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(54) **DISPLAY SYSTEM AND METHOD USING WEATHER RADAR SENSING**

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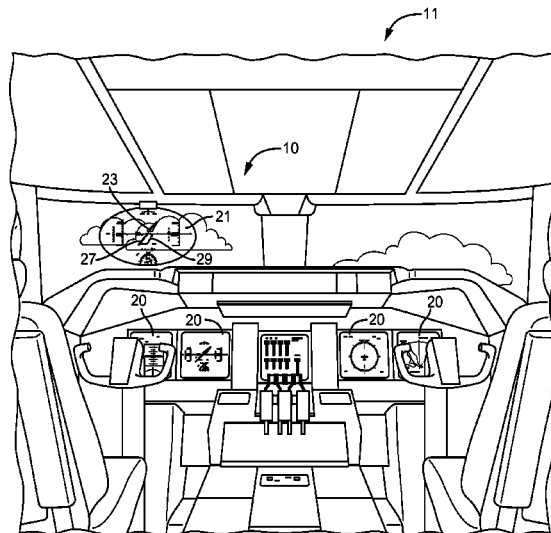
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(57) **ABSTRACT**

An enhanced vision method uses or an enhanced vision system includes an onboard weather radar system configured to improve angular resolution and/or resolution in range. The onboard weather radar system generates image data representative of the external scene topography of a runway environment associated with radar returns received by the onboard weather radar system. The radar returns are in an X-band or a C-band. The enhanced vision system also includes a display in communication with the onboard weather radar system and is configured to display an image associated with the image data that is generated by the onboard weather radar system. The enhanced vision system can also be used as an enhanced flight vision system.

**17 Claims, 4 Drawing Sheets**



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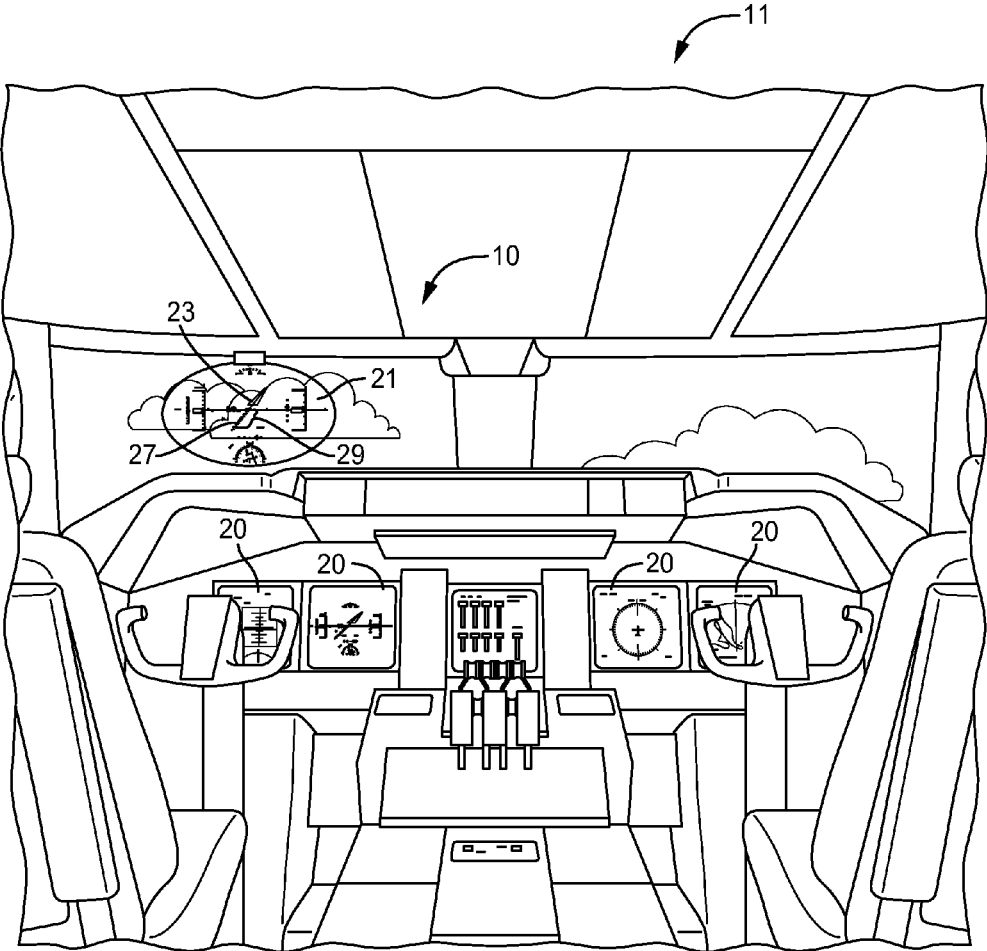


FIG. 1



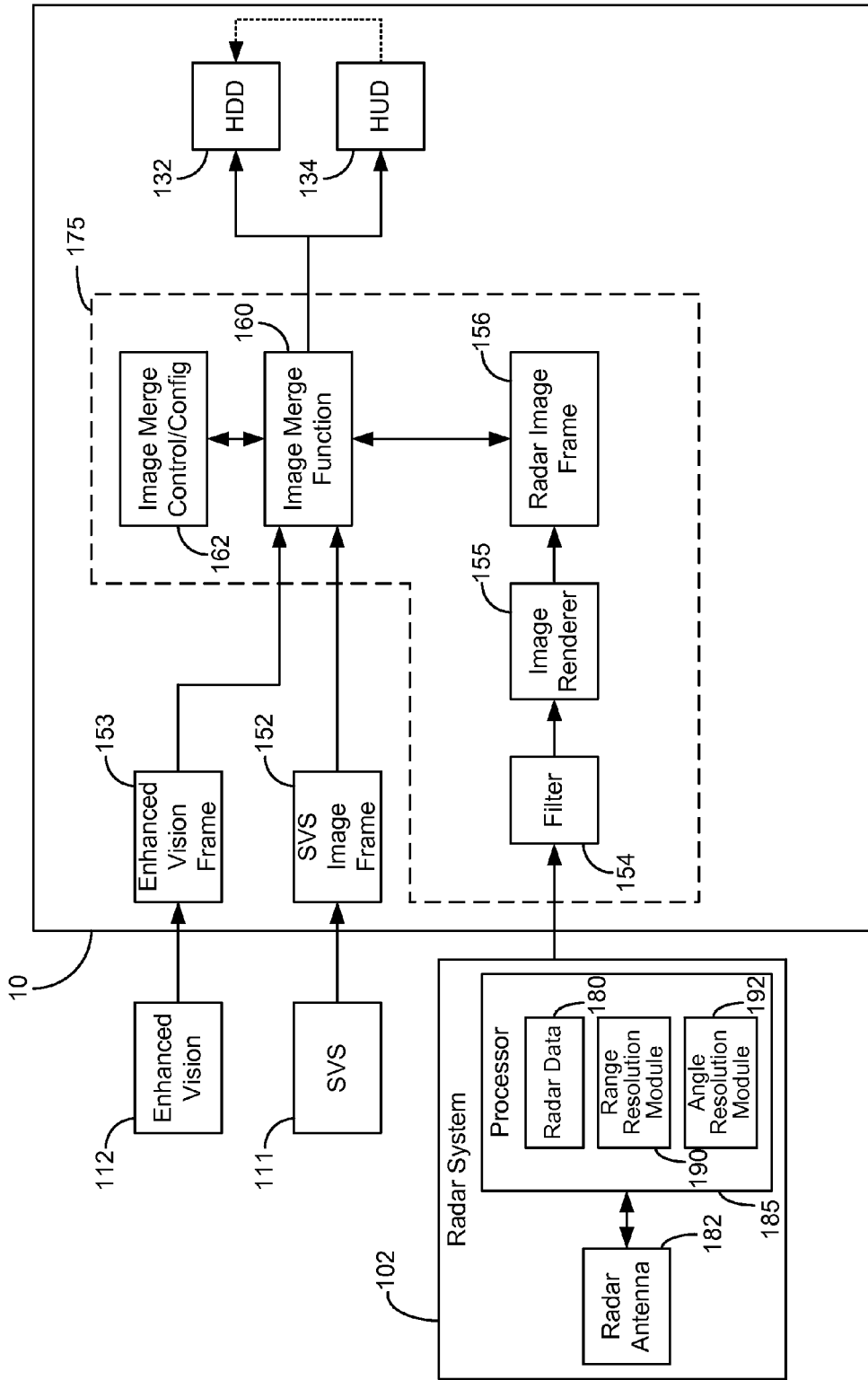


FIG. 2

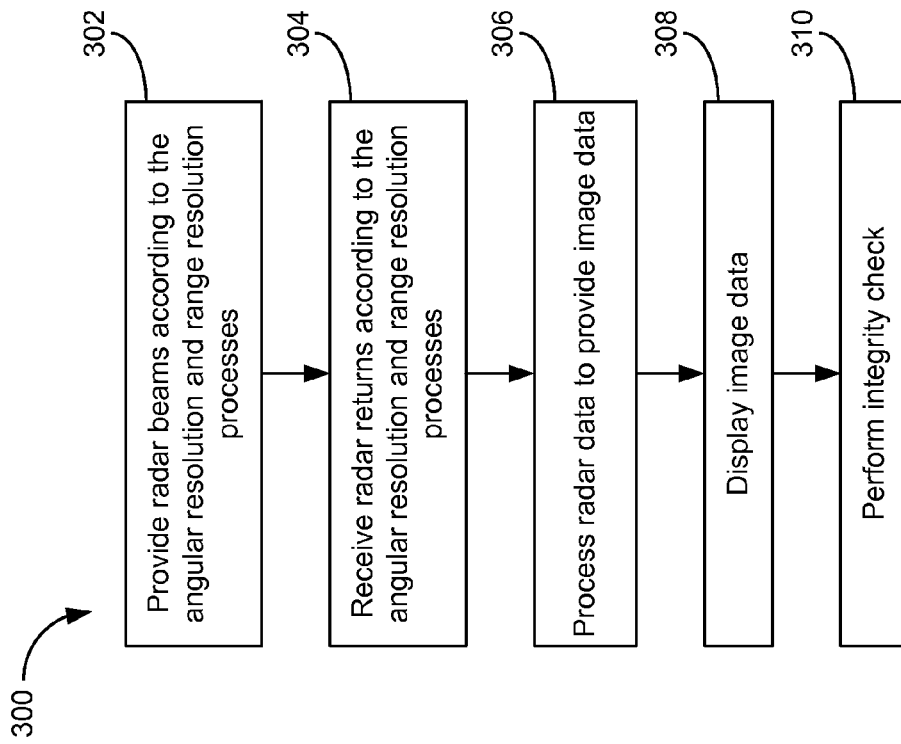


FIG. 3

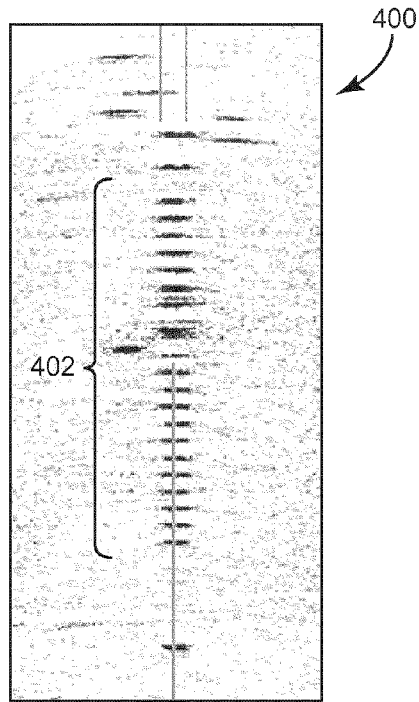


FIG. 4

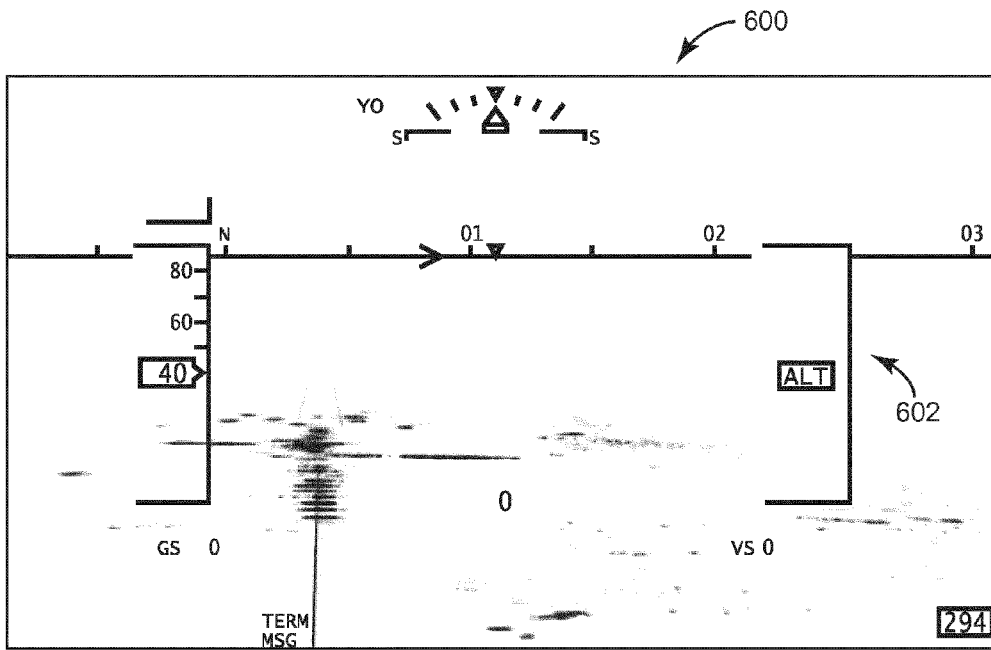


FIG. 5

## DISPLAY SYSTEM AND METHOD USING WEATHER RADAR SENSING

### CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

The present application is related to U.S. patent application Ser. No. 14/482,681 filed Sep. 10, 2014 by Wood et al., U.S. patent application Ser. No. 14/301,199 filed on Jun. 10, 2014 by McCusker et al, U.S. patent application Ser. No. 13/627,788 filed on Sep. 26, 2012; U.S. patent application Ser. No. 12/892,563 filed on Sep. 28, 2010, U.S. patent application Ser. No. 13/250,798 filed on Sep. 30, 2011, U.S. patent application Ser. No. 12/236,464 filed on Sep. 28, 2008, U.S. patent application Ser. No. 12/167,200 filed on Jul. 2, 2008, U.S. patent application Ser. No. 12/180,293 filed on Jul. 25, 2008, U.S. patent application Ser. No. 13/247,742 filed on Sep. 28, 2011, U.S. patent application Ser. No. 11/851,323 filed on Sep. 6, 2007, U.S. patent application Ser. No. 11/904,491 filed on Sep. 26, 2007, U.S. patent application Ser. No. 13/241,051 filed on Sep. 22, 2011, U.S. patent application Ser. No. 12/263,282 filed on Oct. 31, 2008 and U.S. patent application Ser. No. 12/180,293 filed on Jul. 25, 2008, all of which are herein incorporated by reference in their entireties and assigned to the assignee of the present application.

### BACKGROUND

An aircraft uses an enhanced vision system (EVS) to provide imagery to an aircraft crew. The imagery can include an airport terminal area and runway environment when meteorological conditions prevent a clear natural view of the external surroundings of the aircraft through the windscreen. For example, the EVS may overlay an image of an airport terminal area and runway environment over the pilot's natural unaided view of the external surroundings of the aircraft through the aircraft's cockpit windscreen. Such imagery can improve the situational awareness of the flight crew during instrument approach procedures in low visibility conditions such as fog. That same enhanced vision system can be used as an FAA-certified enhanced flight vision systems (EFVS) which can allow pilots landing under instrument flight rules to operate below certain specified altitudes during instrument approaches even when the airport environment is not visible. For example, under Title 14 of the Code of Federal Regulations, part 91, a pilot may not descend below decision altitude (DA) or minimum descent altitude (MDA) to 100 feet above the touchdown zone elevation (TDZE) from a straight-in instrument approach procedure (IAP), other than Category II or Category III, unless the pilot can see certain required visual references. Such visual references include, for example, the approach lighting system, the threshold lighting system, and the runway edge lighting system. The pilot may, however, use an EFVS to identify the required visual references in low visibility conditions where the pilot's natural unaided vision is unable to identify these visual references. Accordingly, the use of an EFVS may minimize losses due to the inability of the pilot to land the plane and deliver cargo and/or passengers on time in low visibility conditions.

EVS imagery is typically presented to the pilot flying (PF) on a head up display (HUD). The HUD is typically a transparent display device that allows the PF to view EVS imagery while looking at the external surroundings of the aircraft through the cockpit windscreen. As long as visibility conditions outside of the aircraft permit the PF to see the

external surroundings of the aircraft through the cockpit windscreen, the PF can verify that the EVS is functioning properly such that the imagery on the HUD is in alignment with the PF's view of the external surroundings of the aircraft.

EVS imagery is sometimes also presented to the pilot monitoring (PM) on a head down display (HDD). For example, in some countries, the system must present the EVS imagery to the PM for confirmation that the EVS information is a reliable and accurate indicator of the required visual references. The PM may also use the EVS imagery to determine whether the PF is taking appropriate action during approach and landing procedures. The HDD is typically a non-transparent display device mounted adjacent to or within a console or instrument panel of the aircraft.

An EVS typically uses either a passive or active sensing system to acquire data used to generate imagery of the airport terminal area and runway environment. A typical passive sensor, such as a forward looking infrared (FLIR) camera or visible light spectrum camera, receives electromagnetic energy from the environment and outputs data that may be used by the system to generate video images from the point of view of the camera. The camera is installed in an appropriate position, such as in the nose of an aircraft, so that the PF may be presented with an appropriately scaled and positioned video image on the HUD having nearly the same point of view as the PF when viewing the external surroundings of the aircraft through the HUD. However, while passive sensors provide higher quality video imagery, they may be unable to identify required visual references in certain low visibility conditions such as heavy fog.

Active sensing systems, such as millimeter wavelength (MMW) radar systems (e.g., 94 GHz), transmit electromagnetic energy into the environment and then receive return electromagnetic energy reflected from the environment. The active sensing system is typically installed in an appropriate position, such as in the nose of an aircraft. Active sensing systems are expensive and require space on-board the aircraft that is required for other types of equipment. In addition, MMW radar systems require expensive radome technology.

Additionally, both passive FLIR cameras and active millimeter wavelength radar systems may have limited range in certain low visibility conditions such as heavy fog.

Thus, there is a need for real time or near real time sensing systems for and methods of providing enhanced vision at longer ranges and in inclement weather. Further, there is a need for real time or near real time sensing systems for and methods of providing enhanced vision imagery that is less expensive and does not require additional space on the aircraft. There is also a need for display systems for and methods of providing images of the external scene topography using radar data from a weather radar system. There is still a further need for systems for and methods of providing images of the runway environment derived from weather radar data where such images enable operation below certain specified altitudes during instrument approaches. Further still, there is a need for systems and methods that achieve higher resolution imaging using X-band and C-band radar data.

It would be desirable to provide a system and/or method that provides one or more of these or other advantageous features. Other features and advantages will be made apparent from the present specification. The teachings disclosed extend to those embodiments which fall within the scope of the appended claims, regardless of whether they accomplish one or more of the aforementioned needs.

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## SUMMARY

In one aspect, embodiments of the inventive concepts disclosed herein are directed to an image processing system for enhanced vision including a processor and memory coupled to the processor. The memory contains program instructions that, when executed, causes the processor to provide radar beams and receive radar returns with improved angular and/or range resolution for deriving image data of the external scene topography.

In a further aspect, embodiments of the inventive concepts disclosed herein are directed to a vision method which uses or a vision system which includes a weather radar system configured to enhance resolution in range and in azimuth. The weather radar system generates image data associated with radar returns received by the weather radar system. The radar returns are in an X-band or a C-band. The vision system also includes a display in communication with the weather radar system configured to display an image associated with the image data.

In a further aspect, embodiments of the inventive concepts disclosed herein are directed to an airborne weather radar system which provides enhanced vision. The weather radar system includes an antenna, and a control circuit configured to provide radar beams via the antenna toward external surroundings and configured to receive radar returns. The control circuit is configured to process the radar returns to provide image data associated with the external surroundings. The weather radar system provides increased range resolution and increased angular resolution compared to weather radar sensing functions for the radar returns used to provide the image data. The radar beams are in the X-band or the C-band, and the image data is for providing a visual image of the external scene topography to a pilot.

In a further aspect, embodiments of the inventive concepts disclosed herein are directed to a method that provides a real time sensor image. The method includes receiving radar returns from an X-band or C-band airborne weather radar system. The radar returns can be processed to have increased range resolution and angular resolution and are received from external surroundings. The method also includes providing a visual image of the external scene topography based on the radar returns.

## BRIEF DESCRIPTION OF THE DRAWINGS

Implementations of the inventive concepts disclosed herein may be better understood when consideration is given to the following detailed description thereof. Such description makes reference to the annexed drawings, which are not necessarily to scale, and in which some features may be exaggerated and some features may be omitted or may be represented schematically in the interest of clarity. Like reference numerals in the figures may represent and refer to the same or similar element, feature, or function. In the drawings:

FIG. 1 is a schematic illustration of an aircraft control center or cockpit, according to an exemplary embodiment of the inventive concepts disclosed herein;

FIG. 2 is a schematic general block diagram of a display system for displaying an image derived from radar data, according to an exemplary embodiment of the inventive concepts disclosed herein;

FIG. 3 is a flow diagram showing an exemplary process used by the system illustrated in FIG. 2, according to a further exemplary embodiment of the inventive concepts disclosed herein;

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FIG. 4 is an illustration of an image derived from radar data provided by the display system illustrated in FIG. 2 according to an exemplary embodiment of the inventive concepts disclosed herein; and

FIG. 5 is an illustration of an image derived from radar data and merged with HUD symbology provided by the display system illustrated in FIG. 2 according to yet another exemplary embodiment of the inventive concepts disclosed herein.

## DETAILED DESCRIPTION

Before describing in detail the inventive concepts disclosed herein, it should be observed that the inventive concepts disclosed herein include, but are not limited to, a novel structural combination of data/signal processing components and communications circuits, and not in the particular detailed configurations thereof. Accordingly, the structure, methods, functions, control and arrangement of components, software, and circuits have, for the most part, been illustrated in the drawings by readily understandable block representations and schematic diagrams, in order not to obscure the disclosure with structural details which will be readily apparent to those skilled in the art, having the benefit of the description herein. Further, the inventive concepts disclosed herein are not limited to the particular embodiments depicted in the exemplary diagrams, but should be construed in accordance with the language in the claims.

According to various exemplary embodiments, an EVS or display system may be provided with radar sensing and imagery displayable to a pilot or co-pilot on an aircraft display, such as an HDD or HUD. For example, the display system may include or use a weather radar system to display an image based upon radar return data. In some embodiments, a Doppler weather radar system may be configured to have enhanced resolution (e.g., angular resolution and/or range resolution). Reflectivity of radar returns from runway structures in an airport terminal or runway environment, such as, an approach lighting system, a threshold lighting system, and or a runway edge lighting system, can be sensed. As will be appreciated, using a weather radar system configured according to the various exemplary embodiments provides greater range than millimeter wavelength radar sensing systems or passive FLIR or visible light camera systems in low visibility conditions, such as, heavy fog, given the weather radar system's superior ability of weather radar system to penetrate heavy fog.

Using the weather radar system configured according to the various exemplary embodiments may also provide EVS imagery having sufficient accuracy in low visibility conditions (given that many of the visual references required under Title 14 of the Code of Federal Regulations, part 91, such as, approach lighting systems, threshold lighting systems, runway edge lighting systems, and other runway structures, are metallic structures that exhibit high radar reflectivity). The imagery may allow lower landing minima (e.g., 100 feet or less) in some embodiments. In some embodiments, the lack of radar returns from the runway surface combined with runway structures and lights can provide a suitable image for runway identification by the pilot.

The display system includes a radar processing module in communication with the radar system and configured to generate high resolution radar image data for display in some embodiments. The image data is processed to provide a two-dimensional aircraft situation display (e.g., vertical

profile display or plan view display) or three dimensional or perspective aircraft situation display image representative of the 3-D positions of runway structures in an airport terminal or runway environment based on the radar returns as described in U.S. patent application Ser. Nos. 14/301,199 and 14/482,681 incorporated herein by reference in their entireties in some embodiments. For example, the radar processing module can be embodied as a processor and a non-transitory memory containing program instructions that, when executed, cause the processor to provide radar beams and receive radar returns and generate image data from the radar returns. In some embodiments, program instructions stored on the non-transitory medium can cause the processor to filter the radar returns data to remove noise.

According to certain exemplary embodiments, a radar system such as a weather radar system, can be used to detect features of a runway environment. Utilizing the high radar cross section associated with metal content of runway lighting advantageously allows detection to be achieved whether at day or night, regardless of whether runway lights are on or are off in some embodiments. In one embodiment, the regular, periodic, equal spacing nature of visual aids, such as, approach lighting system, runway edge lights, taxi way lights, and center line lights, can be identified from the image generated from the radar data. In certain embodiments, the systems and methods can be utilized as extension to a combined vision system (CVS).

Referring to FIG. 1, a display system 10 is provided in an aircraft having an aircraft control center 11 or cockpit. The aircraft control center 11 includes flight displays 20 embodied as head down displays (HDDs). The aircraft control center 11 can also include a combiner 21 association with a head up display (HUD) system. In some embodiments, the combiner 21 is provided as part of a wearable HUD. Conformal images are provided on the combiner 21 in some embodiments.

The flight displays 20 and the combiner 21 can be used to provide information to the flight crew, thereby increasing visual range and enhancing decision-making abilities. In an exemplary embodiment, the flight displays 20 and the combiner 21 can include a weather display, a joint display, a weather radar map and a terrain display. Further, the flight displays 20 may include images from a synthetic vision system (SVS) or an enhanced vision system (EVS) (e.g., an EFVS). For example, the flight displays 20 can include a display configured to display a perspective image of terrain and/or weather information. Other views of terrain and/or weather information may also be provided (e.g., plan view, horizontal view, vertical view, or combinations thereof). Additionally, the flight displays 20 can be implemented using any of a variety of display technologies, including CRT, LCD, organic LED, dot matrix display, and others.

According to some embodiments, the display system 10 is configured to provide an image based upon radar data to at least one of the displays 20 or the combiner 21. In FIG. 1, the image on the combiner 21 includes a runway 23 or features 29 associated with the runway 23 as viewed from the aircraft (e.g., during approach and/or landing). In some embodiments, at least one of the displays 20 or the combiner 21 displays a merged image of terrain derived from two or more of enhanced vision data, radar data, and SVS data. Advantageously, real time radar data can be provided to provide a real time, all weather detection of the runway features 29 associated with the runway 23 in one embodiment. Advantageously, the radar data allows the runway 23 and its orientation to be viewed by one or more pilots in challenging weather conditions in some embodiments.

In some embodiments, a symbol or icon for the runway 23 and extended centerline 27 can be provided on the displays 20 or the combiner 21. In some embodiments, the runway 23 and extended centerline 27 can be associated with SVS data. A set of runway features 29, such as, approach lighting system or other runway and taxi way lights, can be indicated on the displays 20 or the combiner 21 in some embodiments. The runway features 29 can be associated with radar data in some embodiments.

Referring to FIG. 2, the display system 10 can be utilized for providing an image to any of the displays 20 or the combiner 21. The display system 10 is in communication with or includes a radar system 102, a synthetic vision system (SVS) 111 and an enhanced vision system (EVS) 112. The EVS 112 and the SVS 111 are optional in some embodiments. The display system 10 can include an HDD computer 132 and a HUD computer 134. The display system 10 includes a memory 153 for storing enhanced vision frame from the EVS 112, a memory 152 for storing enhanced vision frame from the SVS 111, a filter 154, an image renderer 155, a memory 156 for storing the radar image from the image renderer 155, an image merge function module 160, and an image merge control/configuration module 162.

The filter 154, the image renderer 155, the image merge module 160, and the image merge control/configuration module 162 can be embodied as software modules operating on a computing platform or a processor 175 and can be stored on a non-transitory medium. The processor 175 can be part of or integrated with the radar system 102, the SVS 111, the EVS 112, HDD display computer 132, or HUD computer 134 in certain embodiments. In one embodiment, processor 175 is an independent platform.

The radar system 102 is a weather radar system generally located inside the nose of the aircraft, inside a cockpit of the aircraft, on the top of the aircraft or on the tail of the aircraft in some embodiments. The radar system 102 can include a radar data storage unit 180, a radar antenna 182 and a processor 185. The radar system 102 can be a weather radar system, such as, a Multiscan™ radar system from Rockwell Collins, Inc. configured as described herein. The radar system 102 can utilize a split, half or sub-aperture or other technique for obtaining radar data associated with external surroundings in some embodiments. The radar system 102 can use the split or sub-aperture techniques of the radar systems described in U.S. application Ser. Nos. 13/627,788, 12/892,563, 13/250,798, 12/236,464, and 12/167,200 and U.S. Pat. No. 8,077,078, incorporated herein by reference and assigned to the assignee of the present application. The type of the radar system 102 and data gathering techniques are not discussed in the specification in a limiting fashion.

The processor 185 receives radar returns (e.g., weather radar returns data) from the radar antenna 182, processes the radar returns and provides the radar data in radar data storage unit 180. In certain embodiments, the data stored in radar data storage unit 180 can be stored as an image frame representing the data from a radar scan of the external surroundings (e.g., a runway environment).

The radar system 102 provides radar data (e.g., weather radar data) in the storage unit 180 to a filter 154 in one embodiment. In one embodiment, the image renderer 155 or other image generator can generate an image frame from the data stored in radar data storage unit 180 or filtered by the filter 154 and provides this to memory 156. Alternatively, the processor 185 can build the frame or image based upon radar return data from the radar system 102. Similarly, the SVS 111 can provide data or a frame for SVS image received by a memory 152. Alternatively, the display system 10 can

provide the data or image frame to the memory **152** in response to data from the SVS **111**. Similarly, the EVS **112** can provide data or a frame for EVS image received by a memory **153**. Alternatively, the display system **10** can provide the data or image frame to the memory **153** in response to data from the EVS **112**.

The radar data associated with the external surroundings can represent detected targets and the location of the detected targets. Targets include terrain, man-made features, objects, runways, etc. Improved angular resolution and range resolution techniques allow the location of the targets to be more accurately determined and represented in image data in some embodiments. The radar system **102** scans the external surroundings in front of the aircraft to sense the location of targets. The radar system **102** can utilize clutter suppression and Doppler filtering to improve performance in some embodiments.

In some embodiments, the radar system **102** provides data representing a 120 degree field of view in accordance with a weather radar sweep which takes approximately five seconds to complete in one embodiment. The sweep can be limited during approach to be a 30 degree sweep which requires five seconds before new data is available for display in certain embodiments. The sweep is directed toward the surface of the Earth so that returns are obtained which allow runway environment features to be detected. Various types of sweeps, scans and timings of sweeps and scans can be utilized without departing from the scope of the invention.

The radar system **102** embodied as a weather radar allows existing avionic equipment to be used as a real-time sensor for providing a radar-derived enhanced image of the external scene topography to the pilot in some embodiments. The image or representation generated by the radar system **102** is provided on the displays **20** or the combiner **21** can function as an EVS to provide situation awareness to the pilot in some embodiments. In other embodiments, the image or representation generated by the radar system **102** is provided on the displays **20** or the combiner **21** can function as an EFVS to allow lower landing minima.

The radar system **102** includes a range resolution module **190** and an angle resolution module **192** in some embodiments. The range resolution module **190** advantageously increases the range resolution of the radar system **102** when compared to conventional weather sensing operations in some embodiments. The angle resolution module **190** advantageously increases the angle resolution of the radar system **102** when compared to conventional weather sensing operations in some embodiments. The increased resolution in range and angle allows a higher resolution image to be provided on the displays **20** and the combiner **21** in some embodiments. The range resolution module **190** and the angle resolution module **192** can be software modules executed by the processor **185**.

According to some embodiments, the radar system **102** under control of the angle resolution module **192** can use a beam sharpening method to achieve increased angular resolution. In some embodiments, the radar system **102** can utilize techniques such as beam sharpening (e.g., horizontal beam sharpening) and de-convolution of the beam point spread function for improved angular resolution. In some embodiments, the radar system **102** can use beam sharpening as a process that improves the antenna-induced poor angular resolution (e.g., due to the beam width). There are many methods that can be used such as: Doppler Beam Sharpening, Synthetic Aperture Radar (SAR), Monopulse Radar, Sub-Aperture Radar or Split-Aperture Radar, etc. Mathematical methods can be utilized to determine a center

of the radar echo for identifying runway features. Techniques for beam sharpening are discussed in U.S. patent application Ser. Nos. 13/627,788, 12/892,563, 13/250,798, 12/236,464, and 12/167,200 and U.S. Pat. No. 8,077,078 incorporated herein by reference in their entireties.

The radar system **102** can use the radar antenna **182** configured as a switched aperture antenna for beam sharpening. The radar system **102** can also be configured for sequential lobing or monopulse operation to accurately estimate at which angle the target was located within the radar beam. In some embodiments, the radar beams provided by the radar antenna **182** and returns received by the radar antenna **182** associated with the radar system **102** can be separated into two or more portions and can be used to determine an angle from the radar antenna **182** to a target or a vector from the radar antenna **182** to a target such as a runway feature. The vector can be represented as an angle (bore site angle) and range to the target. Various processes can be utilized to calculate the angle or vector to the target.

The radar system **102** uses the radar antenna **182** that toggles between transmitting and receiving on the full aperture and transmitting on the full aperture while receiving on the partial aperture in some embodiments. These techniques can be used to accurately estimate at which angle the target was located within the radar beam and can be used to improve the accuracy of the Doppler calculations correcting for those angles. The received returns can be processed to determine a high resolution estimate of a target angle relative to the bore site of the antenna beam. According to some embodiments, the returns can be processed using a complex conjugate multiplication method to determine the target angle. The processing can be related to sequential lobing processing but is executed in the phase domain as opposed to the common amplitude domain in some embodiments.

In some embodiments, the radar system **102** uses sequential lobing techniques where two antennas that are close to the same place may be used, going back and forth between the two antennas. An amplitude signature or phase signature that varies between the two halves of the antennas may be used to obtain data about target position for detected targets (e.g., an object such as other aircraft, terrain, towers). Sequential lobing generally does not use phase comparisons with moving targets due to Doppler-induced phase changes that contaminate the phase center measurement. However, using a complex conjugate multiply method allows the Doppler-induced phase changes to be removed by cancellation. Therefore, a change in phase center between multiple different sub-apertures may be determined and used to determine angle to target.

In some embodiments, the range resolution module **190** provides higher resolution by increasing the effective waveform bandwidth of the radar system **102**. The range resolution module **190** can use stepped-frequency compression in some embodiments. To provide higher range resolution, the range resolution module **192** can control the radar system **102** to provide ultra-wideband radar (UWB) beams (e.g., extremely narrow pulses with high power), or to provide intra pulse compression (frequency of phase modulation of the transmitted pulse) in some embodiments. Frequency coding techniques including the common linear frequency modulation (LFM) or chirp method, and discrete coded segments within the pulse can be utilized in some embodiments. Phase coding techniques including binary phase codes as well as various polyphase codes can be utilized in some embodiments. To provide higher range resolution, the range resolution module **192** can control the radar system

**102** to provide interpulse pulse compression or stepped frequency compression (e.g., successive pulses with discrete increasing frequency steps) in some embodiments. In some embodiments, stepped frequency compression advantageously achieves high effective bandwidth with narrow instantaneous bandwidth. The receive bandwidth is smaller, has lower noise bandwidth, and a higher signal to noise ratio in some embodiments. Analog-to-digital sampling rates are lower (vs. pulse-compression) in some embodiments. In addition, the stepped frequency compression also has a smaller peak power (e.g., when compared to impulse), provides flexible transmit frequency control, can “hop” over restricted or undesired transmit frequencies, enables adaptive/cognitive frequency use, and rejects later received clutter from earlier transmit pulses in some embodiments. Further, the stepped frequency compression provides returns from clutter in ambiguous ranges that have frequencies that are different from returns from targets and rejects ambiguous clutter returns in the receiver IF filter of the radar system **102** in some embodiments. Stepped frequency compression generally does not achieve range resolution with a single pulse, requires transmit, receive and processing of a group of pulses for any one bin, and has more pronounced range-Doppler coupling (e.g., different Doppler shifts for each frequency) in some embodiments.

According to one embodiment, the SVS **111** can be any electronic system or device for providing a computer generated image of the external scene topography. The image can be from the perspective of the aircraft flight deck as derived from aircraft attitude, high-precision navigation solutions, and a database of terrain, obstacles and runway features. Generally, only those terrain, obstacle, and runway features which are contained in the current version of the SVS database are displayed in a conventional system. In some embodiments, the pilot uses the synthetic vision images as enhancements to available visual cues.

According to one embodiment, the EVS **112** can be any electronic system or device for providing a sensed image of the external scene topography. The EVS **112** can be an infrared camera in one embodiment.

In some embodiments, the display system **10** combines or fuses images from the HUD computer **134**, the SVS **111** and/or the EVS **112** with the image derived from radar data from the radar system **102** to provide an overall image provided to the pilot according to one embodiment. In some embodiment, the image derived from the radar data are fused with HUD symbology for the displays **20** or the combiner **21**.

The SVS **111** can include a terrain database and a processor according to one exemplary embodiment. The terrain database can be used to create a perspective image of the scene in front of the aircraft on a two-dimensional display or a three dimensional display. The terrain database can employ topographical colors similar to those depicted on standard aeronautical charts.

The SVS **111** can also receive aircraft position data from an aircraft data source. The aircraft data source can include any system or sensor (or combination thereof) that provides navigation data or aircraft flight parameters. For example, a typical navigation system in an aircraft has numerous sub-systems. Sub-systems which provide aircraft position data and flight parameter data could include, but are not limited to, an inertial navigation system (INS), a global navigation satellite system (e.g., global positioning system (GPS)), air data sensors, compasses, and a flight management computer (FMC).

In some embodiments, the filter **154** processes the radar data for better image quality. The filter **154** can be located in the radar system **102**. The filter **154** can reduce noise and employ anti-speckling filtering, Kalman filtering, Chebyshev filtering, adaptive filtering, smoothing, etc. The filter **154** can also perform anti-aliasing in some embodiments. Techniques for increasing image quality and identifying runway features are discussed in U.S. patent application Ser. No. 14/482,681 and incorporated herein by reference.

In order to facilitate generation of clearer images, the processor **185** and/or the filter **154** may be configured to filter the radar returns data to identify areas having a reflectivity lower than a predetermined value. In some embodiments, low energy areas may be zeroed out based on their corresponding reflectivity values, such that the area will be rendered transparent. Such filtering may result in a final image with only highly reflective structures in an airport terminal area or runway environment, such as an approach lighting system, a threshold lighting system, and or a runway edge lighting system.

In some embodiments, the radar data from the radar data storage unit **180** is provided to filter **154**, the image renderer **155**, and the provided as image data to memory **156** and to the HUD computer **134** or the HDD display computer **132** for providing images on the displays **20** or the combiner **21**. In another embodiment, the radar data can be provided as image data to an image merge function module **160**. The image merge function module **160** receives an EVS frame from the memory **153** or an SVS frame from the memory **152** and merges the data to appropriately display an EVS image or an SVS image with the image derived from the radar data.

The processor **175** executes a fusion processing algorithm for fusing the frames from the memory **152**, the memory **153**, and the memory **156** provided as video signals in some embodiments. This fusion process may include special formatting (positioning, sizing, cropping, etc.) of specific features or the entire image from a specific image source based on other sensor inputs or aircraft. After the combined or fused image has been completed, the entire image is sized to fit appropriately within the total HUD field-of-view (e.g., with HUD symbology) and conformally overlay the outside scene, which is viewed through the combiner **21** of the HUD. In addition, the overall fused image contrast is standardized with the brightness/contrast to support the brightness/contrast controls of the HUD.

The processors **175** and **185** can be any hardware and/or software processor or processing architecture capable of executing instructions and operating on navigational and radar data. The processors **175** and **185** can be capable of determining navigational information such as altitude, heading, bearing, and location based on data from aircraft sensors. Applicants note that flow **300** can be performed in various equipment on the aircraft including in the HUD computer **134**, a display processor, the weather radar system **102**, a navigation system, the SVS **111**, etc. in accordance with an exemplary embodiment. The processors **175** and **185** may be, or may include, one or more microprocessors, an application specific integrated circuit (ASIC), a circuit containing one or more processing components, a group of distributed processing components, circuitry for supporting a microprocessor, or other hardware configured for processing.

Image merge control configuration module **162** can provide format adjustments to data. The SVS **111** and the radar system **102** can have their own specific interface type and format. Also, each display of the displays **20** and the



combiner **21** may require specific formatting. A standard format can be a format used in HUD processing functions. The image control configuration module **138** can be implemented in hardware, software, or combinations thereof.

Real time images derived from radar data allow the pilot exact and very reliable confirmation of the presence of a runway in some embodiment. In one embodiment, localization of the pattern of runway environment features, such as the runway approach lights or the runway edge lights allows easy recognition of the location of the runway with respect to the aircraft. In some embodiments the image data can be processed to provide a two-dimensional aircraft situation display (e.g., vertical profile display or plan view display). In other embodiments the image data can be processed to provide a three dimensional or perspective aircraft situation display image representative of the 3-D positions of runway environment features.

With reference to FIG. 3, a flow **300** can be performed by the display system **10** in some embodiments. At an operation **302**, the weather radar system **102** provides a weather radar scan comprised of multiple radar beams. The radar beams are provided according to beam sharpening techniques and stepped frequency compression techniques in a way to increase the angular and range resolution in some embodiments. At an operation **304**, radar returns are received according to the beam sharpening techniques and the stepped frequency compression techniques to increase the angular and range resolution in some embodiments. At an operation **306**, the radar returns are processed to obtain image data in some embodiments. As discussed above, filtering or related techniques can be performed in an optional step by the filter **154**. At an operation **308**, the image data is merged with other image data, such as overlay symbology or sources of SVS or other EVS images. Operation **308** is optional.

At an operation **310**, the image associated with the image data is displayed on a display via a display computer such as the HUD display computer **132** or the HUD computer **134**. After operation **310**, flow **300** returns to operation **302** in some embodiments.

With reference to FIG. 4, an image **400** of the external scene topography derived from radar associated with storage unit **180** includes features **402** associated with runway approach lights.

With reference to FIG. 5, an image **600** derived from the radar data is provided with HUD symbols **602**. The HUD symbols **602** are shown in static format as a representative example only.

The radar system **102** generally operates by sweeping a radar beam horizontally and/or vertically along the sky for weather detection. For example, radar system **102** may conduct a first horizontal sweep directly in front of the aircraft and a second horizontal sweep downward at some tilt angle (e.g., 20 degrees down). Returns from different tilt angles may be electronically merged to form a composite image for display on an electronic display, such as the displays **20** and the combiner **21** in the aircraft control center **11**. Sensing of the external surroundings can be performed at higher resolutions than the weather sensing and use one or more beams directed toward the external surroundings. Sensing of the external surroundings can be performed in a more forward looking direction with smaller azimuthal sweeps than are used for weather detection in some embodiments. GPS and/or other navigation information can be used to point the radar beam toward the external surroundings associated with an airport in some embodiments.

In some embodiments, the weather radar system **102** may operate in a weather sense mode until approach or landing. During approach or landing, the weather radar system **102** alternatively performs radar data gathering for sensing of the external surroundings, radar data gathering for weather sensing, and radar data gathering for wind shear detection. In some embodiments, during approach or landing, the weather radar system **102** alternatively performs radar data gathering for sensing of external surroundings, and radar data gathering for wind shear detection or other hazard detection. During approach or landing, weather radar system **102** alternatively performs radar data gathering for sensing of external surroundings, and radar data gathering for weather sensing in some embodiments. In some embodiments, weather sensing operations are suspended during approach and landing.

The scope of this disclosure should be determined by the claims, their legal equivalents and the fact that it fully encompasses other embodiments which may become apparent to those skilled in the art. All structural, electrical and functional equivalents to the elements of the above-described disclosure that are known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the present claims. A reference to an element in the singular is not intended to mean one and only one, unless explicitly so stated, but rather it should be construed to mean at least one. No claim element herein is to be construed under the provisions of 35 U.S.C. §112, sixth paragraph, unless the element is expressly recited using the phrase "means for." Furthermore, no element, component or method step in the present disclosure is intended to be dedicated to the public, regardless of whether the element, component or method step is explicitly recited in the claims.

Embodiments of the inventive concepts disclosed herein have been described with reference to drawings. The drawings illustrate certain details of specific embodiments that implement the systems and methods and programs of the present disclosure. However, describing the embodiments with drawings should not be construed as imposing any limitations that may be present in the drawings. The present disclosure contemplates methods, systems and program products on any machine-readable media for accomplishing its operations. Embodiments of the inventive concepts disclosed herein may be implemented using an existing computer processor, or by a special purpose computer processor incorporated for this or another purpose or by a hardwired system.

As noted above, embodiments within the scope of the inventive concepts disclosed herein include program products comprising non-transitory machine-readable media for carrying or having machine-executable instructions or data structures stored thereon. Such machine-readable media may be any available media that may be accessed by a computer or other machine with a processor. By way of example, such machine-readable media may comprise RAM, ROM, EPROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium which may be used to carry or store desired program code in the form of machine-executable instructions or data structures and which may be accessed by a computer or other machine with a processor. Thus, any such a connection is properly termed a machine-readable medium. Combinations of the above are also included within the scope of machine-readable media. Machine-executable instructions comprise, for example,

instructions and data which cause processor to perform a certain function or group of functions.

Embodiments in the inventive concepts disclosed herein have been described in the general context of method steps which may be implemented in one embodiment by a program product including machine-executable instructions, such as program code, for example in the form of program modules executed by machines in networked environments. Generally, program modules include routines, programs, objects, components, data structures, etc. that perform particular tasks or implement particular abstract data types. Machine-executable instructions, associated data structures, and program modules represent examples of program code for executing steps of the methods disclosed herein. The particular sequence of such executable instructions or associated data structures represent examples of corresponding acts for implementing the functions described in such steps.

As previously indicated, embodiments in the present disclosure may be practiced in a networked environment using logical connections to one or more remote computers having processors. Those skilled in the art will appreciate that such network computing environments may encompass many types of computers, including personal computers, hand-held devices, multi-processor systems, microprocessor-based or programmable consumer electronics, network PCs, minicomputers, mainframe computers, and so on. Embodiments in the disclosure may also be practiced in distributed computing environments where tasks are performed by local and remote processing devices that are linked (either by hardwired links, wireless links, or by a combination of hardwired or wireless links) through a communications network. In a distributed computing environment, program modules may be located in both local and remote memory storage devices.

The database or system memory may include read only memory (ROM) and random access memory (RAM). The database may also include a magnetic hard disk drive for reading from and writing to a magnetic hard disk, a magnetic disk drive for reading from or writing to a removable magnetic disk, and an optical disk drive for reading from or writing to a removable optical disk such as a CD ROM or other optical media. The drives and their associated machine-readable media provide nonvolatile storage of machine-executable instructions, data structures, program modules and other data for the computer. User interfaces, as described herein, may include a computer with monitor, keyboard, a keypad, a mouse, joystick or other input devices performing a similar function.

It should be noted that although the diagrams herein may show a specific order and composition of method steps, it is understood that the order of these steps may differ from what is depicted. For example, two or more steps may be performed concurrently or with partial concurrence. Also, some method steps that are performed as discrete steps may be combined, steps being performed as a combined step may be separated into discrete steps, the sequence of certain processes may be reversed or otherwise varied, and the nature or number of discrete processes may be altered or varied. The order or sequence of any element or apparatus may be varied or substituted according to alternative embodiments. Accordingly, all such modifications are intended to be included within the scope of the present disclosure.

The foregoing description of embodiments has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the subject matter to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired

from practice of the subject matter disclosed herein. The embodiments were chosen and described in order to explain the principals of the disclosed subject matter and its practical application to enable one skilled in the art to utilize the disclosed subject matter in various embodiments and with various modifications as are suited to the particular use contemplated. Other substitutions, modifications, changes and omissions may be made in the design, operating conditions and arrangement of the embodiments without departing from the scope of the presently disclosed subject matter.

While the exemplary embodiments illustrated in the figures and described above are presently preferred, it should be understood that these embodiments are offered by way of example only. Other embodiments may include, for example, structures with different data mapping or different data. The disclosed subject matter is not limited to a particular embodiment, but extends to various modifications, combinations, and permutations that nevertheless fall within the scope and spirit of the appended claims.

What is claimed is:

1. An airborne weather radar system used for enhanced vision, comprising:
  - an antenna; and
  - a control circuit configured to provide radar beams via the antenna toward external surroundings and configured to receive radar returns, wherein the control circuit is configured to process the radar returns to provide image data associated with the external surroundings, wherein the weather radar system has increased range resolution and angular resolution when used for enhanced vision of external scene topography than when used for weather radar sensing functions, the control circuit configured to transmit successive pulses with discrete increasing frequency steps such that radar returns from clutter in an ambiguous range are different from radar returns from targets, the control circuit configured to reject the radar returns from clutter in the ambiguous range, the radar beams being in the X-band or the C-band, the image data being for providing a visual image of external scene topography to a pilot.
2. The system of claim 1, wherein the angular resolution is increased using a beam sharpening technique and deconvolution of a beam point spread function.
3. The system of claim 1, wherein the antenna is a switched aperture antenna, and the control circuit is further configured to process the radar returns to determine a high resolution estimate of a target angle relative to a bore site of the antenna based on switching between transmitting and receiving on a full aperture and transmitting on the full aperture while receiving on a partial aperture.
4. The system of claim 1, wherein the control circuit is configured to provide a perspective enhanced image as the visual image on a display in response to the image data.
5. The system of claim 1, wherein the radar beams are provided as separate pulses with discrete increasing frequency steps.
6. The system of claim 5, wherein the frequency steps hop over restricted or undesired frequencies.
7. A method of providing a real time sensor image, the method comprising:
  - receiving radar returns from an X-band or C-band airborne weather radar system, the X-band or C-band airborne weather radar system including a switched aperture antenna, wherein the radar returns can be processed to have increased range resolution and angular resolution when used for providing a real time

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- sensor image of external scene topography than when used for weather radar sensing functions;
- processing the radar returns to determine a high resolution estimate of a target angle relative to a bore site of the antenna based on switching between transmitting and receiving on a full aperture and transmitting on the full aperture while receiving on a partial aperture; and filtering the radar returns to identify areas having a reflectivity lower than a predetermined value to provide a visual image of the external scene topography based on the radar returns.
8. The method of claim 7, wherein the radar returns of the X-band or C-band airborne weather radar system comprise a switched aperture, sequential lobing or monopulse weather radar system.
9. The method of claim 7, further comprising displaying an aircraft situation display image on a head down display using the visual image.
10. The method of claim 7, further comprising providing radar beams associated with the radar returns, the radar beams are provided using beam sharpening techniques.
11. The method of claim 10, wherein the beam sharpening techniques comprise a sub-aperture or split aperture technique, the method further comprising using a complex conjugate method to remove Doppler-induced phase changes by cancellation to determine the target angle based on a change in phase center.
12. The method of claim 10, wherein the radar beams are provided using ultra wide band pulses, intra pulse compression, or inter pulse compression.

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13. The method of claim 12, wherein the radar beams are provided using stepped frequency compression.
14. An enhanced vision system, comprising:  
 a weather radar system configured to enhance resolution in range when used for providing an enhanced image of a runway environment than when used for weather radar sensing functions, wherein the weather radar system generates image data representative of the runway environment associated radar returns received by the weather radar system, the radar returns being in an X-band or a C-band, wherein the weather radar system is configured to transmit successive pulses with discrete increasing frequency steps such that radar returns from clutter in an ambiguous range are different from radar returns from targets, the weather radar system configured to reject the radar returns from clutter in the ambiguous range; and  
 a display in communication with the weather radar system and configured to display an image associated with the radar returns.
15. The system of claim 14, wherein the weather radar system includes processing electronics that are configured to provide increased angular resolution using beam sharpening.
16. The system of claim 14, wherein the display is a head down display or head up display.
17. The system of claim 14, wherein the enhanced vision system is used as an enhanced flight vision system.

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