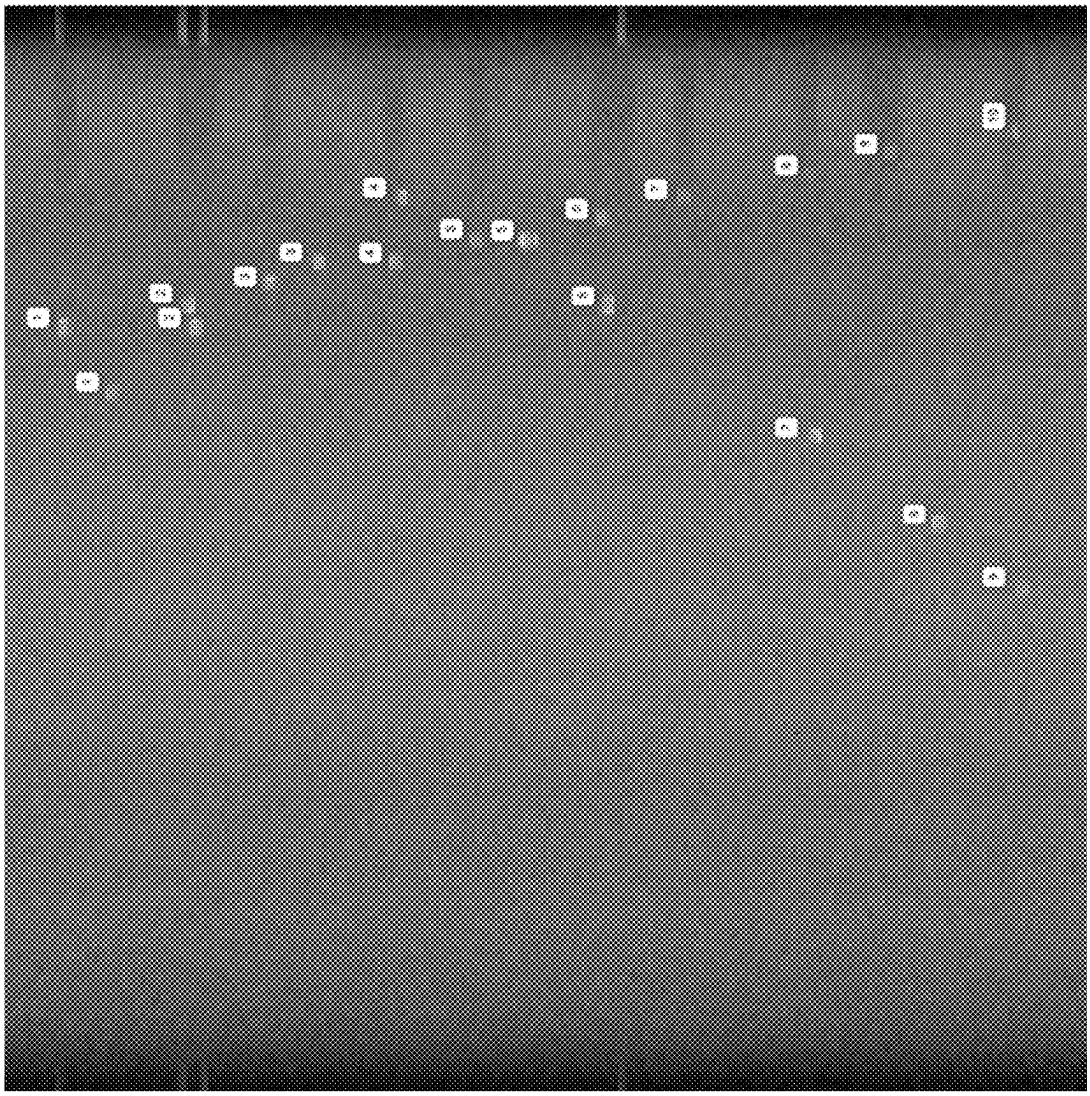


FIG. 23

UNMANNED VEHICLE RECOGNITION AND THREAT MANAGEMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application relates to and claims priority from the following applications. This application is a continuation of U.S. patent application Ser. No. 18/985,777, filed Dec. 18, 2024, which is a continuation of U.S. patent application Ser. No. 18/789,011, filed Jul. 30, 2024, which is a continuation of U.S. patent application Ser. No. 18/785,936, filed Jul. 26, 2024, which is a continuation-in-part of U.S. patent application Ser. No. 18/775,710, filed Jul. 17, 2024, which is a continuation-in-part of U.S. patent application Ser. No. 18/428,606, filed Jan. 31, 2024, which is a continuation of U.S. patent application Ser. No. 18/374,376, filed Sep. 28, 2023, which is a continuation of U.S. patent application Ser. No. 18/142,904, filed May 3, 2023, which is a continuation of U.S. patent application Ser. No. 17/991,348, filed Nov. 21, 2022, which is a continuation of U.S. patent application Ser. No. 17/735,615, filed May 3, 2022, which is a continuation of U.S. patent application Ser. No. 17/190,048 filed Mar. 2, 2021, which is a continuation of U.S. patent application Ser. No. 16/732,811 filed Jan. 2, 2020, which is a continuation of U.S. patent application Ser. No. 16/275,575 filed Feb. 14, 2019, which claims the benefit of U.S. Provisional Application 62/632,276 filed Feb. 19, 2018. U.S. patent application Ser. No. 16/275,575 also claims priority from and is a continuation-in-part of U.S. patent application Ser. No. 16/274,933 filed Feb. 13, 2019, which is a continuation-in-part of U.S. patent application Ser. No. 16/180,690 filed Nov. 5, 2018, which is a continuation-in-part of U.S. patent application Ser. No. 15/412,982 filed Jan. 23, 2017. U.S. patent application Ser. No. 16/180,690 also claims priority from U.S. Provisional Patent Application No. 62/722,420 filed Aug. 24, 2018. U.S. patent application Ser. No. 16/274,933 also claims the benefit of U.S. Provisional Application 62/632,276 filed Feb. 19, 2018. Each of the above-mentioned applications is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] The present invention relates to systems and methods for unmanned vehicle recognition and threat management. More particularly, the systems and methods of the present invention are directed to unmanned vehicle detection, classification and direction finding.

2. Description of the Prior Art

[0003] Unmanned Aerial Vehicles (UAVs), commonly known as drones, have become readily available in commercial and retail stores. Detailed schematics for their control systems are available from many manufacturers and the internet along with Software Development Kits (SDKs). Rapid modifications are enabled by advancements in various technologies (e.g., 3D printing). UAVs can be modified to deploy dangerous actions and threaten societal securities. For example, UAVs can be modified to deliver dangerous payloads. It is no longer a question of if, it is now a question of when. Thus, it is imperative that organizations and governments take steps to protect critical assets (e.g., ports, power plants), structures (e.g., buildings, stadiums), and personnel and their citizens.

[0004] Exemplary U.S. Patent Documents relevant to the prior art include:

[0005] U.S. Pat. No. 9,862,489 for "Method and apparatus for drone detection and disablement" by inventors Lee Weinstein et al., filed Feb. 7, 2016 and issued Jan. 9, 2018, describes a method and apparatus for detection and disablement of an unidentified aerial vehicle (UAV) includes arrays of antenna elements receiving in two modalities (for instance radio frequency (RF) and acoustic modalities, or RF and optical modalities). Signal processing of outputs from multiple antenna arrays locates a potential UAV at specific coordinates within a volume of space under surveillance, and automatically aims video surveillance and a short-range projectile launcher at the UAV, and may automatically fire the projectile launcher to down the UAV.

[0006] U.S. Pat. No. 9,858,947 for "Drone detection and classification methods and apparatus" by inventors Brian Hearing et al., filed Nov. 24, 2015 and issued Jan. 2, 2018, describes a system, method, and apparatus for drone detection and classification. An example method includes receiving a sound signal in a microphone and recording, via a sound card, a digital sound sample of the sound signal, the digital sound sample having a predetermined duration. The method also includes processing, via a processor, the digital sound sample into a feature frequency spectrum. The method further includes applying, via the processor, broad spectrum matching to compare the feature frequency spectrum to at least one drone sound signature stored in a database, the at least one drone sound signature corresponding to a flight characteristic of a drone model. The method moreover includes, conditioned on matching the feature frequency spectrum to one of the drone sound signatures, transmitting, via the processor, an alert.

[0007] U.S. Pat. No. 9,767,699 for "System for and method of detecting drones" by inventors John W. Borghese et al., filed May 14, 2015 and issued Sep. 19, 2017, describes an apparatus and method can provide a warning of a drone or unmanned aerial vehicle in the vicinity of an airport. The apparatus can include at least one antenna directionally disposed at an along the approach or departure path and a detector configured to provide a warning of a presence of sense an unmanned aerial or drone. The warning can be provided in response to a radio frequency signal received by the at least one of the antenna being in a frequency band associated with a transmission frequency for the unmanned aerial vehicle or drone or in a frequency band associated with interaction from receive circuitry of the unmanned aerial vehicle or drone.

[0008] U.S. Pat. No. 9,715,009 for "Deterent for unmanned aerial systems" by inventors Dwaine A. Parker et al., filed Dec. 2, 2016 and issued Jul. 25, 2017, describes a system for providing an integrated multi-sensor detection and countermeasure against commercial unmanned aerial systems/vehicles and includes a detecting element, a tracking element, an identification element, and an interdiction element. The detecting element detects an unmanned aerial vehicle in flight in the region of, or approaching, a property, place, event or very important person. The tracking element determines the exact location of the unmanned aerial vehicle. The identification/classification element utilizing data from the other elements generates the identification and

threat assessment of the UAS. The interdiction element, based on automated algorithms can either direct the unmanned aerial vehicle away from the property, place, event or very important person in a non-destructive manner, or can disable the unmanned aerial vehicle in a destructive manner. The interdiction process may be over ridden by intervention by a System Operator/HiL.

[0009] U.S. Pat. No. 9,529,360 for "System and method for detecting and defeating a drone" by inventors Howard Melamed et al., filed Apr. 22, 2015 and issued Dec. 27, 2016, describes a system for detecting and defeating a drone. The system has a detection antenna array structured and configured to detect the drone and the drone control signal over a 360 degree field relative to the detection antenna array including detecting the directionality of the drone. The system also includes a neutralization system structured and configured in a communicating relation with the detection antenna array. The neutralization system has a transmission antenna structured to transmit an override signal aimed at the direction of the drone, an amplifier configured to boost the gain of the override signal to exceed the signal strength of the drone control signal, and a processing device configured to create and effect the transmission of the override signal. The patent also discloses a method for detecting and defeating a drone.

[0010] U.S. Publication No. 2017/0358103 for "Systems and Methods for Tracking Moving Objects" by inventors Michael Shao et al., filed Jun. 9, 2017 and published Dec. 14, 2017, describes systems and methods for tracking moving objects. The publication discloses an object tracking system comprises a processor, a communications interface, and a memory configured to store an object tracking application. The object tracking application configures the processor to receive a sequence of images; estimate and subtract background pixel values from pixels in a sequence of images; compute sets of summed intensity values for different per frame pixel offsets from a sequence of images; identify summed intensity values from a set of summed intensity values exceeding a threshold; cluster identified summed intensity values exceeding the threshold corresponding to single moving objects; and identify a location of at least one moving object in an image based on at least one summed intensity value cluster.

[0011] U.S. Publication No. 2017/0261613 for "Counter drone system" by inventor Brian R. Van Voorst, filed Feb. 27, 2017 and published Sep. 14, 2017, describes a counter drone system that includes a cueing sensor to detect the presence of an object wherein the cueing sensor cues the presence of a target drone, a long range LIDAR system having a sensor pointed in a direction of the target drone to acquire and track at long range the target drone to provide an accurate location of the target drone wherein once a track is acquired, the motion of the target drone is used to maintain the track of the target drone and a threat detector wherein LIDAR data is provided to the threat detector to determine if the target drone is a threat.

[0012] U.S. Publication No. 2017/0261604 for "Intercept drone tasked to location of lidar tracked drone" by inventor Brian Van Voorst, filed Feb. 27, 2017 and published Sep. 14, 2017, describes a system that includes a long range LIDAR tracking system to track a target drone and provide detection and tracking information of the target drone; a control system to process the detection and tracking information and provide guidance information to intercept the target drone; and a high powered intercept drone controlled by supervised autonomy, the supervised autonomy provided by processing the detection and tracking information of the target drone and sending guidance information to the intercept drone to direct the intercept drone to the target drone.

[0013] U.S. Publication No. 2017/0039413 for "Commercial drone detection" by inventor Gary J. Nadler, filed Aug. 3, 2015 and published Feb. 9, 2017, describes a method of capturing the presence of a drone, including: collecting, using at least one sensor, data associated with an aerial object; analyzing, using a processor, the data to determine at least one characteristic of the aerial object; accessing, in a database, a library of stored characteristics of commercially available drones; determining, based on the analyzing, if the at least one characteristic of the aerial object matches a characteristic of a commercially available drone; and responsive to the determining, generating an indication of a positive match.

[0014] U.S. Pat. No. 11,663,992 for Systems and Methods for Detecting, Monitoring, and Mitigating the Presence of Unauthorized Drones by inventors Jordan, et al., Jun. 29, 2020 and published May 23, 2023, is directed to Systems and methods for detecting, monitoring, and mitigating the presence of a drone are provided herein. In one aspect, a system for detecting presence of a drone includes a radio-frequency (RF) receiver. The system can further include a processor and a computer-readable memory in communication with the processor and having stored thereon computer-executable instructions to cause the at least one processor to receive a set of samples from the RF receiver for a time interval, obtain predetermined data of expected communication protocols used between the drone and a controller, and determine whether the RF signal corresponds to one of the expected communication protocols by comparing the samples of the RF signal to the predetermined data and decoding the RF signal. In further aspects the system extracts a unique identifier of the drone based at least partially on the decoded RF signal.

[0015] U.S. Pat. No. 11,190,233 for Systems and Methods for Detecting, Monitoring, and Mitigating the Presence of a Drone Using Frequency Hopping by inventors Fang-Hsuan Lo, et al., filed May 28, 2020 and published Nov. 10, 2021, is directed to systems and methods for detecting, monitoring, and mitigating the presence of a drone are provided herein. In one aspect, a system for detecting presence of a one or more drones includes a radio-frequency (RF) receiver configured to receive an RF signal transmitted between a drone and a controller. The system can further include a processor and a computer-readable memory in communication with the processor and having stored thereon computer-executable instructions to cause the at least one processor to receive a set of samples from the RF receiver for a time interval, the set of samples comprising samples of the first RF signal, obtain a parameter model of the first frequency hopping parameters, and fit the parameter model to the set of samples.

[0016] U.S. Pat. No. 10,698,076 for Radio Frequency Signal Transmission Detector and Locator by inventors Jones, et al., filed Aug. 2, 2018 and published Jun. 10, 2020, is directed to The present invention is a system and method for detecting and locating the transmission of radio frequency signals from within a defined geographical area. The system uses statistical confidence limits to detect outliers

caused by transmissions in the defined geographical area. The source of the transmission can then be located with triangulation.

[0017] U.S. Pat. No. 10,540,905 for Systems, Aircrafts, and Methods for Drone Detection and Collision Avoidance by inventors Bohanan, et al., filed Mar. 28, 2018 and published Jan. 1, 2020, is directed to a system and a method for drone detection and collision avoidance, particularly for use in an aircraft, is provided. The system includes, but is not limited to a sensor, a processor, and an avoidance unit comprising a control unit. The sensor is configured to detect a drone signal in a predetermined space and to transmit the drone signal to the processor. The processor is configured to determine the presence of a drone in the predetermined space based on the drone signal. The processor is configured to transmit a command to the avoidance unit when the processor determines the presence of a drone. The control unit is configured to receive the command and to generate a warning signal in response to receiving the command.

[0018] U.S. Pat. No. 9,529,360 for System and Method for Detecting and Defeating a Drone by inventors Melamed. et al., filed Apr. 22, 2015 and published Dec. 7, 2016, is directed to The invention is directed to a system for detecting and defeating a drone. The system has a detection antenna array structured and configured to detect the drone and the drone control signal over a 360 degree field relative to the detection antenna array including detecting the directionality of the drone. The system also includes a neutralization system structured and configured in a communicating relation with the detection antenna array. The neutralization system has a transmission antenna structured to transmit an override signal aimed at the direction of the drone, an amplifier configured to boost the gain of the override signal to exceed the signal strength of the drone control signal, and a processing device configured to create and effect the transmission of the override signal. The invention is also directed to a method for detecting and defeating a drone.

SUMMARY OF THE INVENTION

[0019] The present invention provides systems and methods for unmanned vehicle recognition. In one embodiment, a multiplicity of receivers captures RF data and transmits the RF data to at least one node device. The at least one node device comprises a signal processing engine, a detection engine, a classification engine, and a direction finding engine. The at least one node device is configured with an artificial intelligence algorithm. The detection engine and classification engine are trained to detect and classify signals from unmanned vehicles and their controllers based on processed data from the signal processing engine. The direction finding engine is operable to provide lines of bearing for detected unmanned vehicles. A display and control unit is in network communication with the at least one node device for displaying locations and other related data for the detected unmanned vehicles.

[0020] In one embodiment, the present invention includes a system for signal identification in a radiofrequency (RF) environment, including at least one node device including a processor and at least one memory in communication with at least one RF receiver, wherein the at least one RF receiver is operable to capture RF data in the RF environment and transmit the RF data to the at least one node device, wherein the at least one node device is operable to average Fast Fourier Transform (FFT) data derived from the RF data into at least one tile, wherein the at least one tile is visually represented as at least one waterfall image, wherein the at least one node device is operable to analyze the at least one waterfall image using machine learning (ML) or at least one convolutional neural network (CNN) to identify at least one signal, at least one signal type, and/or noise to create at least one analyzed waterfall image, and wherein the at least one analyzed waterfall image includes a visual indication of the at least one signal, the at least one signal type, and/or the noise.

[0021] In another embodiment, the present invention includes an apparatus for signal identification in a radiofrequency (RF) environment, including a node device including a processor and at least one memory, wherein the node device is operable to receive RF data from at least one RF receiver, wherein the node device is operable to average Fast Fourier Transform (FFT) data derived from the RF data into at least one tile, wherein the at least one tile is represented as at least one waterfall image, wherein the node device waterfall image is analyzed using machine learning (ML) or at least one convolutional neural network (CNN) to identify at least one signal, at least one signal type, and/or noise to create at least one analyzed waterfall image, and wherein the at least one analyzed waterfall image includes a visual indication of the at least one signal, the at least one signal type, and/or the noise.

[0022] In yet another embodiment, the present invention includes a method for signal identification in a radiofrequency (RF) environment, including at least one RF receiver capturing Fast Fourier Transform (FFT) data in the RF environment and transmitting the FFT data to at least one node device, the at least one node device averaging the FFT data derived from the RF data into at least one tile, wherein the at least one tile is represented as at least one waterfall image, the at least one node device analyzing the at least one waterfall image using machine learning (ML) or at least one convolutional neural network (CNN) to identify at least one signal, at least one signal type, and/or noise, and the at least one node device creating at least one analyzed waterfall image based on the identification of the at least one signal, the at least one signal type, and/or the noise, wherein the at least one analyzed waterfall image includes a visual indication of the at least one signal, the at least one signal type, and/or the noise.

[0023] These and other aspects of the present invention will become apparent to those skilled in the art after a reading of the following description of the preferred embodiment when considered with the drawings, as they support the claimed invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] FIG. **1** is a system for unmanned vehicle recognition according to one embodiment of the present invention.

[0025] FIG. **2** illustrates signal characterization within a spectrum from 700 MHz to 900 MHz.

[0026] FIG. **3** is an illustration of Phantom 4 controller and drone signals.

[0027] FIG. **4** is a human interface display for drone detection according to one embodiment of the present invention.

[0028] FIG. **5** shows a setup for RF data capture in an Anechoic Chamber according to one embodiment of the present invention.

[0029] FIG. **6** illustrates a simulation for fading and channel hopping of an OcuSync drone.

[0030] FIG. **7** is an illustration of an inception based convolutional neural network.

[0031] FIG. **8** illustrates a scenario for an RF environment with just noise.

[0032] FIG. **9** illustrates a scenario for an RF environment with a Phantom **4** controller and drone.

[0033] FIG. **10** illustrates a scenario for an RF environment with two Mavic Pro drones.

[0034] FIG. **11** illustrates a scenario for an RF environment with a Mavic Pro controller only.

[0035] FIG. **12** illustrates a scenario for an RF environment with one Mavic Pro drone only.

[0036] FIG. **13** illustrates a scenario for an RF environment with one Phantom **3** controller only.

[0037] FIG. **14** illustrates a scenario for an RF environment with a Phantom **3** controller and drone.

[0038] FIG. **15** illustrates a scenario for an RF environment with a Mavic Pro controller and drone in wideband mode.

[0039] FIG. **16** illustrates a scenario for an RF environment with a Mavic Pro drone in wideband mode.

[0040] FIG. **17** illustrates a scenario for an RF environment with a Mavic Pro controller and drone.

[0041] FIG. **18** illustrates a scenario for an RF environment with a Mavic Pro controller and a Phantom **4** controller.

[0042] FIG. **19** is an illustration of identifying drones and controllers based on signal edge detection.

[0043] FIG. **20** is an illustration with averaged signal amplitudes and signal edges according to one embodiment of the present invention.

[0044] FIG. **21** displays a detection range of less than 500 meters based on equipment specification and location.

[0045] FIG. **22** displays a training data set containing two separate drone devices operating on the same type of radio protocol according to one embodiment of the present invention.

[0046] FIG. **23** displays a training data set containing two separate drone devices operating on different types of radio protocols according to one embodiment of the present invention.

DETAILED DESCRIPTION

[0047] The present invention provides systems and methods for unmanned vehicle recognition. The present invention relates to automatic signal detection, temporal feature extraction, geolocation, and edge processing disclosed in U.S. patent application Ser. No. 15/412,982 filed Jan. 23, 2017, U.S. patent application Ser. No. 15/478,916 filed Apr. 4, 2017, U.S. patent application Ser. No. 15/681,521 filed Aug. 21, 2017, U.S. patent application Ser. No. 15/681,540 filed Aug. 21, 2017, and U.S. patent application Ser. No. 15/681,558 filed Aug. 21, 2017, each of which is incorporated herein by reference in its entirety.

[0048] In one embodiment, the present invention includes a system for signal identification in a radiofrequency (RF) environment, including at least one node device including a processor and at least one memory in communication with at least one RF receiver, wherein the at least one RF receiver is operable to capture RF data in the RF environment and transmit the RF data to the at least one node device, wherein the at least one node device is operable to average Fast Fourier Transform (FFT) data derived from the RF data into at least one tile, wherein the at least one tile is visually represented as at least one waterfall image, wherein the at least one node device is operable to analyze the at least one waterfall image using machine learning (ML) or at least one convolutional neural network (CNN) to identify at least one signal, at least one signal type, and/or noise to create at least one analyzed waterfall image, and wherein the at least one analyzed waterfall image includes a visual indication of the at least one signal, the at least one signal type, and/or the noise.

[0049] In another embodiment, the present invention includes an apparatus for signal identification in a radiofrequency (RF) environment, including a node device including a processor and at least one memory, wherein the node device is operable to receive RF data from at least one RF receiver, wherein the node device is operable to average Fast Fourier Transform (FFT) data derived from the RF data into at least one tile, wherein the at least one tile is represented as at least one waterfall image, wherein the node device waterfall image is analyzed using machine learning (ML) or at least one convolutional neural network (CNN) to identify at least one signal, at least one signal type, and/or noise to create at least one analyzed waterfall image, and wherein the at least one analyzed waterfall image includes a visual indication of the at least one signal, the at least one signal type, and/or the noise.

[0050] In yet another embodiment, the present invention includes a method for signal identification in a radiofrequency (RF) environment, including at least one RF receiver capturing Fast Fourier Transform (FFT) data in the RF environment and transmitting the FFT data to at least one node device, the at least one node device averaging the FFT data derived from the RF data into at least one tile, wherein the at least one tile is represented as at least one waterfall image, the at least one node device analyzing the at least one waterfall image using machine learning (ML) or at least one convolutional neural network (CNN) to identify at least one signal, at least one signal type, and/or noise, and the at least one node device creating at least one analyzed waterfall image based on the identification of the at least one signal, the at least one signal type, and/or the noise, wherein the at least one analyzed waterfall image includes a visual indication of the at least one signal, the at least one signal type, and/or the noise.

[0051] Currently, commercial and retail UAVs dominate frequencies including 433 MHZ industrial, scientific, and medical radio band (ISM Band) Region 1, 900 MHz ISM Band Region 1,2,3 (varies by country), 2.4 GHz (channels 1-14), 5 GHZ (channels 7-165 most predominant), and 3.6 GHZ (channels 131-183). Modulation types used by commercial and retail UAVs include Direct Sequence Spread Spectrum (DSSS), Orthogonal Frequency Division Multiplexing (OFDM), Frequency Hopping Spread Spectrum (FHSS), Fataba Advanced Spread Spectrum Technology (FASST).

[0052] Many counter UAV systems in the prior art focus on the 2.4 GHz and 5.8 GHz bands utilizing demodulation and decryption of radio frequency (RF) signals to detect and analyze each signal to determine if it is related to a UAV.

[0053] The present invention provides systems and methods for unmanned vehicle recognition including detection, classification and direction finding. Unmanned vehicles comprise aerial, terrestrial or water borne unmanned

vehicles. The systems and methods for unmanned vehicle recognition are operable to counter threats from the aerial, terrestrial or water borne unmanned vehicles.

[0054] In one embodiment, a multiplicity of receivers captures RF data and transmits the RF data to at least one node device. The at least one node device comprises a signal processing engine, a detection engine, a classification engine, and a direction finding engine. The at least one node device is configured with an artificial intelligence algorithm. The detection engine and classification engine are trained to detect and classify signals from unmanned vehicles and their controllers based on processed data from the signal processing engine. The direction finding engine is operable to provide lines of bearing for detected unmanned vehicles. A display and control unit is in network communication with the at least one node device for displaying locations and other related data for the detected unmanned vehicles.

[0055] In one embodiment, the present invention provides systems and methods for unmanned vehicle (UV) recognition in a radio frequency (RF) environment. A multiplicity of RF receivers and a displaying device are in network communication with a multiplicity of node devices. The multiplicity of RF receivers is operable to capture the RF data in the RF environment, convert the RF data to fast Fourier transform (FFT) data, and transmit the FFT data to the multiplicity of node devices. The multiplicity of node devices each comprises a signal processing engine, a detection engine, a classification engine, a direction-finding engine, and at least one artificial intelligence (AI) engine. The signal processing engine is operable to average the FFT data into at least one tile. The detection engine is operable to group the FFT data into discrete FFT bins over time, calculate average and standard deviation of power for the discrete FFT bins, and identify at least one signal related to at least one UV and/or corresponding at least one UV controller. The at least one AI engine is operable to generate an output for each of the at least one tile to identify at least one UV and corresponding at least one UV controller with a probability, and calculate an average probability based on the output from each of the at least one tile. The classification engine is operable to classify the at least one UV and/or the at least one UV controller by comparing the at least one signal to classification data stored in a classification library in real time or near real time. The direction-finding engine is operable to calculate a line of bearing for the at least one UV. The displaying device is operable to display a classification of the at least one UV and/or the at least one UV controller and/or the line of bearing of the at least one UV. Each of the at least one tile is visually represented in a waterfall image via a graphical user interface on the displaying device.

[0056] FIG. **1** illustrates a system for unmanned vehicle recognition according to one embodiment of the present invention. The system includes a multiplicity of antennas, a receiver and processing unit, and a display and control unit. In one embodiment, there are four multiband omnidirectional antennas. In one embodiment, three multiband omnidirectional antennas are positioned to form an equilateral with **6** meters spacing as illustrated in FIG. **1** as an example. The receiver and processing unit includes a signal processing engine, a UAV detection engine, a UAV classification engine, a direction finding processing engine, and an internal Global Positioning System (GPS). The receiver and processing unit is operable to receive RF data from the antennas and automatically process the RF data for UAV detection and classification and direction finding. The display and control unit includes a human interface display. In one embodiment, the human interface display is provided by a remote web-based interface. The display and control unit is operable to display lines of bearings for detected UAVs and controllers, classification for detected UAVs and controllers, received signal strength (RSS) values, and operating frequencies. In one embodiment, the display and control unit is SigBase 4000 as shown in FIG. **1**. In another embodiment, any computer, laptop, or tablet configured with the human interface display of the present invention is operable to function as a display and control unit. In one embodiment, the receiver and processing unit is a node device, and there are multiple node devices communicating with each other and forming a group of networked nodes for UAV detection, classification, and direction finding.

[0057] The present invention provides a more efficient methodology for UAV detection and identification, which takes advantage of Fast Fourier Transform (FFT) over a short period of time and its derivation. RF data received from antennas are directly converted to FFT data with finer granularity. This allows rapid identification of protocols used by high threat drones without demodulation, and the identification is probability based. An analytics engine is operable to perform near real-time analysis and characterize signals within the spectrum under observation. FIG. 2 illustrates signal characterization within a spectrum from 700 MHz to 900 MHz. Temporal feature extraction is applied for signal characterization, which is described in U.S. patent application Ser. No. 15/412,982 filed Jan. 23, 2017, U.S. patent application Ser. No. 15/681,521 filed Aug. 21, 2017, U.S. patent application Ser. No. 15/681,540 filed Aug. 21, 2017, U.S. patent application Ser. No. 15/681,558 filed Aug. 21, 2017, each of which is incorporated herein by reference in its entirety.

[0058] Advantageously, multiple receivers in the present invention work together to ingest spectral activities across large blocks of spectrum. The multiple receivers have an instantaneous bandwidth from 40 MHz to 500 MHz. In one embodiment, the multiple receivers are configurable in 40 MHz and 125 MHz segment building blocks. Input data are converted directly to FFT data and fed into process engines, which significantly decreases latency. The process engines are designed for rapid identification of signals of interest (SOI). When an SOI is detected, a direction finding process is initiated autonomously. In one embodiment, the direction finding process is configurable by an operator.

[0059] There are multiple types of communications links utilized for command and control of an unmanned vehicle. Although several cost-effective radio communication (RC) protocols are gaining global popularity, WI-FI is still the most popular protocol for command and control of UAVs and camera systems. A remote controller of a UAV acts as a WI-FI access point and the UAV acts as a client. There are several limiting factors for WI-FI-based UAVs. For example, the operational range of a WI-FI-based UAV is typically limited to 150 feet (46 m) indoor and 300 feet (92 m) outdoor. There is significant latency for control and video behaviors. Interference by other WI-FI devices affects operational continuity of the WI-FI-based UAVs. Demand in the UAV user community has made more professional-level protocols available in the commercial and retail markets. By way of example but not limitation, two common RC proto-

cols used for UAVs are Lightbridge and OcuSync. Enhancements in drone technology inevitably increases the capability of drones for use in industrial espionage and as weapons for nefarious activities.

[0060] Lightbridge is developed for long range and reliable communication. Communication is available within a range up to 5 km. Lightbridge supports 8 selectable channels, and the selection can be manual or automatic. Drones with Lightbridge protocol also have the ability to assess interference and move to alternate channels for greater quality.

[0061] OcuSync is developed based on the LightBridge protocol. OcuSync uses effective digital compression and other improvements, which decreases knowledge required to operate. OcuSync provides reliable HD and UHD video, and OcuSync-based drones can be operated in areas with greater dynamic interference. Ocusync improves command and control efficiencies and reduces latency. With OcuSync, video communications are improved substantially, operational range is increased, command and control recovery are enhanced when interference occurs.

[0062] The systems and methods of the present invention for unmanned vehicle recognition are operable to detect and classify UAVs at a distance, provide directions of the UAVs, and take defensive measures to mitigate risks. The detection and classification are fast, which provides more time to react and respond to threats. Exact detection range is based upon selection of antenna systems, topology, morphology, and client criteria. Classification of the detected UAVs provides knowledge of the UAVs and defines effective actions and capabilities for countering UAV threats. In one embodiment, the direction information of the UAVs provides orientation within the environment based on the location of the UAV detector.

[0063] In one embodiment, the systems and methods of the present invention provides unmanned vehicle recognition solution targeting radio controlled and WI-FI-based drones. The overall system is capable of surveying the spectrum from 20 MHz to 6 GHz, not just the common 2.4 GHz and 5.8 GHz areas as in the prior art. In one embodiment, the systems and methods of the present invention are applied to address 2 major categories: RC-based UAV systems and WI-FI-based UAV systems. In one embodiment, UAV systems utilize RC protocols comprising LightBridge and OcuSync. In another embodiment, UAV systems are WI-FI based, for example but not for limitation, 3DR Solo and Parrot SkyController. The systems and methods of the present invention are operable to detect UAVs and their controllers by protocol.

[0064] The systems and methods of the present invention maintain a state-of-the-art learning system and library for classifying detected signals by manufacturer and controller type. The state-of-the-art learning system and library are updated as new protocols emerge.

[0065] In one embodiment, classification by protocol chipset is utilized to provide valuable intelligence and knowledge for risk mitigation and threat defense. The valuable intelligence and knowledge include effective operational range, supported peripherals (e.g., external or internal camera, barometers, GPS and dead reckoning capabilities), integrated obstacle avoidance systems, and interference mitigation techniques.

[0066] The state-of-the-art learning system of the present invention is highly accurate and capable of assessing detected UAV signals and/or controller signals for classification in less than a few seconds with a high confidence level. The state-of-the-art learning system is operable to discriminate changes in the environment for non-drone signals as well as drone signals. FIG. **3** is an illustration of Phantom 4 controller and drone signals. A human interface is operable to display the classification results. FIG. **4** illustrates a human interface display for drone detection according to one embodiment of the present invention.

[0067] It is difficult to recognize commercial and retail drones with the naked eye over 100 meters. It is critical to obtain a vector to the target for situational awareness and defense execution. The systems and methods of the present invention provides lines of bearing for direction finding for multiple UAVs flying simultaneously. Each line of bearing is color coded for display. Angles, along with frequencies utilized for uplink and downlink, are also displayed on the human interface.

[0068] Once a UAV is detected and classified, an alert is posted to a counter UAV system operator (e.g., a network operation center, an individual operator) including azimuth of the UAV and other information. The alert is transmitted via email, short message service (SMS) or third-party system integration. The counter UAV system is operable to engage an intercession transmission, which will disrupt the communication between the UAV and its controller. When the communication between the UAV and its controller is intercepted, the UAV will invoke certain safety protocols, such as reduce height and hover, land, or return to the launch point. The counter UAV system may have certain restrictions based on country and classification of the UAV.

[0069] In one embodiment, the systems and methods of the present invention are operable to update the UAV library with emerging protocols for classification purposes, and refine the learning engine for wideband spectrum analysis for other potential UAV signatures, emerging protocols and technologies. In other words, the systems and methods of the present invention are adaptable to any new and emerging protocols and technologies developed for unmanned vehicles. In one embodiment, multiple node devices in the present invention are deployed to operate as a group of networked nodes. In one embodiment, the group of networked nodes are operable to estimate geographical locations for unmanned vehicles. In one embodiment, two node devices are operable to provide a single line of bearing and approximate a geographical location of a detected drone or controller. The more node devices there are in the group of network nodes, the more lines of bearing are operable to be provided, and the more accurate the geographical location is estimated for the detected drone or controller. In one embodiment, the geolocation function provides altitude and distance of a targeted drone.

[0070] In one embodiment, the counter UAV system in the present invention is operable to alert when unexpected signal characteristics are detected in 2.4 GHz and 5.8 GHz areas and classify the unexpected signal characteristics as potential UAV activities. In another embodiment, the counter UAV system in the present invention is operable to alert when unexpected signal characteristics are detected anywhere from 20 MHz to 6 GHz and classify the unexpected signal characteristics as potential UAV activities. In another embodiment, the counter UAV system in the present invention is operable to classify the unexpected signal characteristics as potential UAV activities when unexpected signal

characteristics are detected anywhere from 40 MHz to 6 GHz. The automatic signal detection engine and analytics engine are enhanced in the counter UAV system to recognize potential UAV activities across a great portion of the spectrum. In one embodiment, any blocks of spectrum from 40 MHz to 6 GHz are operable to be selected for UAV recognition.

[0071] In one embodiment, vector-based information including inclinations, declinations, topology deviations, and user configurable Northing map orientation is added to the WGS**84** mapping system for direction finding and location estimation. In one embodiment, earth-centered earth-fixed vector analysis is provided for multi-node systems to estimate UAV locations, derive UAV velocities from position changes over time, and determine UAV trajectory vectors in fixed nodal processing. In one embodiment, a group of networked node devices are operable to continually provide lines of bearing over time, approximate geographical locations of a detected unmanned vehicle on or above the earth, and track the movement of the detected unmanned vehicle from one estimated location to another. In one embodiment, the group of networked node devices are operable to determine velocities of the detected unmanned vehicle based on estimated locations and travel time. In one embodiment, the group of networked node devices are operable to estimate a trajectory of the detected unmanned vehicle based on the estimated geographical locations over time. In one embodiment, the group of networked node devices are operable to estimate accelerations and decelerations of the unmanned vehicle based on the velocities of the unmanned vehicles over time.

[0072] In one embodiment, the systems and methods of the present invention are operable for UAV detection and direction finding for different modulation schemes including but not limited to DSSS, OFDM, FHSS, FASST, etc. In one embodiment, the counter UAV system in the present invention is configured with cameras for motion detection. The cameras have both day and night vision.

[0073] In one embodiment, systems and methods of the present invention provides training for unmanned vehicle recognition. RF data is captured for a Phantom 3 drone and its controller and a Phantom 4 drone and its controller, both of which use Lightbridge protocol. RF data is also captured for a Mavic Pro drone and its controller, which uses OcuSync protocol. The RF data is recorded at different channels, different RF bandwidths, and different video quality settings inside and outside an Anechoic Chamber. FIG. **5** shows a setup for RF data capture in an Anechoic Chamber according to one embodiment of the present invention. The recordings are overlaid on the RF environment, and fading and channel hopping are simulated. FIG. **6** illustrates a simulation for fading and channel hopping of an OcuSync drone.

[0074] In one embodiment, the recorded RF data is used to train and calibrate an inception based convolutional neural network comprised in a drone detection system. FIG. **7** is an illustration of an inception based convolutional neural network. U.S. Patent Publication No. 2018/0137406 titled "Efficient Convolutional Neural Networks and Techniques to Reduce Associated Computational Costs" is incorporated herein by reference in its entirety. The inception based convolutional neural network generates probabilities that drones or their controllers are detected. The detection probabilities are updated multiple times per second.

[0075] The trained inception based convolutional neural network is operable to identify Lightbridge 1 controller and drone, Lightbridge 2 controller and drone, and OcuSync controller and drone. The trained inception based convolutional neural network is operable to identify Lightbridge and Ocusync controllers and drones at the same time. In one embodiment, the drone detection system comprising the trained inception based convolutional neural network is operable to search an instantaneous bandwidth of 147.2 MHz.

[0076] In one embodiment, the drone detection system of the present invention includes an artificial intelligence (AI) algorithm running on a single board computer (e.g., Nvidia Jetson TX2) with an execution time less than 10 ms. The drone detection system is operable to separate Phantom 3 and Phantom 4 controllers. Waveforms for Phantom 3 and Phantom 4 controllers are sufficiently different to assign separate probabilities.

[0077] The Artificial Intelligence (AI) algorithm is used to enhance performance for RF data analytics. The RF data analytics process based on the AI algorithm is visualized. The RF waterfalls of several drone scenarios are presented in FIGS. **8-18**. FIG. **8** illustrates a scenario for an RF environment with just noise. FIG. **9** illustrates a scenario for an RF environment with a Phantom 4 controller and drone. FIG. **10** illustrates a scenario for an RF environment with two Mavic Pro drones. FIG. **11** illustrates a scenario for an RF environment with a Mavic Pro controller only. FIG. **12** illustrates a scenario for an RF environment with one Mavic Pro drone only. FIG. **13** illustrates a scenario for an RF environment with one Phantom 3 controller only. FIG. **14** illustrates a scenario for an RF environment with a Phantom 3 controller and drone. FIG. **15** illustrates a scenario for an RF environment with a Mavic Pro controller and drone in wideband mode. FIG. **16** illustrates a scenario for an RF environment with a Mavic Pro drone in wideband mode. FIG. **17** illustrates a scenario for an RF environment with a Mavic Pro controller and drone. FIG. **18** illustrates a scenario for an RF environment with a Mavic Pro controller and a Phantom 4 controller.

[0078] Each scenario is illustrated with 6 waterfall images. Each waterfall represents ~80 ms of time and 125 MHz of bandwidth. The top left image is the waterfall before an AI processing. The other five images are waterfalls after the AI processing. For each signal type, the areas of the waterfall that are likely for the RF signal type are highlighted. Areas that are not for the signal type are grayed out. The overall probability that a signal exists in the image is printed in the title of each waterfall image. In one embodiment, the AI algorithm is securely integrated with a state engine and a detection process of the present invention. In one embodiment, AI processing or processing of the waterfall includes a comparison of the waterfall image to a database of waterfall images of the RF environment or similar RF environments for which signals or noise were identified. The comparison of the waterfall image to the database of waterfall images is operable to be performed in real time or near real time. In one embodiment, the database of waterfall images is operable to be updated in real time or near real time with the waterfall image created based on the at least one tile and associated information with the waterfall image, including but not limited to the signal identified in the waterfall image, the signal type(s) identified in the waterfall image, and/or noise identified in the waterfall image.

[0079] The comparison includes the use of machine learning (ML) or convolutional neural networks (CNN) in one embodiment. In other embodiments, the node or system is operable to utilize a plurality of learning techniques for analyzing waterfall images including, but not limited to, artificial intelligence (AI), deep learning (DL), artificial neural networks (ANNs), support vector machines (SVMs), Markov decision process (MDP), and/or natural language processing (NLP). The node or system is operable to use any of the aforementioned learning techniques alone or in combination. Further, the node or system is operable to utilize predictive analytics techniques including, but not limited to, machine learning (ML), artificial intelligence (AI), neural networks (NNs) (e.g., long short term memory (LSTM) neural networks), deep learning, historical data, and/or data mining to make future predictions and/or models. The node or system is preferably operable to recommend and/or perform actions based on historical data, external data sources, ML, AI, NNs, and/or other learning techniques. The node or system is operable to utilize predictive modeling and/or optimization algorithms including, but not limited to, heuristic algorithms, particle swarm optimization, genetic algorithms, technical analysis descriptors, combinatorial algorithms, quantum optimization algorithms, iterative methods, deep learning techniques, and/or feature selection techniques.

[0080] In one embodiment, a method for drone detection and classification comprises applying FFT function to RF data, converting FFT data into logarithmic scale in magnitude, averaging converted FFT into 256 by 256 array representing 125 MHz of bandwidth and 80 ms of time as a base tile, applying normalization function to the base tile, applying a series of convolutional and pooling layers, applying modified You Only Look Once (YOLO) algorithm for detection, grouping bounding boxes displayed in the waterfall images (e.g., waterfall plots in FIGS. **8-18**), classifying signals based on the shape of detection output, verifying results with a second level recurrent neural network (RNN) based pattern estimator.

[0081] In one embodiment, a method for training comprises recording clean RF signals, shifting RF signals in frequency randomly, creating truth data for YOLO output, adding a simulated channel to the RF signals, recording typical RF backgrounds, applying FFT function to RF data, converting FFT data into logarithmic scale in magnitude, averaging converted FFT into 256 by 256 array representing 125 MHz of bandwidth and 80 ms of time as a base tile, applying normalization function to the base tile, applying a series of convolutional and pooling layers, applying modified You Only Look Once (YOLO) algorithm for detection, grouping bounding boxes displayed in the waterfall images (e.g., waterfall plots in FIGS. **8-18**), applying a sigmoid cross entropy function, and applying an Adaptive Moment Estimation (Adam) based back propagation algorithm.

[0082] In one embodiment, a drone detection engine is operable to convert FFT flows from a radio to a tile. For each channel, the drone detection engine is operable to standardize the FFT output from the radio at a defined resolution bandwidth, and group high resolution FFT data into distinct bins overtime. The drone detection engine is further operable to calculate average and standard deviation of power for discrete FFT bins, assign a power value to each channel within the tile. Each scan or single stare at the radio is a time slice, and multiple time slices with power and channel assignment create a tile. Tiles from different frequency spans and center frequencies are identified as a tile group by a tile group number. Receivers in the drone detection system are operable to be re-tuned to different frequencies and spans. In one embodiment, the drone detection system comprises multiple receivers to generate tiles and tile groups.

[0083] In one embodiment, a tile is sent to a YOLO AI Engine. Outputs of a decision tree in the YOLO AI engine are used to detect multiple drones and their controllers. Drones of the same type of radio protocol are operable to be identified within the tile. Controllers of the same type of radio protocol are operable to be identified within the tile. Drones of different radio protocols are also operable to be identified within the tile. Controllers of different radio protocols are also operable to be identified within the tile. FIG. **19** is an illustration of identifying drones and controllers based on signal edge detection.

[0084] In one embodiment, a plurality of tiles is sent to the YOLO AI engine. In one embodiment, a tile group is sent to the YOLO AI engine. The YOLO AI engine generates an output for each tile to identify drones and their controllers with a probability. An average probability is calculated based on outputs for multiple tiles in the tile group. For each tile group, the YOLO AI engine computes outputs for several tiles per second.

[0085] In one embodiment, a state engine controls the flows of tiles and tile groups into one or more AI engines. AI engines do not use frequency values for analytics. Thus, the one or more AI engines are operable for any frequency and frequency span that a drone radio supports. The state engine further correlates output of the one or more AI engines to appropriate tiles and tile groups.

[0086] The systems and methods of the present invention are operable for direction finding of drones and their controllers. Outputs from the AI engine are denoted with time basis for the drones and their controllers.

[0087] Drones typically maintain the same frequency unless their firmware detects interference. Then the drones may negotiate a change with their controllers. This does not create an issue for detection as long as the new frequency and span is monitored by the systems and methods of the present invention. Drone controllers typically use a frequency hopping spread spectrum (FHSS) or other Frequency hopping system (e.g., Gaussian frequency shift keying (GFSK)).

[0088] In one embodiment, the systems and method of the present invention are operable to approximate a start time of a line of bearing for a direction finding (DF) system. The time intervals are either known or estimated based upon the behavior monitored by the AI engine and state engine. This allows the time slice and frequency of each individual drone and/or controller to be passed to the DF system. In one embodiment, three or four receivers are coordinated to collect information in appropriate frequency segments, wherein the frequency segments are similar to tiles described earlier. FIG. **20** is an illustration with averaged signal amplitudes and signal edges according to one embodiment of the present invention.

[0089] The AI engine examines the segments to determine if a drone or controller exists. An azimuth of the drone or controller in an Earth-Centered Earth-Fixed coordinate system is determined based on other information collected from

the three or four receivers using time difference of arrival (TDOA), angle of arrival (AOA), power correlative, or interferometry techniques.

[0090] Distance capability of UAV detection and classification system depends on hardware configuration, environment morphology and restrictions based on country and classification of the counter UAV operator. In one embodiment, the systems and methods for unmanned vehicle recognition are operable to detect unmanned vehicles within 3-4 kilometers. FIG. **21** displays a detection range of less than 500 meters based on equipment specification and location.

[0091] In one embodiment, the systems and methods of the present invention are operable to utilize training data. In one embodiment training data contains at least one tile displaying at least one waterfall image for one or more drones. These images are numbered based on the time slices and color coded to keep track of each drone. The numbering and color coding of each drone is fed into the ML drone frequency hopping algorithm. The color coding and numbering of each drone signal allows for easy training of the image analysis algorithm to quickly pick up on trends in drone frequency hopping which allows for quick training of the algorithm to account for multiple drones and/or frequency hopping types. In one embodiment, one or more drones contain the same and/or different types of radio protocols within at least one tile. In one embodiment the training data is further utilizable by one or more AI engines operable for any frequency and frequency span supported by drone radio. In one embodiment, the AI engine is operable to use machine learning (ML), artificial intelligence (AI), You Only Look Once Artificial Intelligence (YOLO AI), deep learning (DL), neural networks (NNs), artificial neural networks (ANNs), convolutional neural networks (CNNs), support vector machines (SVMs), Markov decision process (MDP), natural language processing (NLP), control theory, and/or statistical learning techniques. FIG. **22** displays a tile containing drones of the same type of radio protocol. FIG. **23** displays training data of a tile containing drones of different types of radio protocols.

[0092] In one embodiment the AI and/or ML algorithm is operable to classify the drone and/or signal modulation type based on the waterfall image created by the signal. The training data and/or waterfall images are operable to be sets of known modulation schemes for drones for the ML algorithm to provide an image comparison to the signal in the RF environment. The known frequency hopping schemes are operable to be learned by the algorithm and then identified by pattern recognition when a signal in the environment is analyzed and put into a waterfall graphical representation. The image comparison ML or AI algorithm is operable to detect the modulation type patterns of the signal.

[0093] In one embodiment, the training data is operable to be utilized for "No Drone Zone" identification and avoidance. The Federal Aviation Administration (FAA) denotes areas where drones are unable to operate as "No Drone Zones", with each zone containing specific operating restrictions. To report "No Drone Zones" to recreational flyers, the FAA released B4UFLY—a service that allows recreational flyers to determine where drones are operable and not operable.

[0094] In one embodiment, the training data is operable to be fed to the ML Drone Frequency Hopping algorithm to allow for identification and avoidance of "No Drone Zones". In a further embodiment, the ML Drone Frequency Hopping algorithm is operable to cross reference detected signals with B4UFLY to determine if the signal is in a restricted area.

[0095] In one embodiment, the training data includes at least a tile or group of tiles representing a drone that is operable to exist in a "No Drone Zone". In one embodiment, the system utilizes the ML or AI Drone Frequency Hopping algorithm to confirm detection of a drone before cross referencing the signal with B4UFLY, the geolocation engine, and other sensors to determine if the drone has breached a "No Drone Zone". In one embodiment, other sensors include visual systems such as LIDAR, cameras and radar. The system is operable to interface with the multiple data sources, determine if the information from the multiple data sources is consistent or in agreement, and create a report identifying and determining if the drone has breached a "No Drone Zone". If the sensor information is not in agreement, the system is operable to discard the data and create a report identifying the faulty data.

[0096] In one embodiment, the present invention is operable to utilize training data to detect friendly drones (F-Drone) and nefarious drones (N-Drone). In one embodiment an F-Drone is identified by a specific radio protocol and/or a N-Drone is identified by not fitting into the desired radio protocol. In another embodiment, an N-Drone is identified by a desired radio protocol and/or a F-Drone is identified by not identifying with a targeted radio protocol. In a further embodiment one or more AI engines is operable to detect F-Drones and/or N-Drones utilizing training data. Training data is further utilizable by one or more AI engines that are operable for any frequency and frequency span supported by drone radio. In one embodiment, training data is operable to be utilized by one or more AI engines to define a "No Drone Zone". In a further embodiment, the AI engine is operable to detect a N-Drones by identifying a signal within the "No Drone Zone". In one embodiment training data is cross referenced with B4UFLY, the geolocation engine, and other sensors to embody parameters, including but not limited to altitude, to detect friendly and/or nefarious drones. In one embodiment, a report is created and sent identifying and detecting F-Drones and/or N-Drones.

[0097] Certain modifications and improvements will occur to those skilled in the art upon a reading of the foregoing description. The above-mentioned examples are provided to serve the purpose of clarifying the aspects of the invention and it will be apparent to one skilled in the art that they do not serve to limit the scope of the invention. All modifications and improvements have been deleted herein for the sake of conciseness and readability but are properly within the scope of the present invention.

What is claimed is:

1. A system for signal identification in a radiofrequency (RF) environment, comprising:

at least one node device including a processor and memory in communication with at least one RF receiver;

wherein the at least one node device is in communication with at least one artificial intelligence (AI) engine;

wherein the at least one RF receiver is operable to capture RF data in the RF environment and transmit the RF data to the at least one node device;

wherein the at least one node device is operable to average Fast Fourier Transform (FFT) data derived from the RF data into at least one tile;

wherein the at least one AI engine is operable to generate an output for the at least one tile to identify and correlate at least one signal with a probability;

wherein the at least one tile is represented as at least one waterfall image; and

wherein location information for the at least one signal is displayed on at least one user interface as at least one line of bearing.

2. The system of claim **1**, wherein the at least one AI engine is operable to calculate an average probability based on the output.

3. The system of claim **1**, wherein the at least one AI engine is trained using at least one training data set.

4. The system of claim **1**, wherein a signal modulation type of the at least one signal includes direct sequence spread spectrum (DSSS), orthogonal frequency division multiplexing (OFDM), frequency hopping spread spectrum (FHSS), and/or Futaba advanced spread spectrum technology (FASST).

5. The system of claim **1**, wherein the at least one signal includes a drone signal.

6. The system of claim **1**, wherein the at least one node device is operable to transmit an alert and/or report related to a comparison of the location information of the at least one signal against at least one location of interest.

7. The system of claim **1**, wherein the at least one line of bearing is calculated by a direction-finding engine.

8. The system of claim **1**, wherein the at least one signal is highlighted on the at least one waterfall image.

9. The system of claim **1**, wherein the at least one RF receiver is operable to transform the RF data to the FFT data.

10. An apparatus for signal identification in a radiofrequency (RF) environment, comprising:

a node device including a processor and memory;

wherein the node device is in communication with at least one artificial intelligence (AI) engine;

wherein the node device is operable to receive RF data from at least one RF receiver;

wherein the node device is operable to average Fast Fourier Transform (FFT) data derived from the RF data into at least one tile;

wherein the at least one AI engine is operable to generate an output for the at least one tile to identify and correspond at least one signal with a probability;

wherein the RF data includes location information of the at least one signal;

wherein the at least one tile is represented as at least one waterfall image; and

wherein the location information for the at least one signal is displayed on at least one user interface as at least one color coded line of bearing.

11. The apparatus of claim **10**, wherein the location information includes an airport no-fly-zone and/or at least one geofence.

12. The apparatus of claim **10**, wherein the at least one AI engine is operable to calculate an average probability based on the output.

13. The apparatus of claim **10**, wherein the at least one node device is operable to transmit an alert and/or report related to a comparison of the location information of the at least one signal against at least one location of interest.

14. The apparatus of claim **10**, wherein the at least one AI engine is operable to be trained using at least one training data set.

15. The apparatus of claim **10**, wherein the at least one color coded line of bearing is calculated by a direction-finding engine.

16. A method for signal analysis in a radiofrequency (RF) environment, comprising:

capturing RF data in the RF environment by at least one RF receiver, converting the RF data to Fast Fourier Transform (FFT) data by the at least one RF receiver and transmitting the FFT data to at least one node device;

averaging the FFT data by the at least one node device into at least one tile and representing the at least one tile as at least one waterfall image;

generating an output for the at least one tile by at least one artificial intelligence (AI) engine in communication with the at least one node device to identify and correlate at least one signal with a probability;

calculating an average probability based on the output of the at least one tile;

classifying at least one signal emitting device based by comparing the at least one signal emitted from the at least one signal emitting device to classification data stored in a classification library; and

wherein location information for the at least one signal is displayed on at least one user interface as at least one line of bearing.

17. The method of claim **16**, wherein the location information includes an airport no-fly-zone and/or at least one geofence.

18. The method of claim **16**, further comprising the at least one node device transmitting an alert and/or report related to a comparison of the location information for the at least one signal against at least one location of interest.

19. The method of claim **16**, wherein the at least one AI engine is trained using at least one training data set.

20. The method of claim **16**, wherein the at least one signal characteristic includes a modulation type of the at least one signal that includes direct sequence spread spectrum (DSSS), orthogonal frequency division multiplexing (OFDM), frequency hopping spread spectrum (FHSS), and/or Futaba advanced spread spectrum technology (FASST).

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