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Laufer et al.

(54) **MITIGATION OF SMALL UNMANNED AIRCRAFT SYSTEMS THREATS**

(71) Applicant: **Laufer Wind Group LLC**, New York, NY (US)

(72) Inventors: **Eric David Laufer**, New York, NY (US); **John Knag**, New Boston, NH (US); **Rodney Petr**, Acton, MA (US)

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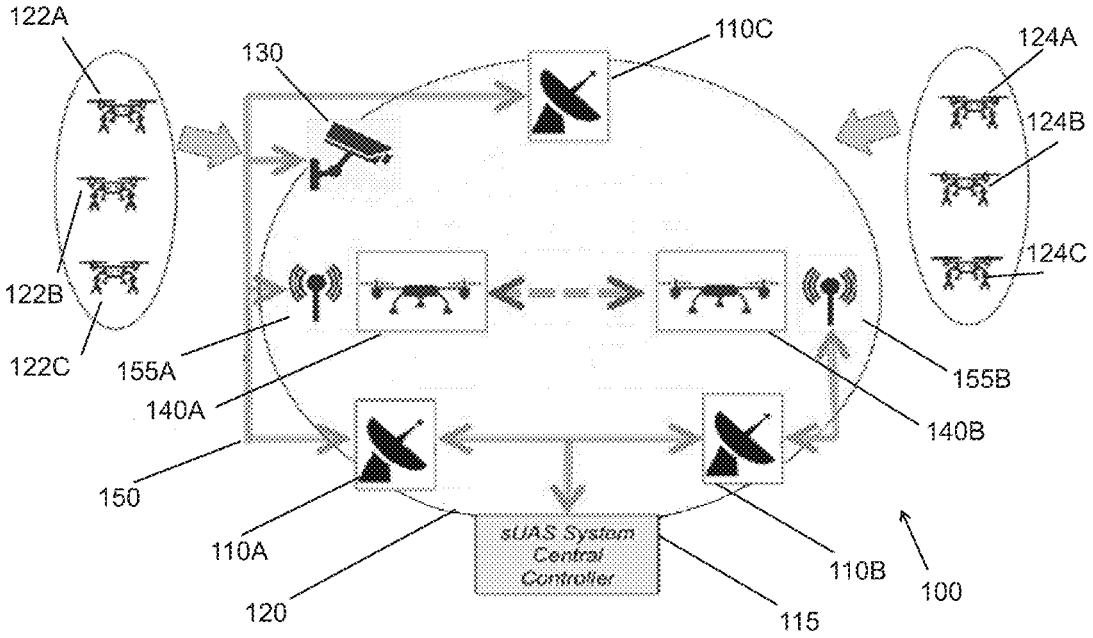
(57) **ABSTRACT**

Described are systems and methods for drone interdiction. A target aircraft is detected based on data from one or more of one or more radars, a fixed camera image from one or more fixed cameras, and an interceptor aircraft image from a camera mounted to an interceptor aircraft. An interception location is generated describing where the interceptor aircraft and the target aircraft are expected to meet. The interceptor aircraft is directed to the interception location to immobilize the target aircraft.



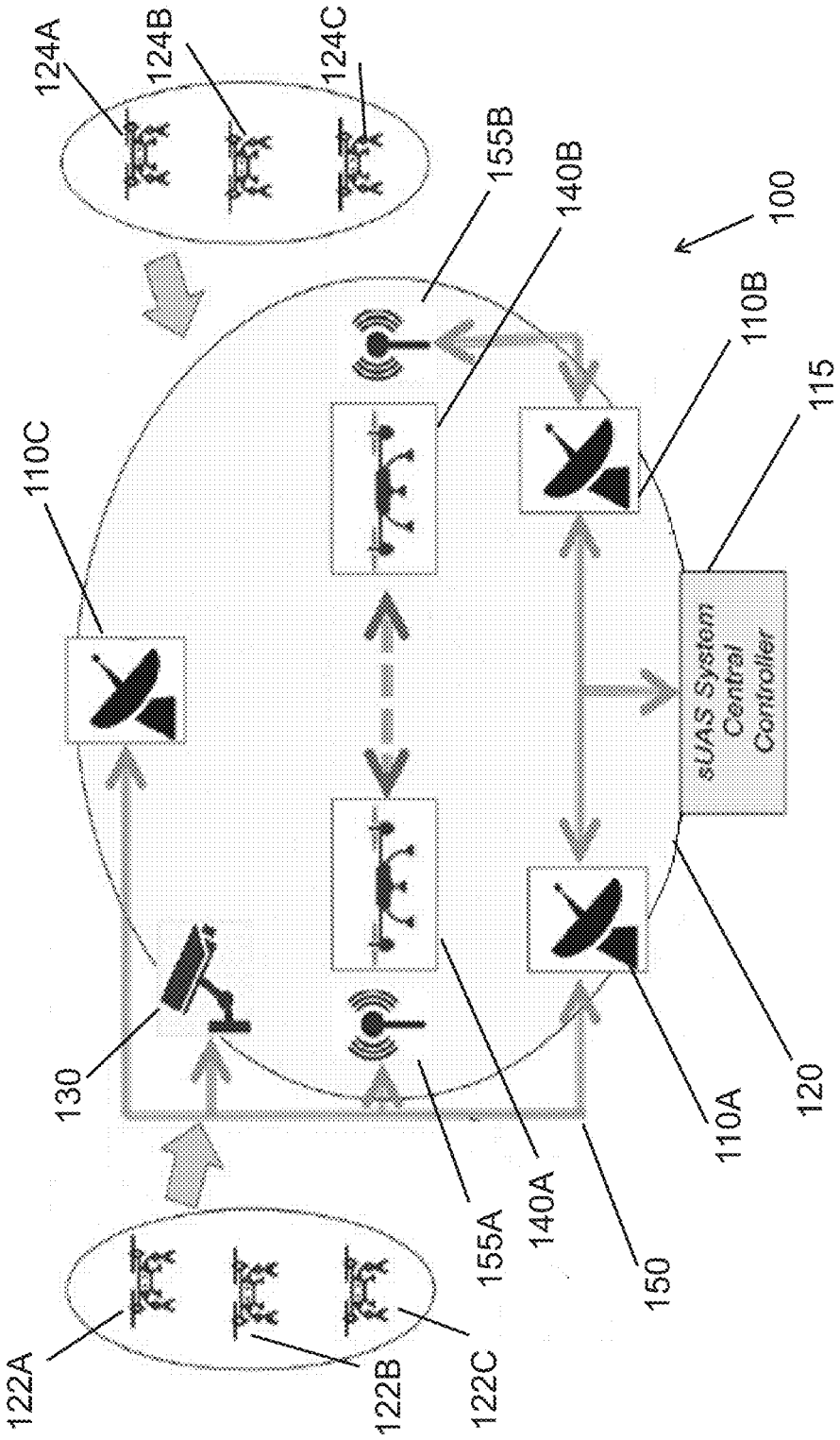

124A
124B
124C
155B
140B
100
110B
115
110C
sUAS System Central Controller
130
120
110A
155A
140A
150
122A
122B
122C

FIGURE 1

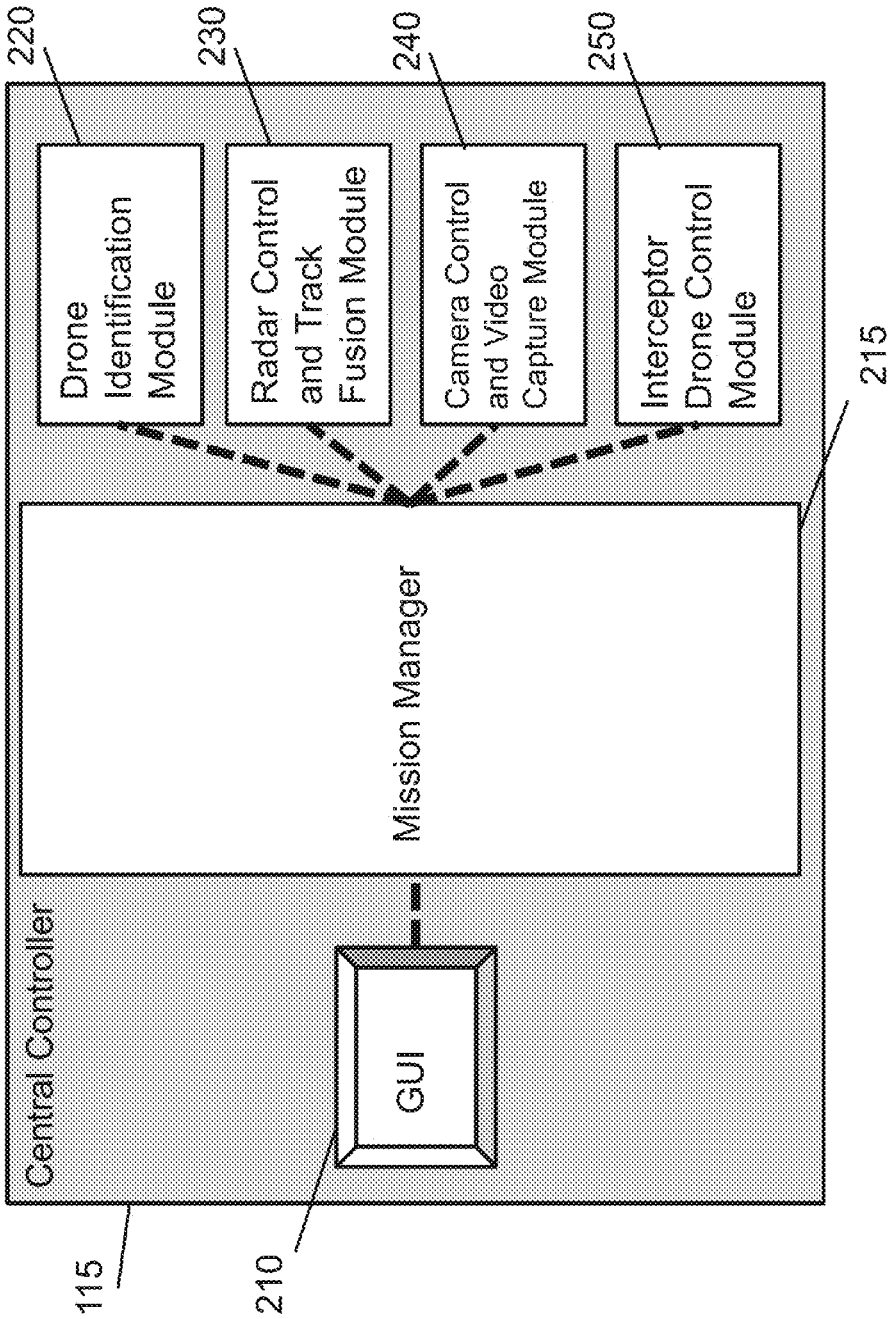

220
230
240
250
Drone Identification Module
Radar Control and Track Fusion Module
Camera Control and Video Capture Module
Interceptor Drone Control Module
215
Mission Manager
Central Controller
GUI
115
210

FIGURE 2

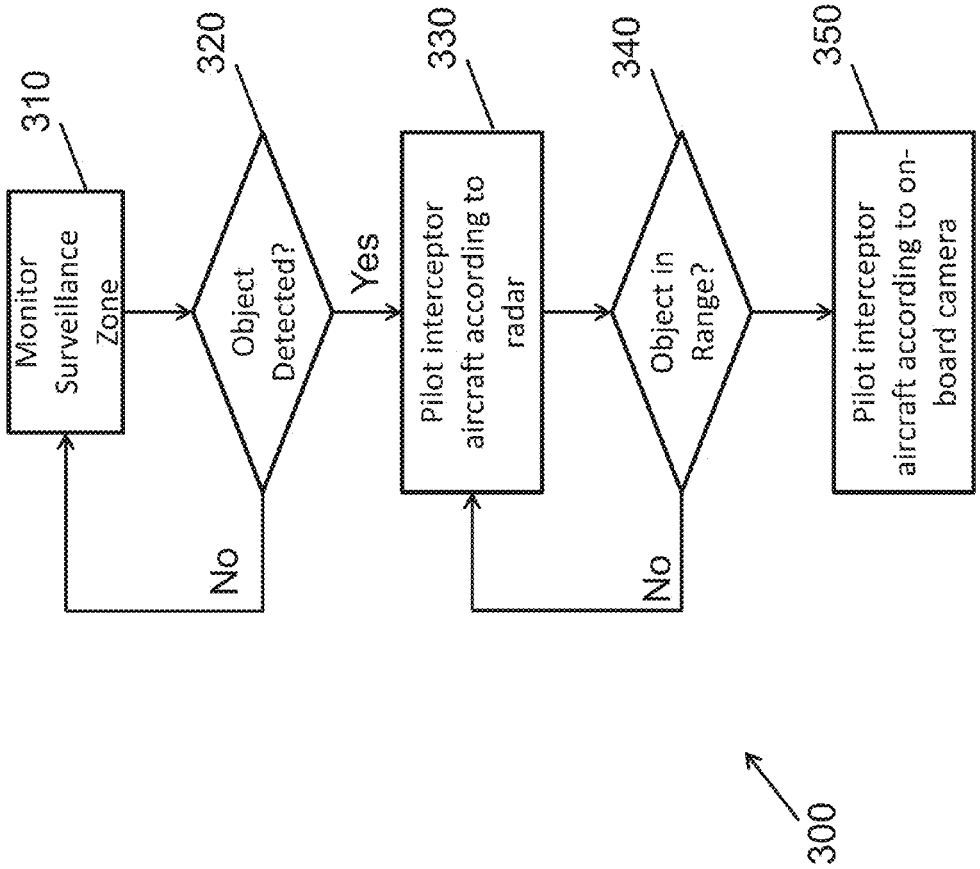

310
Monitor Surveillance Zone
320
Object Detected?
Yes
No
330
Pilot interceptor aircraft according to radar
340
Object in Range?
No
350
Pilot interceptor aircraft according to on-board camera
300

FIGURE 3

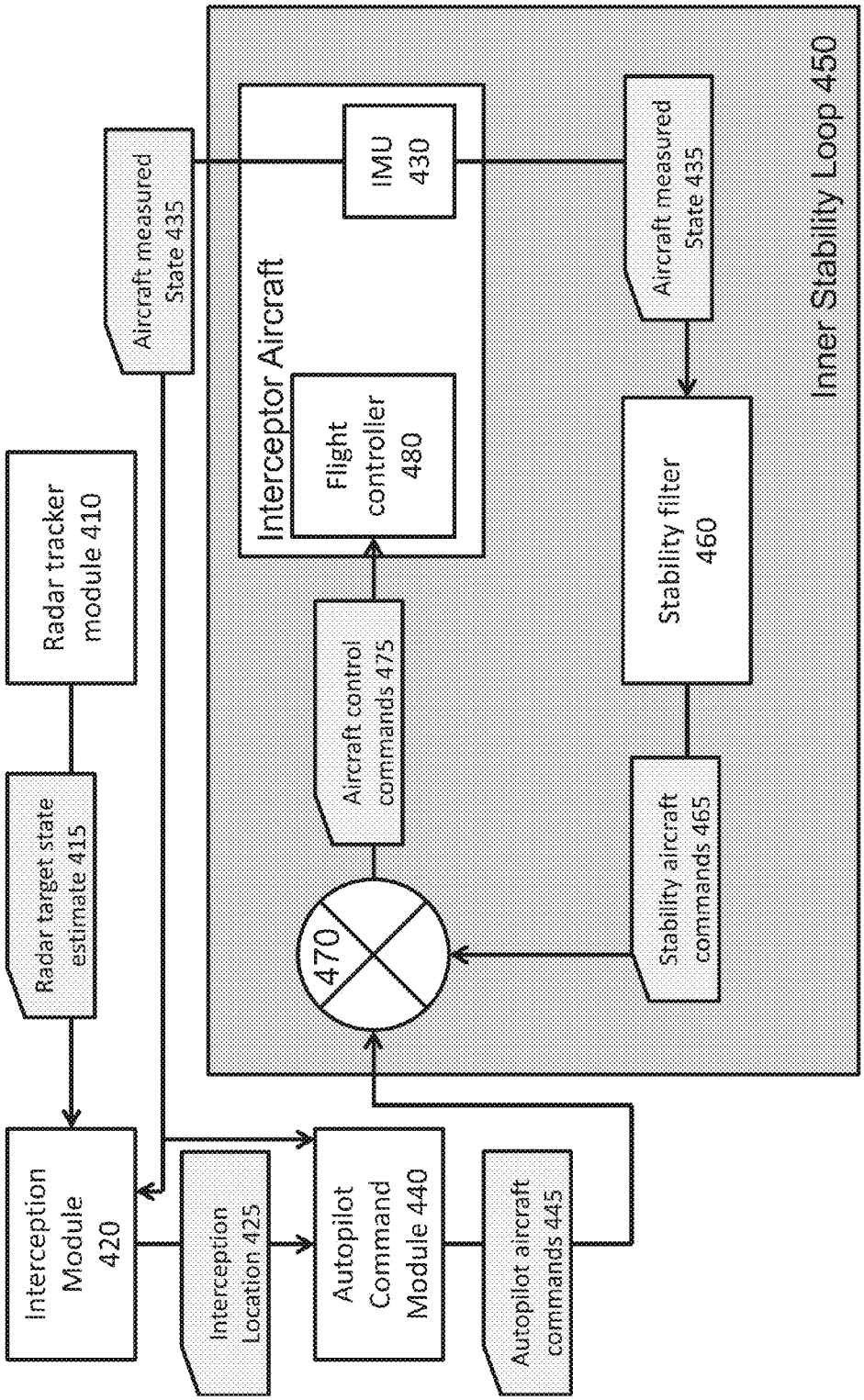

Radar tracker module 410
Radar target state estimate 415
Interception Module 420
Aircraft measured State 435
Interceptor Aircraft
IMU 430
Flight controller 480
Aircraft control commands 475
470
Interception Location 425
Autopilot Command Module 440
Autopilot aircraft commands 445
Aircraft measured State 435
Stability filter 460
Stability aircraft commands 465
Inner Stability Loop 450

FIGURE 4

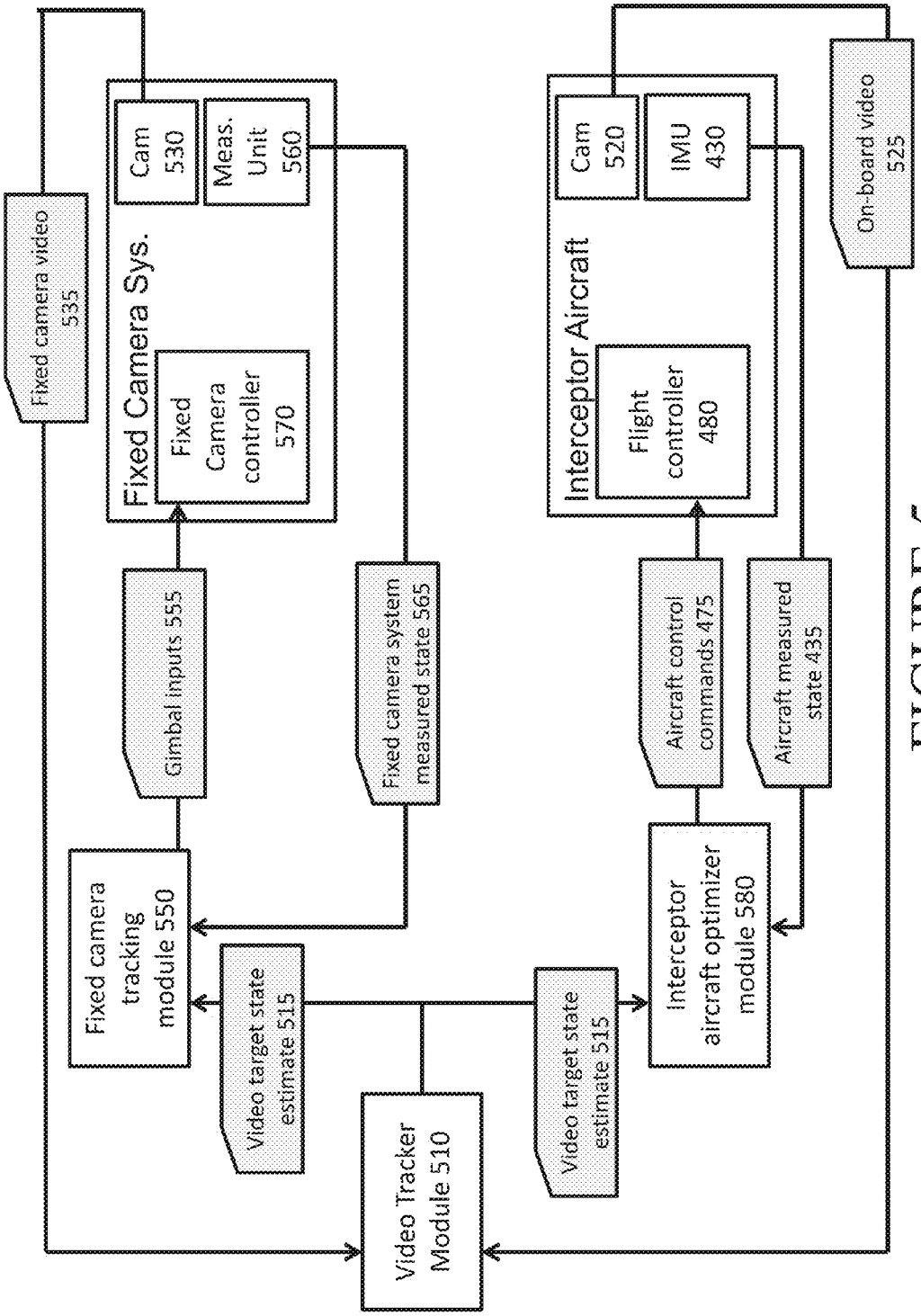

Fixed camera video 535
Fixed Camera Sys.
Cam 530
Meas. Unit 560
Fixed Camera controller 570
Gimbal inputs 555
Fixed camera system measured state 565
Fixed camera tracking module 550
Video target state estimate 515
Video Tracker Module 510
Video target state estimate 515
Interceptor aircraft optimizer module 580
Aircraft control commands 475
Aircraft measured state 435
Interceptor Aircraft
Cam 520
IMU 430
Flight controller 480
On-board video 525

FIGURE 5

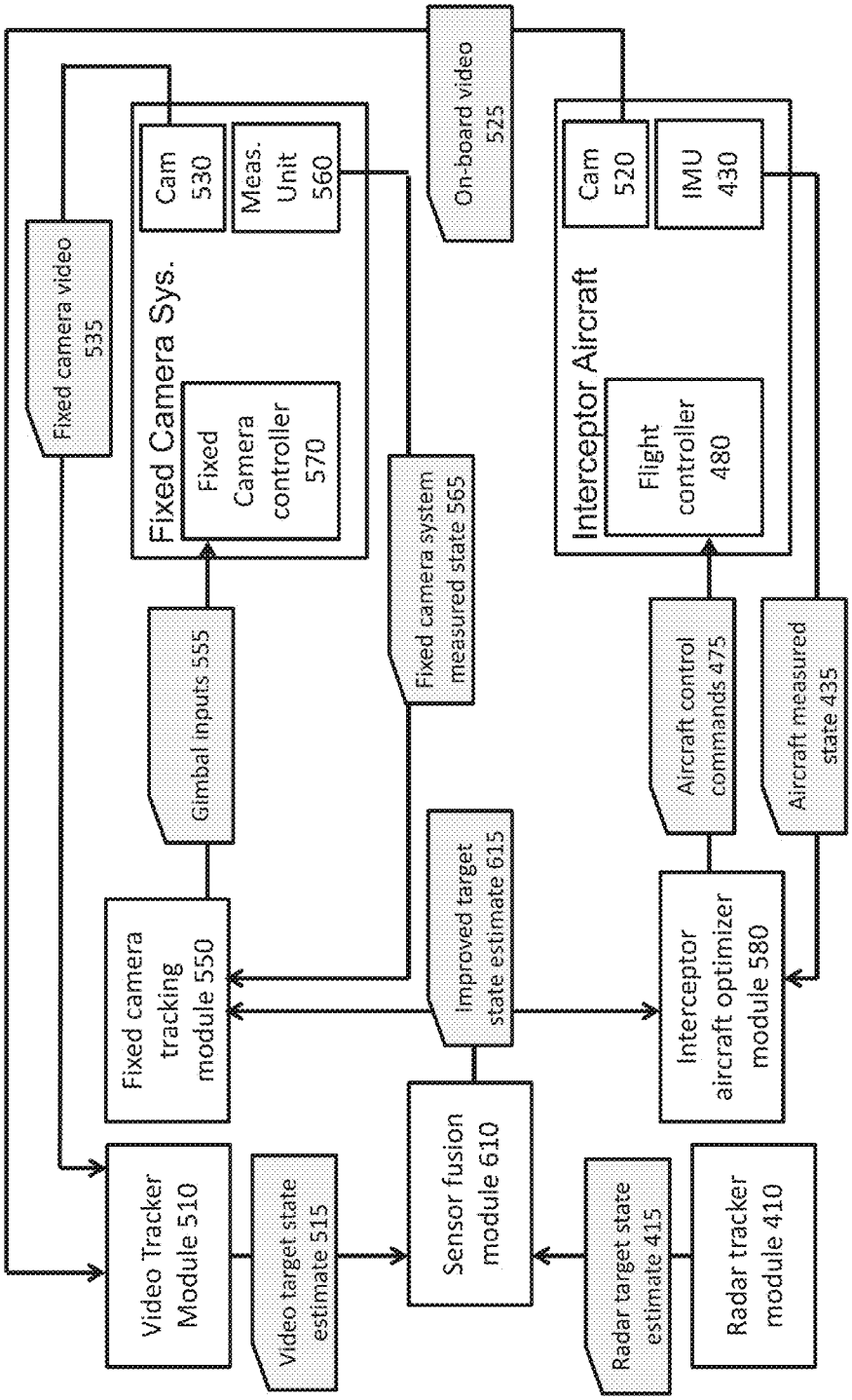

Fixed camera video 535
Fixed Camera Sys.
Cam 530
Meas. Unit 560
Fixed Camera controller 570
On-board video 525
Interceptor Aircraft
Cam 520
IMU 430
Flight controller 480
Gimbal inputs 555
Fixed camera system measured state 565
Aircraft control commands 475
Aircraft measured state 435
Fixed camera tracking module 550
Improved target state estimate 615
Interceptor aircraft optimizer module 580
Video Tracker Module 510
Video target state estimate 515
Sensor fusion module 610
Radar target state estimate 415
Radar tracker module 410

FIGURE 6

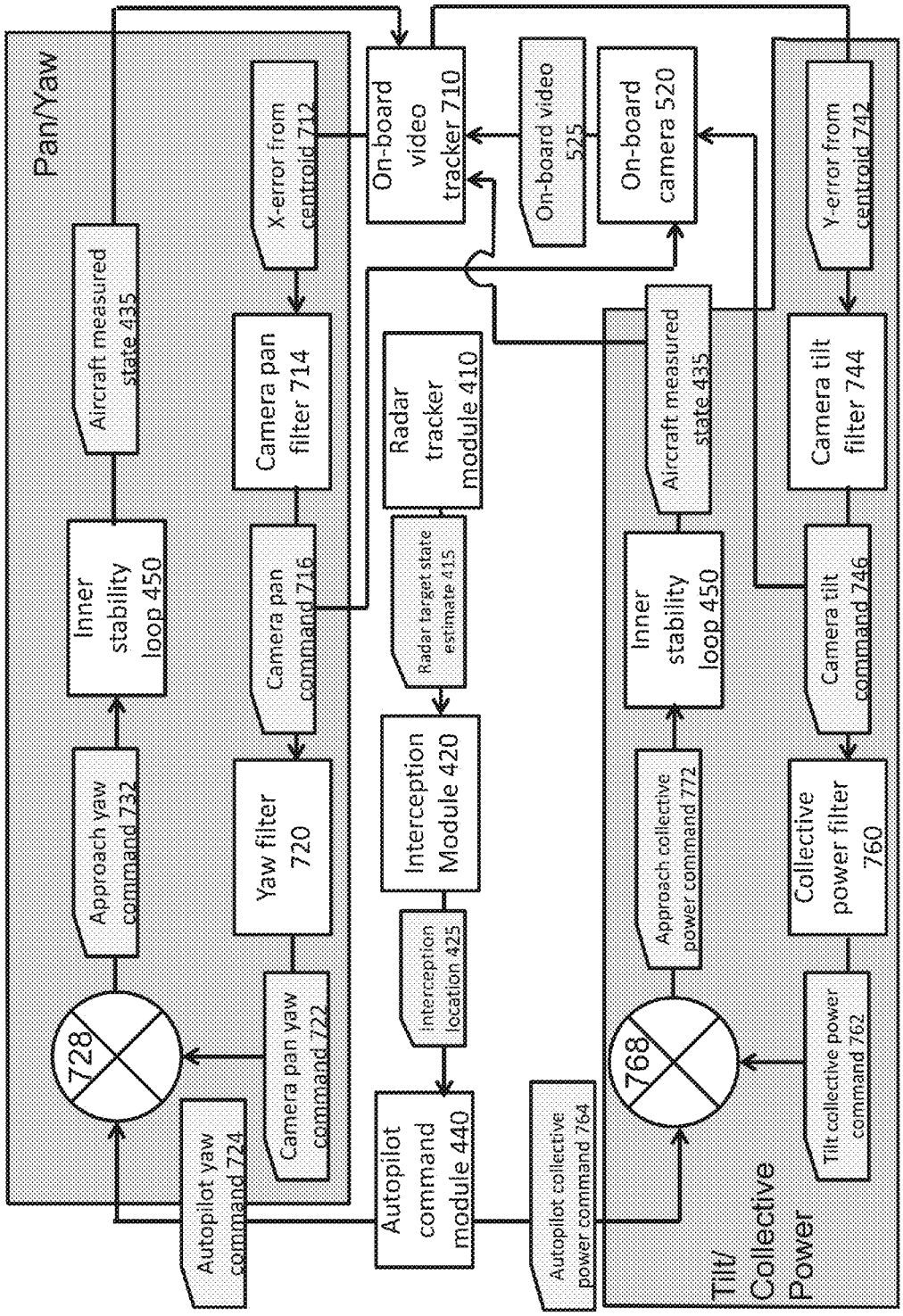

Pan/Yaw
Aircraft measured state 435
Inner stability loop 450
Approach yaw command 732
728
Autopilot yaw command 724
X-error from centroid 712
Camera pan filter 714
Camera pan command 716
Yaw filter 720
Camera pan yaw command 722
On-board video tracker 710
Radar tracker module 410
Radar target state estimate 415
Interception Module 420
Interception location 425
Autopilot command module 440
On-board video 525
On-board camera 520
Autopilot collective power command 764
Tilt/ Collective Power
Aircraft measured state 435
Inner stability loop 450
Approach collective power command 772
768
Tilt collective power command 762
Y-error from centroid 742
Camera tilt filter 744
Camera tilt command 746
Collective power filter 760

FIGURE 7

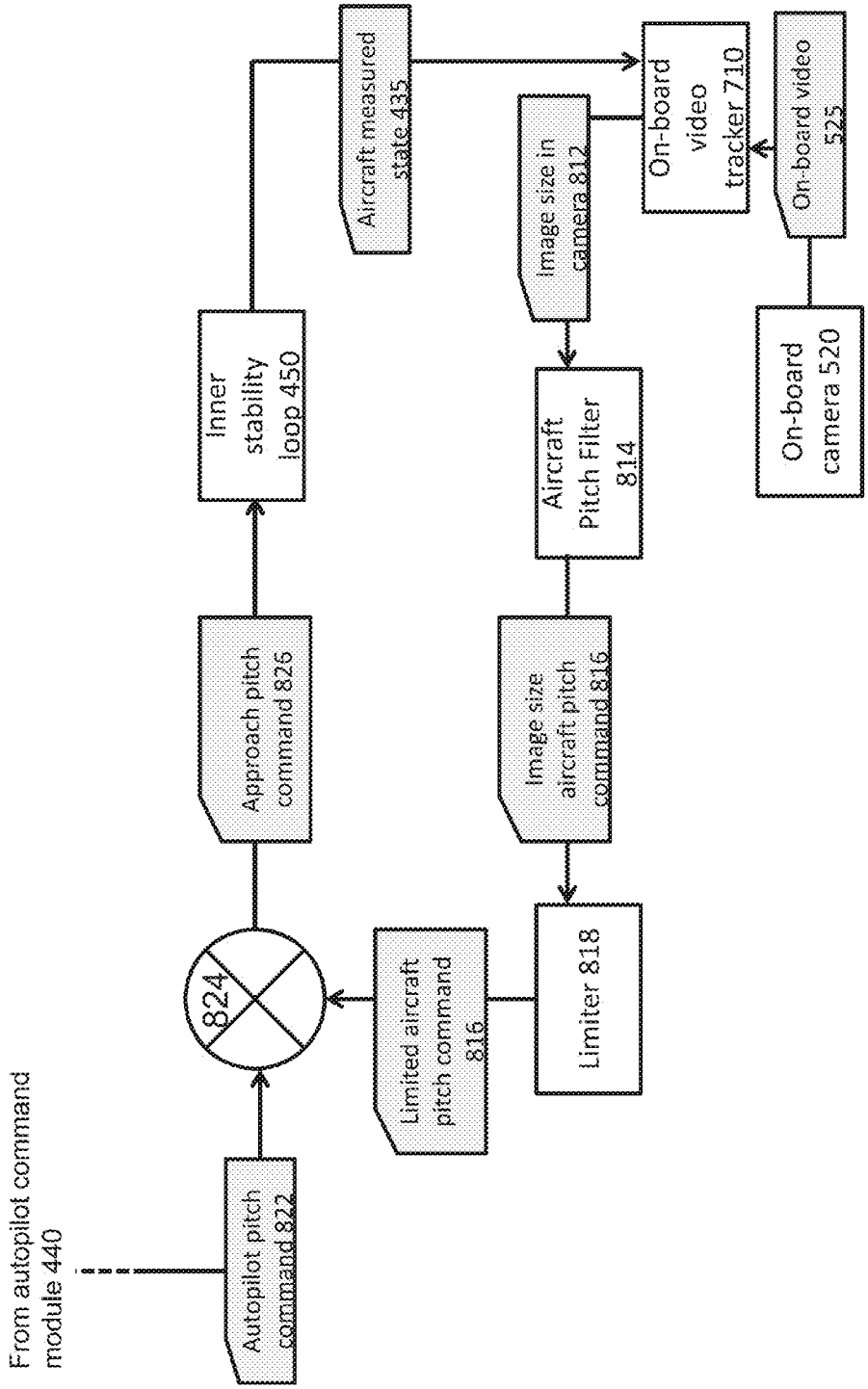

From autopilot command module 440
Autopilot pitch command 822
824
Approach pitch command 826
Inner stability loop 450
Limited aircraft pitch command 816
Limiter 818
Image size aircraft pitch command 816
Aircraft Pitch Filter 814
Image size in camera 812
Aircraft measured state 435
On-board video tracker 710
On-board video 525
On-board camera 520

FIGURE 8

MITIGATION OF SMALL UNMANNED AIRCRAFT SYSTEMS THREATS

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Patent Application No. 62/211,319, filed on Aug. 28, 2015, and titled "Drone Interdiction System," and U.S. Patent Application No. 62/352,728, filed on Jun. 21, 2016, and titled "Mitigation of Small Unmanned Aircraft Systems (sUAS) Threats;" the entire contents of each are incorporated herein by reference.

FIELD OF THE TECHNOLOGY

[0002] The present technology relates generally to the mitigation of threats from unmanned aircraft systems threats and, more specifically, to interdiction systems using one or more of radar, fixed cameras, and interceptor aircraft to mitigate such threats.

BACKGROUND

[0003] Small unmanned aircraft systems ("sUAS"), such as radio-controlled drones or quadcopters, can pose a serious threat to civil aviation traffic and airspaces, ground installations, other high value assets, and large crowds. These sUAS can be easily obtained by recreational hobbyists and by those who seek to operate them for malicious purposes. The effective guidance and control capability of commercially-available sUAS as well as their capability for autonomous flight control features make these devices especially dangerous as standoff threats. Weapons or other dangerous instruments can be attached to the sUAS, further increasing the threat posed to sensitive locations. Swarm attacks involving multiple simultaneous sUAS threats are especially worrisome and present unique challenges.

[0004] Attempts to counter the threat posed by autonomous sUAS using radio frequency, for instance by detecting sUAS control signals, co-opting sUAS wireless communication links, or disrupting GPS signals by spoofing, can be ineffective in some situations. Recent improvements of the signal security of commercial GPS systems by adding digital signatures onto GPS civil navigation messages have made spoofing increasingly difficult. Similarly, approaches based on radio frequency disruption or control are becoming increasingly ineffective as attackers become more sophisticated. These radio frequency approaches can be ineffective against fully-autonomous sUAS. Accordingly, a need exists for an interdiction system to counter the threat posed by sUAS.

SUMMARY OF THE TECHNOLOGY

[0005] Systems and methods are provided for the interdiction of sUAS systems, such as a drone, and other threats that can provide greater efficacy than spoofing approaches. In one aspect, there is a method for drone interdiction. The method can include detecting, using one or more radars, a target aircraft within a surveillance zone. The method can include generating first one or more interceptor aircraft commands to direct an interceptor aircraft to the target aircraft, based on data from the one or more radars. The method can include commanding the interceptor aircraft according to the first one or more interceptor aircraft commands. The method can include acquiring a target image using a camera mounted on the interceptor aircraft. The method can include, generating, in response to determining the target aircraft is in the target image, second one or more interceptor aircraft commands to direct the interceptor aircraft to the target aircraft, based on at least one of the target image, a fixed camera target image from one or more fixed cameras and the data from the one or more radars. The method can include commanding the interceptor aircraft according to the second one or more interceptor aircraft commands.

[0006] In some embodiments, the method can include tracking the target aircraft based on the fixed camera target image, a fixed camera system model, and the data from the one or more radars. In some embodiments, the method can include determining that the target aircraft is a threat. In some embodiments, the method can include determining that the target is a threat by analyzing the fixed camera target image. In some embodiments, the method can include commanding the interceptor aircraft to an interceptor aircraft base station in response to determining the target aircraft is not a threat.

[0007] In some embodiments, the method can include immobilizing, by the interceptor aircraft, the target aircraft. In some embodiments, the method can include immobilizing, by the interceptor aircraft, the target aircraft by the interceptor aircraft using a net assembly to immobilize the target aircraft. In some embodiments, the method can include immobilizing, by the interceptor aircraft, the target aircraft by the interceptor aircraft using a net gun to immobilize the target aircraft.

[0008] In another aspect, there is a method for drone interdiction. The method can include detecting, using one or more radars, a target aircraft within a surveillance zone. The method can include generating first one or more interceptor aircraft commands to direct an interceptor aircraft to the target aircraft, based on data from the one or more radars. The method can include commanding the interceptor aircraft according to the first one or more interceptor aircraft commands. The method can include acquiring a target image using a camera mounted on the interceptor aircraft. The method can include determining, in response to determining the target aircraft is in the target image, an interception location, based on at least one of the target image, a fixed camera target image from one or more fixed cameras and the data from the one or more radars. The method can include generating second one or more interceptor aircraft commands to direct the interceptor aircraft to the target aircraft, based on the interception location. The method can include commanding the interceptor aircraft according to the second one or more interceptor aircraft commands.

[0009] In some embodiments, determining, in response to determining the target aircraft is in the target image, an interception location, based on at least one of the target image, a fixed camera target image from one or more fixed cameras and the data from the one or more radars can include generating a first track state, based on the target image. In some embodiments, determining, in response to determining the target aircraft is in the target image, an interception location, based on at least one of the target image, a fixed camera target image from one or more fixed cameras and the data from the one or more radars can include generating a first track score, based on the first track state. In some embodiments, determining, in response to determining the target aircraft is in the target image, an

interception location, based on at least one of the target image, a fixed camera target image from one or more fixed cameras and the data from the one or more radars can include generating a second track state, based on one or more of the fixed camera target image from the one or more fixed cameras and the data from the one or more radars. In some embodiments, determining, in response to determining the target aircraft is in the target image, an interception location, based on at least one of the target image, a fixed camera target image from one or more fixed cameras and the data from the one or more radars can include generating a second track score, based on the second track state. In some embodiments, determining, in response to determining the target aircraft is in the target image, an interception location, based on at least one of the target image, a fixed camera target image from one or more fixed cameras and the data from the one or more radars can include selecting the first track state or the second track state by comparing the first track score and the second track score.

[0010] In another aspect, there is a method for drone interdiction. The method can include detecting a target aircraft, based on data from one or more of one or more radars, a fixed camera image from one or more fixed cameras, and an interceptor aircraft image from a camera mounted to an interceptor aircraft. The method can include generating an interception location where the interceptor aircraft and the target aircraft are expected to meet. The method can include directing, based on the interception location, the interceptor aircraft to the interception location to immobilize the target aircraft. In some embodiments, directing, based on the interception location, the interceptor aircraft to the interception location to immobilize the target aircraft can include capturing the target aircraft using a hanging net. In some embodiments, directing, based on the interception location, the interceptor aircraft to the interception location to immobilize the target aircraft can include firing a net gun at the target to capture the target aircraft.

[0011] Other aspects and advantages of the present technology will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating the principles of the technology by way of example only.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The foregoing and other objects, features, and advantages of the present technology, as well as the technology itself, will be more fully understood from the following description of various embodiments, when read together with the accompanying drawings, in which:

[0013] FIG. **1** illustrates an interdiction system in accordance with embodiments of the technology;

[0014] FIG. **2** illustrates a system diagram of a central controller in accordance with embodiments of the technology;

[0015] FIG. **3** illustrates a flow diagram of a method for interdiction in accordance with embodiments of the technology;

[0016] FIG. **4** illustrates a block control diagram of radar tracking according to embodiments of the technology;

[0017] FIG. **5** illustrates a block control diagram of video tracking in accordance embodiments of the technology;

[0018] FIG. **6** illustrates a block control diagram of radar and video tracking in accordance with embodiments of the technology;

[0019] FIG. **7** illustrates block control diagrams for two axes of an interceptor aircraft on final approach to a target in accordance with embodiments of the technology;

[0020] FIG. **8** illustrates a block control diagram for an axis of an interceptor aircraft on final approach to a target in accordance with embodiments of the technology.

DETAILED DESCRIPTION

[0021] The interdiction systems and methods described herein can offer improved real-time monitoring and interception capabilities over other methods of sUAS interdiction. The use of multiple modes of detection, including, for example, distributed radar, fixed camera sensors, and distributed interceptor aircraft can provide a flexible and rapid sUAS mitigation response to reliably identify, capture, and defeat sUAS and swarm threats. The interdiction systems and methods described herein can lead to faster response and verification times, as well as improve the time between when the sUAS threat is detected and when it is immobilized. Immobilizing or capturing sUAS threats intact can advantageously improve the likelihood that the sUAS operator can be identified and held accountable.

[0022] FIG. **1** illustrates interdiction system **100** in accordance with embodiments of the technology. Doppler radars **110**A-**110**C are distributed throughout an area, such as an area including a high value asset that requires protection. Data from Doppler radars **110**A-**110**C is transmitted to and monitored by central controller **115**. Doppler radars **110**A-**110**C can receive control or other signals from central controller **115**. In some embodiments, central controller **115** can fuse track output from an individual Doppler radar, such as Doppler radar **110**A, with track output from another individual Doppler radar, such as Doppler radar **110**B, to create a wider coverage area.

[0023] Surveillance zone **120** represents the area that is monitored and protected from the threat of incoming sUAS, like drones **122**A-**122**C and **124**A-**124**C. In some embodiments, the coverage of Doppler radars **110**A-**110**C can define surveillance zone **120**. In other embodiments, each of Doppler radars **110**A-**110**C can individually define its own surveillance zone. The number of Doppler radars used in an interdiction system can be based on the desired size of the surveillance zone as well as the coverage area of each individual Doppler radar. Longer range detection can be achieved by increasing transmit power of radars **110**A-**110**C, or by increasing antenna gain of radars **110**A-**110**C. Doppler radars **110**A-**110**C can be, for example, Laufer Wind MD-12 Doppler radars produced by Laufer Wind of New York, N.Y., though other types of radars can be used in accordance with the technology. Radars of this type can detect and track small targets with a radar cross section ("RCS") of less than 0.03 square meters, for example, birds and small sUAS, to ranges up to four kilometers.

[0024] Fixed camera **130** monitors surveillance zone **120**. Fixed camera **130** can be disposed at a fixed location in surveillance zone **120** and can be capable of tilting and panning by a gimbal. In some embodiments, fixed camera **130** can be a plurality of fixed cameras distributed along the perimeter of surveillance zone **120**. In some embodiments, the coverage range of fixed camera **130** can define surveillance zone **120**. Fixed camera **130** can be mounted above the ground, for example 20 feet from the ground or at a height that can surmount nearby obstacles such as trees and buildings. In some embodiments, there may be multiple fixed

cameras, to increase the coverage area of the fixed cameras or improve resolution of images captured by utilizing the nearest camera. Fixed camera **130** can acquire images of targets and track targets at a shorter range than radars **110**A-**110**C, for example a range of less than 500 meters. In some embodiments, fixed camera **130** is cued or pointed in the direction of a target by central controller **115** based on track data from radars **110**A-**110**C. Fixed camera **130** can transmit video and/or image data to central controller **115**. Images from fixed camera **130** can be used to discriminate between targets that present a threat, such as drones **122**A-**122**C and **124**A-**124**C, and targets that do not present a threat, such as birds or random ground clutter. In some embodiments, a user can verify a threat based on a video or still image feed from fixed camera **130**. In other embodiments, central controller **115** can analyze images captured by fixed camera **130** to verify whether an object is a threat automatically. In some embodiments, images captured by fixed camera **130** can be analyzed by a processor collocated with fixed camera **130**. Fixed camera **130** can capture video or images in the visible spectrum, in the infrared (IR) spectrum, or both. In some embodiments, the field of view ("FOV") of fixed camera **130** can be selected based on the angular accuracy of radars **110**A-**110**C and optics of fixed camera **130**. For example, where the angular resolution of the radar is +/−0.2 degrees, the minimum fixed camera FOV can be 4 degrees. Fixed camera **130** can have a zoom lens, which can have a wider FOV at a lower zoom, as compared with a higher zoom. In some embodiments, fixed camera **130** can require an FOV that is, for example, five times larger, than the angular resolution of radars **110**A-**110**C.

[0025] Interceptor aircraft **140**A-**140**B are distributed in surveillance zone **120**. Interceptor aircraft **140**A-**140**B can be, for example quadcopter drones. Interceptor aircraft **140**A-**140**B can be approximately 105 centimeters square by 30 centimeters high. The dimensions of interceptor aircraft **140**A-**140**B can vary depending on the application, including, for example, using a smaller interceptor aircraft where a smaller surveillance zone is desired or a larger interceptor aircraft where a larger surveillance zone is required. Interceptor aircraft **140**A-**140**B can be, for example, a quadcopter, or an octocopter, such as the DJI S1000+. In some embodiments, there can be only one interceptor aircraft per surveillance zone **120**. In other embodiments, two or more interceptor aircraft can be used, depending on the size of the surveillance zone and the desired time of response of the interceptor aircraft. In some embodiments, each interceptor aircraft can intercept its own target, such as in the event of a swarm attack with multiple target sUAS. Interceptor aircraft **140**A-**140**B can be distributed at regular intervals throughout surveillance zone **120** to minimize the time between when a target, such as drones **122**A-**122**C and **124**A-**124**C, is detected by interdiction system **100** and when it is intercepted and immobilized by one or more of interceptor aircraft **140**A-**140**B.

[0026] Interceptor aircraft **140**A-**140**B can transmit video or image data or other information detected about its operational state, including, for example, pitch, yaw, or rotor power, via a wireless connection to central controller **115**. Interceptor aircraft **140**A-**140**B can include inertial measurement units ("IMUs") that include sensors to measure various parameters of the flight of interceptor aircraft **140**A-**140**B. For example, the IMU can include rate gyros and accelerometers for measuring the acceleration of interceptor aircraft **140**A-**140**B and angular rates (e.g., roll, pitch, and yaw) of interceptor aircraft **140**A-**140**B. Interceptor aircraft **140**A-**140**B can receive command data via a wireless connection from central controller **115**. In some embodiments, a user can manually override control of interceptor aircraft **140**A-**140**B by central controller **115** and pilot interceptor aircraft **140**A-**140**B via manual input.

[0027] Interceptor aircraft **140**A-**140**B include an on-board camera, capable of capturing video or images in the visible spectrum, IR spectrum, or both. In some embodiments, the on-board camera can have a range of up to 75 meters and can have six times zoom capability. The on-board camera can have an FOV capable of compensating for any angular accuracy deficiencies of radars **110**A-**110**C, for example, a 4 degree FOV. The on-board camera can have a zoom lens, which can have a wider FOV at a lower zoom, as compared with a higher zoom. In some embodiments, interceptor aircraft **140**A-**140**B can use an on-board camera to verify whether an object, such as drones **122**A-**122**C and **124**A-**124**C, presents a threat. Central controller **115** can determine whether objects detected by the cameras mounted to interceptor aircraft **140**A-**140**B pose a threat, such as drones **122**A-**122**C and **124**A-**124**C or whether they do not, such as birds or miscellaneous ground clutter. Where interdiction system **100** determines that the tracked object shown in the image acquired by cameras mounted to interceptor aircraft **140**A-**140**B is not a threat, it can command interceptor aircraft **140**A-**140**B to return to an interceptor aircraft base station.

[0028] In some embodiments, interceptor aircraft **140**A-**140**B can be capable of a maximum flight speed of 30-45 miles per hour. Interceptor aircraft **140**A-**140**B can be located at interceptor aircraft base stations, not depicted, when not in use. In some embodiments, interceptor aircraft **140**A-**140**B are capable of a flight time of fifteen minutes or longer before requiring charging. In some embodiments, interceptor aircraft **140**A-**140**B are capable of carrying a payload capacity of up to six kilograms.

[0029] In some embodiments, interceptor aircraft **140**A-**140**B include hanging nets to intercept, disrupt the flight of, and/or capture sUAS targets, such as drones **122**A-**122**C and **124**A-**124**C. In other embodiments, interceptor aircraft **140**A-**140**B include mounted net guns that can be fired at a sUAS target. The net gun can include a net gun housing and a net propulsion barrel that cooperate to propel a net toward a target with the aid of, for example, a high pressure carbon dioxide canister. The net gun can fire, for example, a square net that is eight feet by eight feet by two inches square in dimension. The net gun can propel a net at a nominal velocity of, for example, thirty feet per second, with a range of thirty feet. Net guns can be advantageous because they minimize drag and energy dissipation of interception drones **140**A-**140**B during flight. In some embodiments, central controller **115** can control the firing of the net gun. In some embodiments, a computer on interceptor aircraft **140**A-**140**B can control the firing of the net gun.

[0030] Central controller **115** of interdiction system **100** can transmit and receive data from each of the components of interdiction system **100**, including, for example, Doppler radars **110**A-**110**C, fixed camera **130**, and interceptor aircraft **140**A-**140**B. Central controller **115** connects with these components through network **150**, which can be, for example, an encrypted managed-UDP (user datagram protocol) wide area network. In some embodiments, central

controller **115** is connected to stationary components of interdiction system **100** by a wired connection, for example 10/100 and Gigabit Ethernet connections. Central controller **115** can be connected to interceptor aircraft **140**A-**140**B through a wireless connection. The wireless connection can be established by RF receivers **155**A-**155**B connected to central controller **115** that interfaces with a radio modem, for example a 900 MHz radio modem, on interceptor aircraft **140**A-**140**B. In other embodiments, central controller **115** can be connected to all components through wireless connections. In some embodiments, central controller **115** can monitor the health of one or more of radars **110**A-**110**C, fixed camera **130**, and interceptor aircraft **140**A-**140**B. In some embodiments, central controller **115** can be a rack-mounted computer. In other embodiments, central controller **115** can be a ruggedized unit for outdoor operation. Central controller **115** can be capable of simultaneously tracking more than thirty targets in surveillance zone **120**.

[0031] FIG. **2** illustrates a system diagram of central controller **115** in accordance with embodiments of the technology. Central controller **115** can include software and hardware components for controlling interdiction system **100**. Central controller **115** can include graphical user interface ("GUI") **210**. GUI **210** can display real-time tracking maps and information based on, for example, signals and information received from radars **110**A-**110**C, fixed camera **130**, and/or cameras mounted on interceptor aircraft **140**A-**140**B. GUI **210** can accept user input, for example where a user desires to manually override flight controls of interceptor aircraft **140**A-**140**B. Central controller **115** includes Mission Manager **215**. Mission Manager **215** includes modules for controlling interdiction system **100**. Drone identification module **220** permits central controller **115** to positively detect targets as threats. Drone identification module **220** can use video or image data from fixed camera **130** and/or cameras mounted on interceptor aircraft **140**A-**140**B and/or data from radars **110**A-**110**C to determine whether a detected target exhibits characteristics that would indicate it was a threat. Machine learning algorithms, for example Deep Convolutional Neural Network architectures such as those available from OpenCV or TensorFlow, can be used to classify whether a target is a threat or not. In some embodiments, the machine learning algorithms can determine whether a target is a drone, and if the target is a drone, whether it is a threat.

[0032] Mission manager **215** includes radar control and track fusion module **230**. Radar control and track fusion module **230** provides control parameters to radars **110**A-**110**C of interdiction system **100**. Radar control and track fusion module **230** can use software available from Laufer Wind. Radar control and track fusion module **230** fuses data from radars **110**A-**110**C to increase the size of surveillance zone **120**. Radar control and track fusion module **230** can determine which of radars **110**A-**110**C provide the highest likelihood of accurately locating a target, for example by using a predictor/corrector filtering, such as alpha/beta filtering or kalman filtering, to correct for inaccuracies. In some embodiments, radar control and track fusion module **230** can fuse data by generating a track score for each tracked target. The track score can be based on certain attributes of the tracked target, such as strength of the signal return, or the time last detected, to resolve the most accurate track for the target. In some embodiments, radar control and track fusion module **230** can fuse data from radars **110**A-**110**C or additional radars to extend the size of surveillance zone **120** of interdiction system **100**.

[0033] Mission manager **215** includes camera control and video capture module **240**. Camera control and video capture module **240** provides control for fixed camera **130** and cameras mounted to drones **140**A-**140**B, for example directional control. Camera control and video capture module **240** can provide control for fixed camera **130** and cameras mounted to drones **140**A-**140**B based on data from those cameras and/or data from radars **110**A-**110**C. Camera control and video capture module **240** can control parameters of video capture performed by fixed camera **130** and cameras mounted to drones **140**A-**140**B. For example, camera control and video capture module **240** can set the frame rate for video capture, which can be, for example, 30 Hz or 60 Hz.

[0034] Mission Manager **215** includes interceptor aircraft control module **250**. Interceptor aircraft control module **250** can use data from radar control and track fusion module **230** and/or camera control and video capture module **240** to generate commands and control interceptor aircrafts **140**A-**140**B to intercept and immobilize a target, such as drones **122**A-**122**C and **124**A-**124**C. In some embodiments, interceptor aircraft control module **250** can use software such as Dronecode APM Planner or DJI Guidance SDK to facilitate control of interceptor aircrafts **140**A-**140**B.

[0035] FIG. **3** illustrates a flow diagram of a method for interdiction in accordance with embodiments of the technology. Interdiction method **300** can be performed by, for example, the components of interdiction system **100**. At step **310**, the components of the interdiction system, for example radars or fixed cameras, monitor the surveillance area, for example surveillance zone **120**. At step **320**, interdiction method **300** determines whether an object has been detected. Central controller **115** can process signals from radars **110**A-**110**C to determine whether an object has been detected. In some embodiments, central controller **115** can process images or video from fixed camera **130** or a patrolling interceptor aircraft to determine whether an object has been detected. If the interdiction system does not detect any objects in the surveillance zone, the method returns to step **310** to continue monitoring the surveillance zone.

[0036] When interdiction method **300** detects an object in step **320**, the interdiction system pilots the interceptor aircraft toward the target in step **330**. Central controller **115** can use a radar tracker, in conjunction with an interception model, to determine a location where the interceptor aircraft can intercept the target. Central controller **115** can generate commands to pilot the interceptor aircraft to an expected interception location, as described in greater detail with respect to FIG. **4**. Interdiction method **300** includes determining whether an object is within range of a camera mounted to an interceptor aircraft, such as interceptor aircraft **140**A-**140**B, in step **340**. In some embodiments, the range of the interceptor aircraft-mounted camera can be 75 meters. Where the object detected is not in range at step **340**, interdiction method **300** continues piloting the interceptor aircraft toward the calculated interception location in accordance with radar signals, at step **330**. If the object detected is in range at step **340**, interdiction method **300** ceases piloting the interceptor aircraft according to the radar track information and begins piloting the interceptor aircraft based on video or images from a camera mounted to the interceptor aircraft, in step **350**, as described in further detail with respect to FIG. **5**. In some embodiments, interceptor aircraft

includes a net gun, and the interdiction method includes the additional steps of determining whether the net gun is in range and firing the net gun in the direction of a target to immobilize the target. In some embodiments, once the object is determined to be in range at step **340**, the generation of commands to pilot the interceptor aircraft can be performed on-board the interceptor aircraft, without the aid of a central controller.

[0037] In some embodiments, central controller **115** can use a video or image acquired from a fixed camera, such as fixed camera **130**, to verify whether a detected object is a threat, for example by comparing a threat profile against the image detected by the fixed camera. If the object is determined not to be a threat, interdiction method **300** is stopped. In some embodiments, verification of whether an object is a threat can be performed by central controller **115** according to signals from radars **110**A-**110**C, or from cameras mounted to interceptor aircraft **140**A-**140**B. In other embodiments, a user monitoring interdiction method **300** can manually override the controls of interceptor aircraft **140**A-**140**B by an interface through central controller **115**, for example through GUI **210**.

[0038] FIG. **4** illustrates a block control diagram of radar tracking according to embodiments of the technology. Radars **110**A-**110**C can detect an object within surveillance zone **120**. When an object is first detected, as in step **320** shown in FIG. **3**, central controller **115** can track the motion of a target within surveillance zone **120** using signals reflected from an object and detected by a radar, such as radars **110**A-**110**C. Central controller **115** can use radar tracker module **410** to generate a radar target state estimate **415** from signals detected by the radar monitoring surveillance zone **120**. Radar target state estimate **415** can include information about a detected object's position, velocity, and/or acceleration. In some embodiments, radar tracker module **410** can be a part of radar control and track fusion module **230** of central controller **115**. In other embodiments, radar tracker module **410** can be a part of a radar unit.

[0039] Central controller **115** uses interception module **420** to generate an interception location **425** based on an interceptor aircraft dynamics model and a radar target model. The interceptor aircraft dynamics model can be an equation that accounts for attributes of the interceptor aircraft, such as interceptor aircraft **140**A-**140**B, including flight characteristics and capabilities and aerodynamic properties, such as the effects of control surfaces, rates of differential motor torques, and/or the collective motor torques. The interceptor aircraft dynamics model can also incorporate aircraft measured state **435**, which can include data about the current flight conditions of the interceptor aircraft, measured by IMU **430** of the interceptor aircraft. The radar target model can be an equation that accounts for the known or expected attributes of the detected object, which can be, for example, drones **122**A-**122**C or drones **124**A-**124**C. The radar target model can incorporate radar target state estimate **415** from radar tracker module **410**. Central controller **115** can use interception module **420** to determine the location at which the interceptor aircraft dynamics model and the target model predict the target and the interceptor aircraft will intersect, which is output as interception location **425**. In some embodiments, the interceptor aircraft dynamics model can update at a rate of 30 Hz or a rate of 60 Hz, based on the refresh rate of IMU **430** generating aircraft measured state **435**. In some embodiments, the target model can update at a rate of 0.3 Hz, based on the radar scan cycle.

[0040] Central controller **115** uses autopilot command module **440** to generate autopilot aircraft commands **445** based on interception location **425** and the interceptor aircraft dynamics model. Central controller **115** uses autopilot command module **440** to solve for the set of autopilot aircraft commands **445** to cause the interceptor aircraft to fly to interception location **425**. The set of autopilot aircraft commands **445** can include, for example, a yaw command, pitch command, and/or motor speed commands. In some embodiments, autopilot command module **440** can solve for the set of autopilot aircraft commands **445** to pilot an interceptor aircraft to interception location **425** using a matrix-type approach to determine all of the commands collectively. In other embodiments, autopilot command module **440** can calculate the command for each axis separately. In some embodiments, interceptor aircraft dynamics model can be a collection of models, where each model accounts for differences based upon certain flight conditions. For example, there may be different interceptor aircraft dynamics models where an interceptor aircraft is flying at a comparatively higher speed, such as at the interceptor aircraft's maximum speed, or a comparatively lower rate of speed.

[0041] An updated interception location **425** can be generated each time radar target state estimate **415** is updated, for example at the refresh rate of radars **110**A-C and/or as quickly as the refresh rate of aircraft measured state **435** information provided by IMU **430** about the flight of the interceptor aircraft. Inner stability loop **450** can facilitate the interceptor aircraft maintaining level flight. Inner stability loop **450** can be performed by a computer on-board the interceptor aircraft. IMU **430** of the interceptor aircraft generates aircraft measured state **435** based on information detected about the interceptor aircraft's current flight conditions. Inner stability loop **450** uses stability filter **460** to generate stability aircraft commands **465** that are intended to correct for disturbances encountered by the interceptor aircraft during flight, for example, impact by small objects, wind disturbances, or any other irregularities. Stability filter **460** can include, for example, a rate feedback or lagged rate feedback filter, which can calculate stability aircraft commands **465** on a per-axis basis according to aircraft measured state **435** and an interceptor aircraft dynamics model. In other embodiments, stability filter **460** can be a model following filter. Stability filter **460** outputs stability aircraft commands **465**, for example a yaw command, pitch command, or rotor power command, to maintain the interceptor aircraft in an upright position. Inner stability loop **450** uses command summer **470** which sums autopilot aircraft commands **445** and stability aircraft commands **465** to generate aircraft control commands **475**. Aircraft control commands **475** are used by interceptor aircraft flight controller **480** to pilot the interceptor aircraft toward interception location **425**, for example, as in step **330**.

[0042] FIG. **5** illustrates a block control diagram of video tracking in accordance embodiments of the technology. When an object, such as drones **122**A-**122**C or drones **124**A-**124**C, is determined to be within the range of a camera mounted to the interceptor aircraft, for example as in step **340** of interdiction method **300**, the interceptor aircraft can be piloted according to the image or video data acquired

by the on-board camera, for example as in step **350** of interdiction method **300**. Central controller **115** uses video tracker module **510** to track detected objects using on-board video **525** and/or fixed camera video **535**. In some embodiments, on-board video **525** and/or fixed camera video **535** can be an image or images of the target. Based on on-board video **525** and/or fixed camera video **535**, video tracker module **510** can generate video target state estimate **515**. Video target state estimate **515** can include information about a target's detected position, velocity, and/or acceleration, based on on-board video **525** or fixed camera video **535**. Central controller **115** uses video tracker module **510** to process on-board video **525** or fixed camera video **535** and acquire an image or video of the tracked object against the background of each frame of the respective on-board video **525** or fixed camera video **535**. In some embodiments, video tracker module **510** employs centroid tracking or correlation tracking based on the position of each target within each frame of on-board video **525** or fixed camera video **535** to track the position of the detected object. In some embodiments, on-board video **525** or fixed camera video **535** can be an image of the target. In some embodiments, there can be separate video trackers for on-board video **525** and for fixed camera video **535**. In other embodiments, the video tracking performed by video tracker **510** for on-board video **525** is performed on a computer on-board the interceptor aircraft.

[0043] Fixed camera tracking module **550** is used by central controller **115** to generate gimbal inputs **555**. Central controller **115** calculates gimbal inputs **555** with fixed camera tracking module **550** based on a video target model and a fixed camera system model. The video target model can be an equation that accounts for the known or expected attributes, such as size or flight characteristics, of the detected object, incorporating video target state estimate **515**. The fixed camera system model can be an equation that accounts for the dynamics of the fixed camera system. For example, the fixed camera system model can reflect servo dynamics and/or inertia of the gimbal of the fixed camera system and can reflect structural dynamics of a fixed support structure on which the gimbal camera is mounted. The fixed camera system can use fixed camera measurement unit **560** to measure current conditions of the fixed camera system and generate fixed camera system measured state **565**. The fixed camera system model incorporates fixed camera system measured state **565**, describing, for example, current position, current orientation, and current motion of the fixed camera system. Central controller **115** can use fixed camera tracking module **550** to determine gimbal inputs **555** to cause fixed camera **530** to point at a tracked object. For example, fixed camera tracking module **550** can use Newton's Method or the Broyden-Fletcher-Goldfarb-Shanno ("BFGS") algorithm, or a similar method, to determine the set of gimbal inputs **555** based on the fixed camera system model and the video target model. Fixed camera controller **570** uses gimbal inputs **555** to cause fixed camera **530** to pan, tilt, or zoom to track the detected object. In some embodiments, video tracker module **510** can use fixed camera system measured state **565** to improve the performance of tracking a detected object.

[0044] Central controller **115** uses interceptor aircraft optimizer module **580** to generate aircraft control commands **475**. Interceptor aircraft optimizer module **580** calculates aircraft control commands **475** based on the video target model and an interceptor aircraft dynamics model. Interceptor aircraft dynamics model can incorporate aircraft measured state **435** from IMU **430**. The video target model can be an equation that accounts for the known or expected attributes, such as size or flight characteristics, of the detected object and incorporates video target state estimate **515**. Central controller **115** uses interceptor aircraft optimizer module **580** can predict the interception location where the interceptor aircraft will meet the target. In some embodiments, interceptor aircraft dynamics model and video target model are solved as a system of linear equations by interceptor aircraft optimizer module **580** to establish an interception location where the paths of the interceptor aircraft and the detected target can be expected to intercept. In other embodiments, interceptor aircraft optimizer module **580** can use Newton's Method or the Broyden-Fletcher-Goldfarb-Shanno ("BFGS") algorithm, or a similar method, to determine the set of aircraft control commands **475** that can be used to pilot the interceptor aircraft toward a target. In some embodiments, video tracker module **510** can use aircraft measured state **435** to improve the performance of tracking a detected object. In some embodiments, interceptor aircraft optimizer module **580** can use video target state estimate **515** to determine whether a detected object, such as drones **122**A-**122**C or drones **124**A-**124**C, are in range of a net gun mounted to the interceptor aircraft and/or whether the interceptor aircraft is pointed at the target. Interceptor aircraft optimizer module **580** can generate a command to cause the interceptor aircraft to fire the net gun to immobilize the target. In some embodiments, interceptor aircraft optimizer module **580** can be a part of central controller **115**, for example as part of interceptor aircraft control module **250**. In some embodiments, interceptor aircraft optimizer module **580** can be a part of a computer on-board the interceptor aircraft.

[0045] FIG. **6** illustrates a block control diagram of radar and video tracking in accordance with embodiments of the technology. Central controller **115** can generate improved target state estimate **615** using sensor fusion module **610**. Sensor fusion module **610** receives video target state estimate **515** from video tracker module **510** and radar target state estimate **415** from radar tracker module **410**. In some embodiments, there may be more than one video target state estimate or radar target state estimate. Sensor fusion module **610** can generate a track score for each input, such as video target state estimate **515** and radar target state estimate **415**. Track scores can be developed for a target state estimate based on a log-likelihood ratio using both the target state estimate as well as target state estimate attribute probabilities in the manner described by Blackman and Popoli (Design and Analysis of Modern Tracking Systems. Blackman, Samuel and Popoli, Robert. Artech House 1999. p. 328-330). A target state estimate can consist of the target position and its first derivatives. A target state estimate attribute for the radar track can include signal-to-noise ratio ("SNR"), scalar speed, heading, heading rate, and the area of the target detection in range-Doppler space. Track attributes for optical tracking can include, for example, include SNR, scalar speed, heading, heading rate, and color.

[0046] Tracks can be fused in an asynchronous manner whenever a track update is received from either radar tracker module **410** or video tracker module **510**. At each update, the track scores of the two can be compared by sensor fusion module **610**, and the track with the better score is used as to update the fused track. Track updates with measurements are

filtered using a Kalman filter by sensor fusion module **610** to generate the improved target state estimate **615**. The track scores can normalized using the measurement and attribute covariances. Since the tracks are updating asynchronously, the normalization factor in the track score (the inverse of the square root of the determinant of the measurement and attribute covariance matrix) can be predicted up to the current time using the same kinematic model and process noise used in the Kalman filter. The track score update can be described by the equation provided by Blackman and Popoli:

$$\Delta L = \ln\left(\frac{V_c}{\sqrt{|S|}}\right) - \ln\left(\frac{M\ln(2\pi) + d^2}{2}\right) + \ln\left(\frac{P_d}{P_{fa}}\right) + \ln\left(\frac{p(y_s \mid Det, H_1)}{p(y_s \mid Det, H_0)}\right)$$

but for a non-updating track, S, d, and $p(y_s)$ are decayed by the time increment:

$$S_{decayed}=H(FPF^T+GQG^T)H^T+R$$

Where H is the measurement matrix, F is the kinematic matrix (which includes the time increment), P is the covariance matrix of the measurements, G is the state transition matrix, Q is the process noise and R is the measurement variances. Similarly, the covariance of the residual for the signal attributes is decayed using a model of their kinematics, transitions and covariances. d is the Mahalanobis distance, which also includes $S_{decayed}$. In this way the track scores can be normalized for their disparate attributes as well as their asynchronous updates, and at every update the better scored track can be determined by sensor fusion module **610** and used to generate improved target state estimate **615**.

[0047] Once improved target state estimate **615** is generated by sensor fusion module **610**, fixed camera tracking module **550** and interceptor aircraft optimizer module **580** can use improved target state estimate **615** in the same manner as described with respect to target state estimate **515** in FIG. **5**. The use of improved target state estimate **615** can enable more accurate tracking of a detected object, such as drones **122**A-**122**C or drones **124**A-**124**C. In particular, the use of improved target state **615** takes advantage of the plurality of sensors that are used in interdiction system **100** or interdiction method **300**.

[0048] FIG. **7** illustrates block control diagrams for two axes of an interceptor aircraft on final approach to a target in accordance with embodiments of the technology. On final approach, the interceptor aircraft can rely more heavily on cameras mounted to the interceptor aircraft, such as on-board camera **520**, to track the detected object and pilot the interceptor aircraft. In some embodiments, video tracking of a detected object does not begin until the detected object is in range, such as at step **340**. In other embodiments, video tracking of a detected object is used exclusively once a target is within range. As shown in FIG. **7**, on-board video tracker **710** can process on-board video **525** from on-board camera **520**. On-board video tracker **710** outputs x-error from centroid **712**, which reflects the distance along the x-axis or horizontal axis that a detected object is from the center of a frame of on-board video **525**. Camera pan filter **714** processes x-error from centroid **712** to generate camera pan command **716**. Camera pan filter **714** generates camera pan command **716** by determining the pan distance or pan angle that would be required to change the direction of on-board camera **520** to be pointed at the detected object. The direction of on-board camera **520** is controlled according to camera pan command **716**. Yaw filter **720** receives camera pan command **716** from camera pan filter **714** and generates camera pan yaw command **722**. Yaw filter **720** includes a model correlating the amount of pan dictated by camera pan command **716** with the amount of interceptor aircraft yaw that would be required to orient the tracked object at the centroid of a frame of on-board video **525** when on-board camera **520** is not panned, or is at zero degrees of pan from its central position. Yaw summer **728** sums camera pan yaw command **722** and autopilot yaw command **724** to generate an approach yaw command **732**. Inner stability loop **450** can use approach yaw command **732**, for example by flight controller **480**, to control the interceptor aircraft yaw to pilot the interceptor aircraft in the direction of the tracked object. Autopilot yaw command **724** can be, for example, a portion of autopilot aircraft commands **445** corresponding to a single axis.

[0049] On-board video tracker **710** also generates y-error from centroid **742**, which reflects the distance along the y-axis or vertical axis that a detected object is from the center of a frame of on-board video **525**. Camera tilt filter **744** generates camera tilt command **746** by determining the tilt distance or tilt angle that would be required to change the direction of the on-board camera **520** to be pointed at the detected object. The direction of on-board camera **520** is controlled according to camera tilt command **746**. Collective power filter **760** includes a model correlating the amount of tilt dictated by camera tilt command **746** with the amount of interceptor aircraft collective rotor power, which can dictate the height or altitude of the interceptor aircraft, that would be required to orient the tracked object at the centroid of a frame of on-board video **525** if the on-board camera **520** is not tilted, or is at zero degrees of tilt from its central position. Collective power summer **768** sums camera tilt collective power command **762** and autopilot collective power command **764** to generate an approach collective power command **772**. Inner stability loop **450** can use approach collective power command **772** to pilot the interceptor aircraft in the direction of the tracked object. Autopilot collective power command **764** can be, for example, a portion of autopilot aircraft commands **445** corresponding to a single axis. In some embodiments, such as where an interceptor aircraft is using a passive net hanging from the interceptor aircraft to immobilize a target, central controller **115** can modify approach collective power command **772** such that the interceptor aircraft will be just above the tracked target so that it can interdict and immobilize the target. In some embodiments, incorporating flight commands according to on-board camera **520** does not occur until a target is in range, which can be controlled, for example, by a switch that controls whether camera pan yaw command **722** or tilt collective power command **762** reach yaw summer **728** or collective power summer **768**. The switch can be controlled by central controller **115** or by a computer on-board the interceptor aircraft.

[0050] FIG. **8** illustrates a block control diagram for an axis of an interceptor aircraft on final approach to a target in accordance with embodiments of the technology. On-board video tracker **710** can generate image size in camera **812**, which reflects the size of the detected object in a frame of on-board video **525**. Aircraft pitch filter **814** uses image size in camera **812** to generate image size aircraft pitch command

816. Image size aircraft pitch command **816** reflects the amount of aircraft pitch would be required to cause the detected object image to take up a greater percentage of a frame of on-board video **525** in a subsequent frame. The pitch of an interceptor aircraft, like a quadcopter, is associated with its velocity, with the interceptor aircraft with a greater angle pitch traveling faster toward a target than one with a lower angle pitch. Image size aircraft pitch command **816** is fed through limiter **818**, which can cap or reduce image size aircraft pitch command **816** to avoid the interceptor aircraft attempting to execute a pitch that would cause it to become unstable. Limiter **818** generates limited aircraft pitch command **820**. Pitch summer **824** sums limited aircraft pitch command **820** and autopilot pitch command **822** to obtain approach pitch command **826**. Inner stability loop **450** can use approach pitch command **820** to pilot the interceptor aircraft in the direction of the tracked object. Autopilot pitch command **822** can be, for example, a portion of autopilot aircraft commands **445** corresponding to a single axis. In some embodiments, incorporating flight commands according to on-board camera **520** does not occur until a target is in range, which can be controlled, for example, by a switch that controls whether limited aircraft pitch command **816** reaches pitch summer **824**. The switch can be controlled by central controller **115** or by a computer on-board the interceptor aircraft. In some embodiments, image size in camera **812** can be used to slow the velocity of an interception drone as it nears a target. In other embodiments, image size in camera **812** can be used to determine when a net gun mounted to the interceptor aircraft is fired at a target.

[0051] The above-described techniques can be implemented in digital electronic circuitry, or in computer hardware, firmware, software, or in combinations of them. The implementation can be as a computer program product, i.e., a computer program tangibly embodied in an information carrier, e.g., in a non-transitory machine-readable storage device, for execution by, or to control the operation of, data processing apparatus, e.g., a programmable processor, a computer, or multiple computers. A computer program can be written in any form of programming language, including compiled or interpreted languages, and it can be deployed in any form, including as a stand-alone program or as a module, component, subroutine, or other unit suitable for use in a computing environment. A computer program can be deployed to be executed on one computer or on multiple computers at one site or distributed across multiple sites and interconnected by a communication network.

[0052] Method steps can be performed by one or more programmable processors executing a computer program to perform functions of the technology by operating on input data and generating output. Method steps can also be performed by, and apparatus can be implemented as, special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application-specific integrated circuit). Modules can refer to portions of the computer program and/or the processor/special circuitry that implements that functionality.

[0053] Processors suitable for the execution of a computer program include, by way of example, both general and special purpose microprocessors, and any one or more processors of any kind of digital computer. Generally, a processor receives instructions and data from a read-only memory or a random access memory or both. The essential elements of a computer are a processor for executing instructions and one or more memory devices for storing instructions and data. Generally, a computer also includes, or be operatively coupled to receive data from or transfer data to, or both, one or more mass storage devices for storing data, e.g., magnetic, magneto-optical disks, or optical disks. Data transmission and instructions can also occur over a communications network. Information carriers suitable for embodying computer program instructions and data include all forms of non-volatile memory, including by way of example semiconductor memory devices, e.g., EPROM, EEPROM, and flash memory devices; magnetic disks, e.g., internal hard disks or removable disks; magneto-optical disks; and CD-ROM and DVD-ROM disks. The processor and the memory can be supplemented by, or incorporated in special purpose logic circuitry.

[0054] To provide for interaction with a user, the above described techniques can be implemented on a computer having a display device, e.g., a CRT (cathode ray tube) or LCD (liquid crystal display) monitor, for displaying information to the user and a keyboard and a pointing device, e.g., a mouse or a trackball, by which the user can provide input to the computer (e.g., interact with a user interface element). Other kinds of devices can be used to provide for interaction with a user as well; for example, feedback provided to the user can be any form of sensory feedback, e.g., visual feedback, auditory feedback, or tactile feedback; and input from the user can be received in any form, including acoustic, speech, or tactile input.

[0055] The above described techniques can be implemented in a distributed computing system that includes a back-end component, e.g., as a data server, and/or a middleware component, e.g., an application server, and/or a front-end component, e.g., a client computer having a graphical user interface and/or a Web browser through which a user can interact with an example implementation, or any combination of such back-end, middleware, or front-end components. The components of the system can be interconnected by any form or medium of digital data communication, e.g., a communication network. Examples of communication networks include a local area network ("LAN") and a wide area network ("WAN"), e.g., the Internet, and include both wired and wireless networks.

[0056] The computing system can include clients and servers. A client and server are generally remote from each other and typically interact through a communication network. The relationship of client and server arises by virtue of computer programs running on the respective computers and having a client-server relationship to each other.

[0057] The technology has been described in terms of particular embodiments. The alternatives described herein are examples for illustration only and not to limit the alternatives in any way. The steps of the technology can be performed in a different order and still achieve desirable results. Other embodiments are within the scope of the following claims.

What is claimed is:

1. A method for drone interdiction, the method comprising:

detecting, using one or more radars, a target aircraft within a surveillance zone;

generating first one or more interceptor aircraft commands to direct an interceptor aircraft to the target aircraft, based on data from the one or more radars;

commanding the interceptor aircraft according to the first one or more interceptor aircraft commands;

acquiring a target image using a camera mounted on the interceptor aircraft;

generating, in response to determining the target aircraft is in the target image, second one or more interceptor aircraft commands to direct the interceptor aircraft to the target aircraft, based on at least one of the target image, a fixed camera target image from one or more fixed cameras and the data from the one or more radars; and

commanding the interceptor aircraft according to the second one or more interceptor aircraft commands.

2. The method of claim **1**, further comprising:

tracking the target aircraft based on the fixed camera target image, a fixed camera system model, and the data from the one or more radars.

3. The method of claim **1**, further comprising:

determining that the target aircraft is a threat.

4. The method of claim **3**, wherein determining that the target aircraft is a threat comprises analyzing the fixed camera target image.

5. The method of claim **1**, further comprising:

commanding the interceptor aircraft to an interceptor aircraft base station in response to determining the target aircraft is not a threat.

6. The method of claim **1**, further comprising:

immobilizing, by the interceptor aircraft, the target aircraft.

7. The method of claim **6**, wherein immobilizing, by the interceptor aircraft, the target aircraft comprises the interceptor aircraft using a net assembly to immobilize the target aircraft.

8. The method of claim **6**, wherein immobilizing, by the interceptor aircraft, the target aircraft comprises the interceptor aircraft using a net gun to immobilize the target aircraft.

9. A method for drone interdiction, the method comprising:

detecting, using one or more radars, a target aircraft within a surveillance zone;

generating first one or more interceptor aircraft commands to direct an interceptor aircraft to the target aircraft, based on data from the one or more radars;

commanding the interceptor aircraft according to the first one or more interceptor aircraft commands;

acquiring a target image using a camera mounted on the interceptor aircraft;

determining, in response to determining the target aircraft is in the target image, an interception location, based on at least one of the target image, a fixed camera target image from one or more fixed cameras and the data from the one or more radars;

generating second one or more interceptor aircraft commands to direct the interceptor aircraft to the target aircraft, based on the interception location; and

commanding the interceptor aircraft according to the second one or more interceptor aircraft commands.

10. The method of claim **9**, wherein determining, in response to determining the target aircraft is in the target image, an interception location, based on at least one of the target image, a fixed camera target image from one or more fixed cameras and the data from the one or more radars further comprises:

generating a first track state, based on the target image;

generating a first track score, based on the first track state;

generating a second track state, based on one or more of the fixed camera target image from the one or more fixed cameras and the data from the one or more radars;

generating a second track score, based on the second track state;

selecting the first track state or the second track state by comparing the first track score and the second track score.

11. The method of claim **9**, further comprising:

immobilizing, by the interceptor aircraft, the target aircraft.

12. The method of claim **11**, wherein immobilizing, by the interceptor aircraft, the target aircraft comprises using a net assembly to immobilize the target aircraft.

13. The method of claim **11**, wherein immobilizing, by the interceptor aircraft, the target aircraft comprises using a net gun to immobilize the target aircraft.

14. The method of claim **9**, further comprising:

tracking the target aircraft based on the fixed camera target image, a fixed camera system model, and the data from the one or more radars.

15. The method of claim **9**, further comprising:

determining that the target aircraft is a threat.

16. The method of claim **15**, wherein determining that the target is a threat comprises analyzing the fixed camera target image.

17. The method of claim **9**, further comprising:

commanding the interceptor aircraft to an interceptor aircraft base station in response to determining the target aircraft is not a threat.

18. A method for drone interdiction, the method comprising:

detecting a target aircraft, based on data from one or more of: one or more radars, a fixed camera image from one or more fixed cameras, and an interceptor aircraft image from a camera mounted to an interceptor aircraft;

generating an interception location where the interceptor aircraft and the target aircraft are expected to meet;

directing, based on the interception location, the interceptor aircraft to the interception location to immobilize the target aircraft.

19. The method of claim **18**, wherein directing, based on the interception location, the interceptor aircraft to the interception location to immobilize the target aircraft further comprises capturing the target aircraft using a hanging net.

20. The method of claim **18**, wherein directing, based on the interception location, the interceptor aircraft to the interception location to immobilize the target aircraft further comprises firing a net gun at the target to capture the target aircraft.

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