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Moya et al.

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(54) **SUPERPIXELS FOR IMPROVED STRUCTURE AND TERRAIN CLASSIFICATION USING MULTIPLE SYNTHETIC APERTURE RADAR IMAGE PRODUCTS**

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(57) **ABSTRACT**

Various embodiments presented herein relate to assigning labels to segments of a synthetic aperture radar (SAR) image, where the segments are based upon a speckle-reduced SAR image product. A plurality of SAR images of a scene are co-registered to form a registered stack of SAR images. A speckle-reduced SAR image product is generated based upon at least one registered SAR image in the registered stack of SAR images. The speckle-reduced SAR image product is segmented into a plurality of superpixels, and boundaries of the superpixels are applied to the at least one registered SAR image to form a segmented SAR image. A segment of the SAR image is then labeled as including or not including a feature, wherein the label is assigned based upon values of pixels in the segment.

Related U.S. Application Data

(60) Provisional application No. 61/942,532, filed on Feb. 20, 2014.

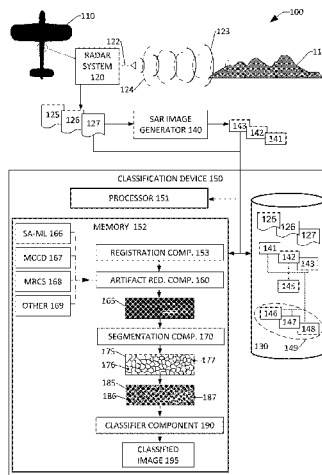
(51) **Int. Cl.**
G01S 13/90 (2006.01)

(52) **U.S. Cl.**
CPC **G01S 13/9023** (2013.01)

(58) **Field of Classification Search**
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USPC 342/25

See application file for complete search history.

20 Claims, 12 Drawing Sheets



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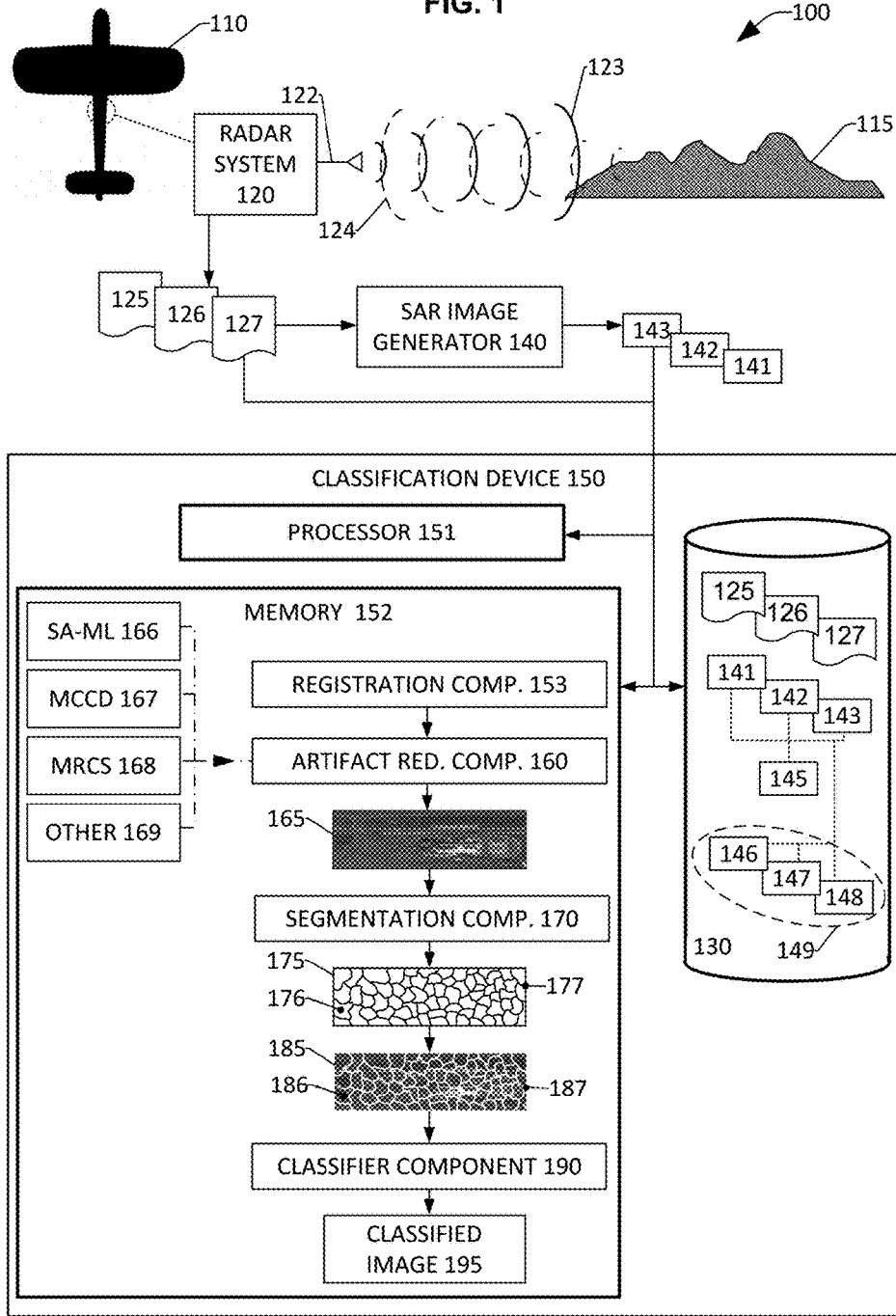
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FIG. 1



200



FIG. 2

300



FIG. 3

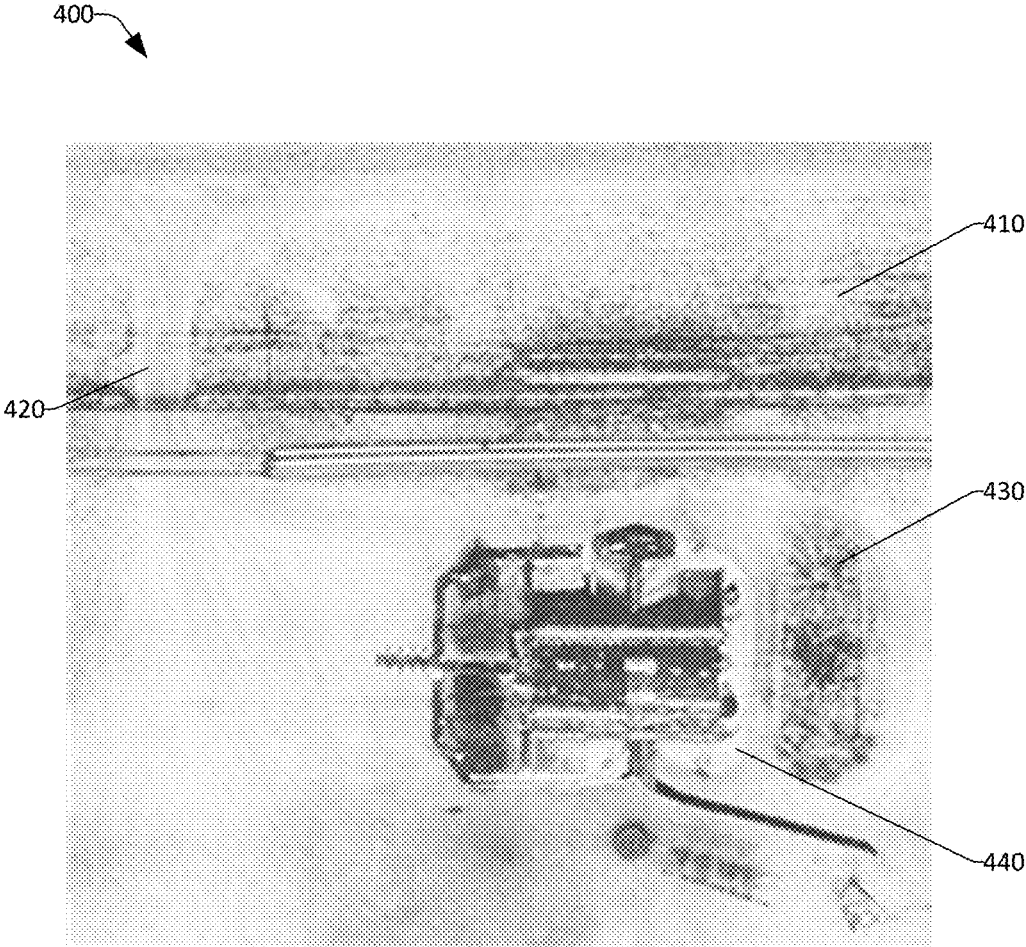
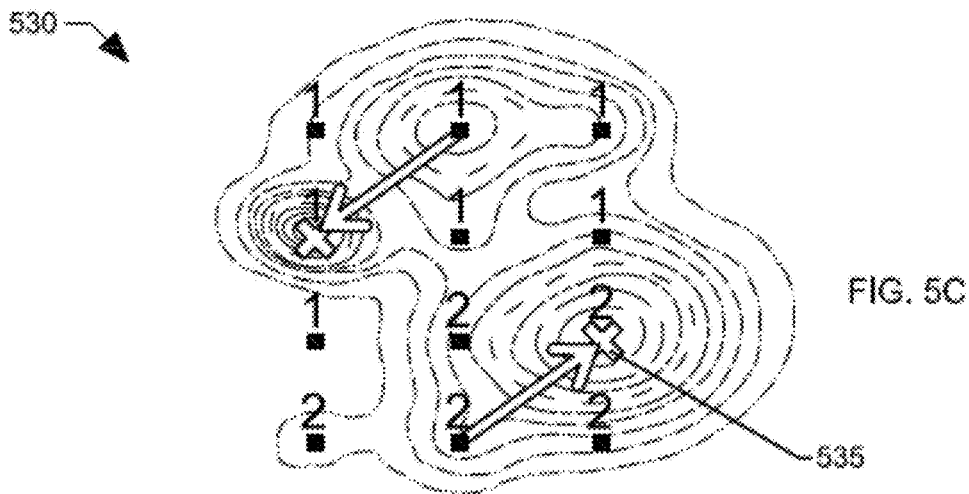
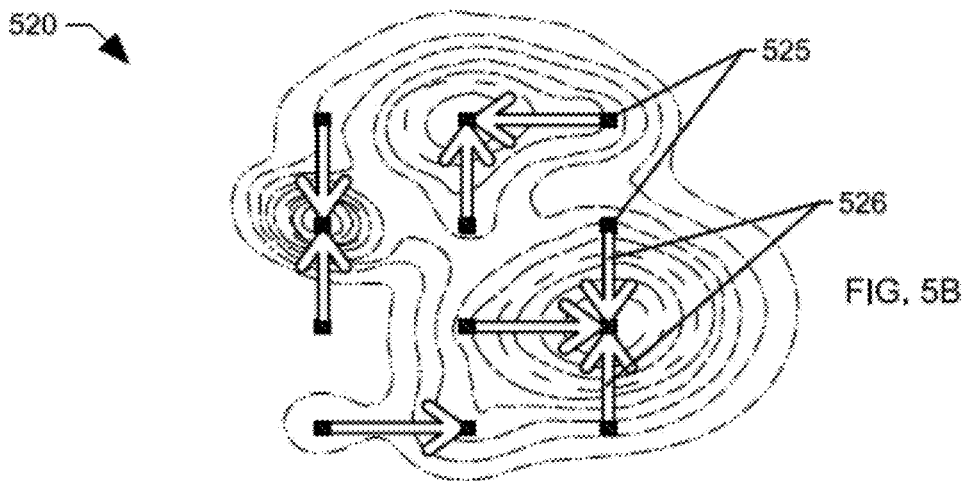
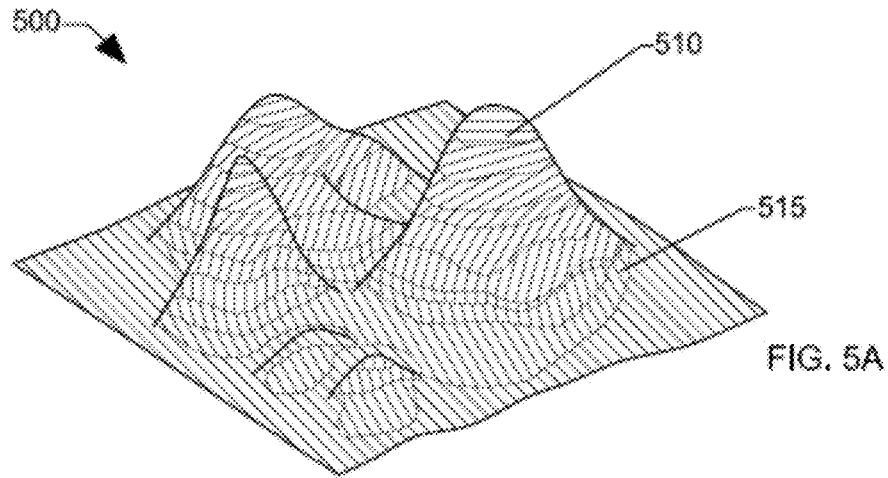


FIG. 4



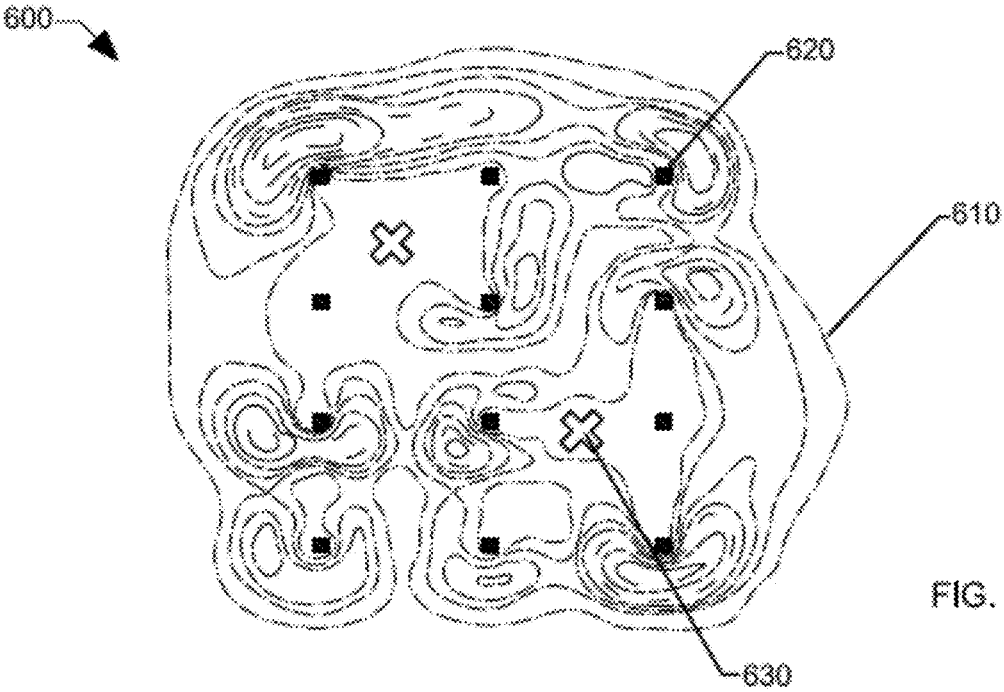


FIG. 6A

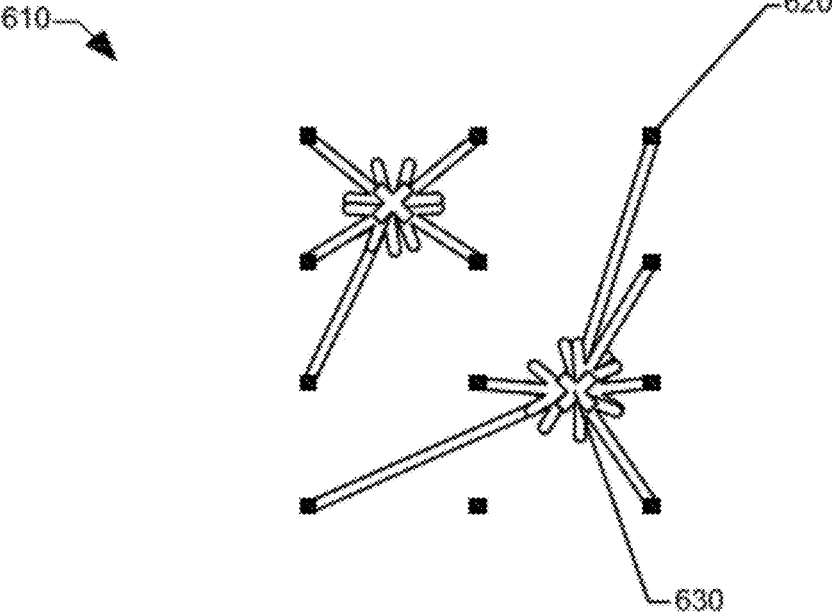
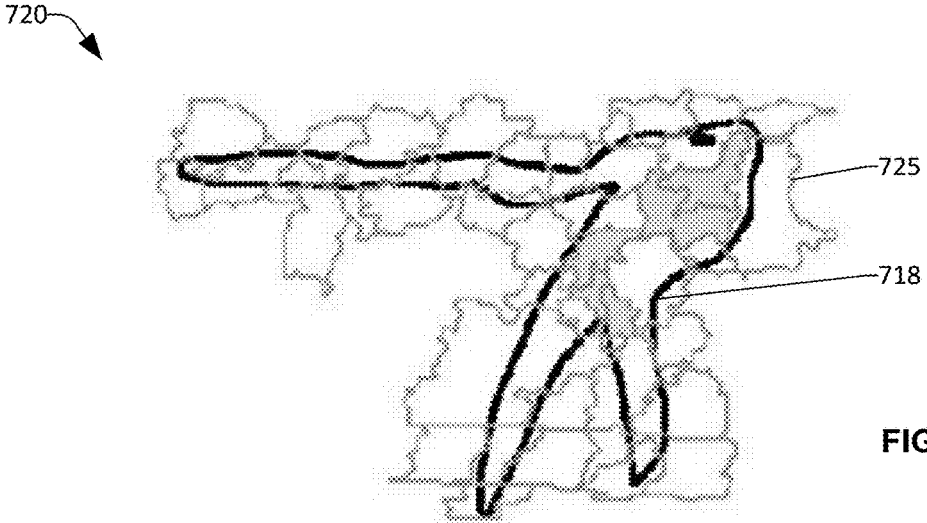
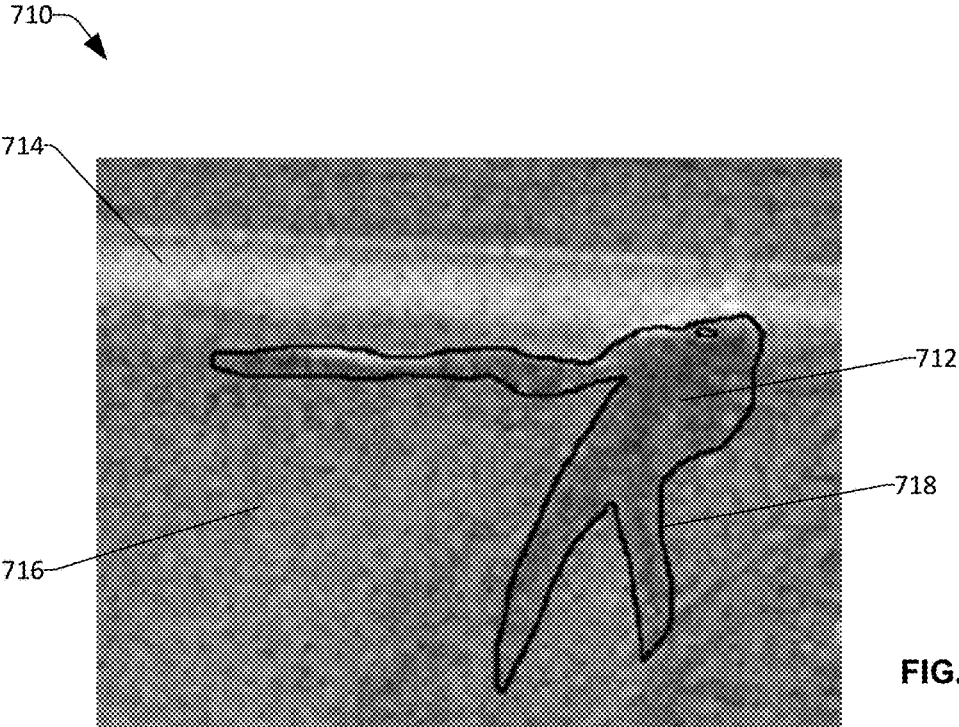


FIG. 6B



730

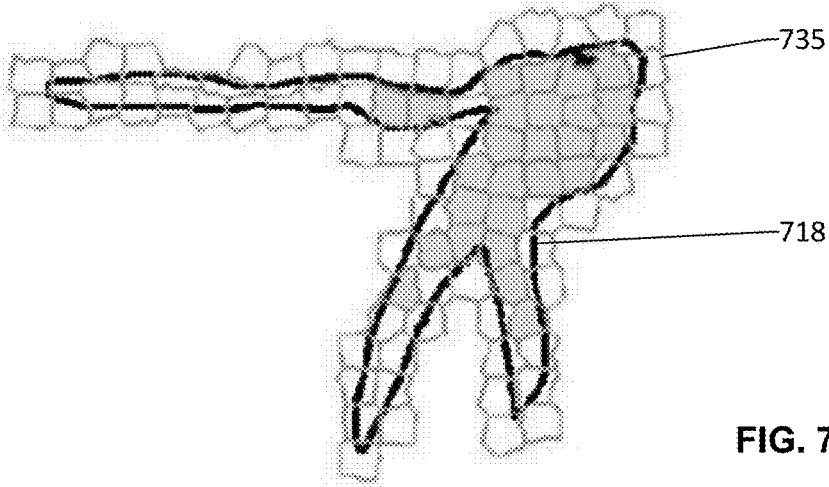


FIG. 7C

740

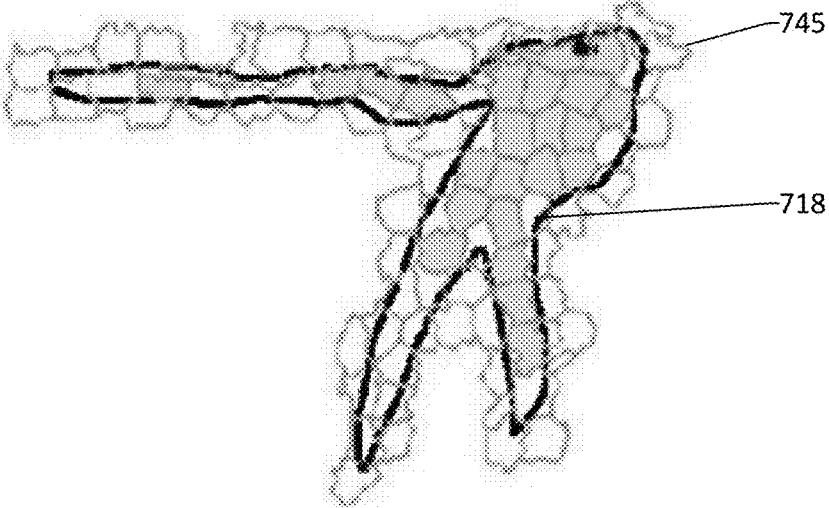


FIG. 7D

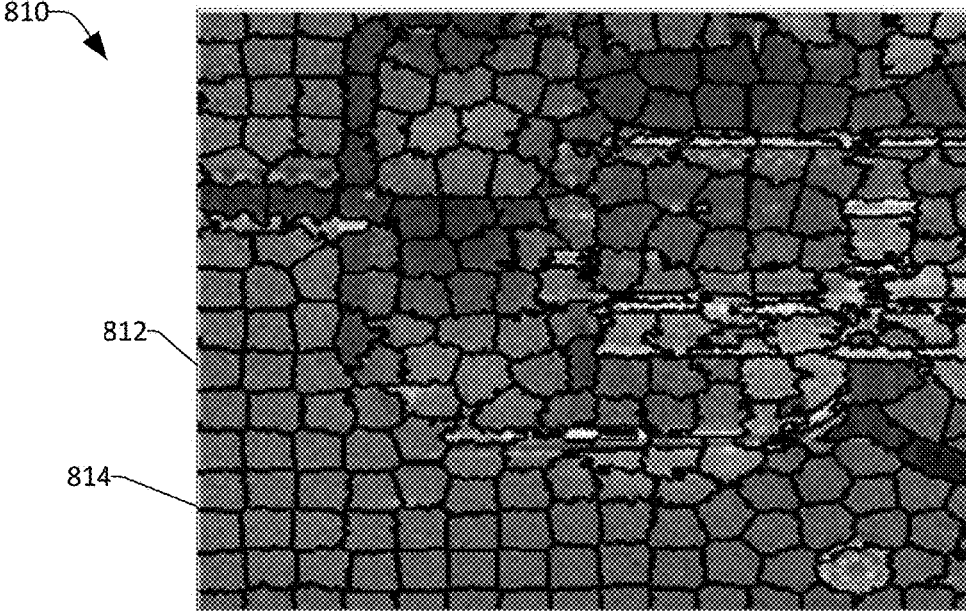


FIG. 8A

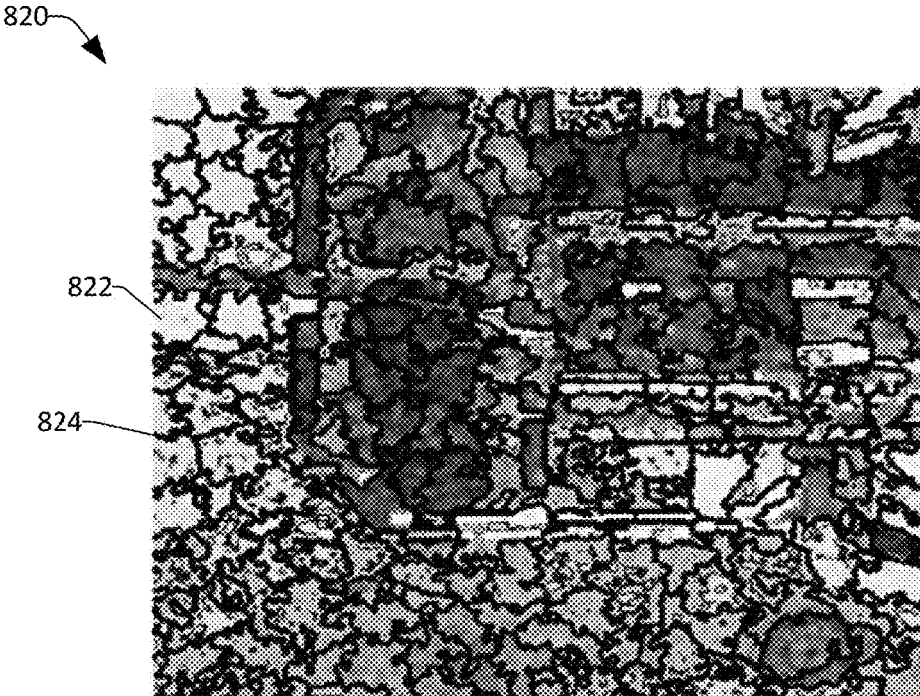


FIG. 8B

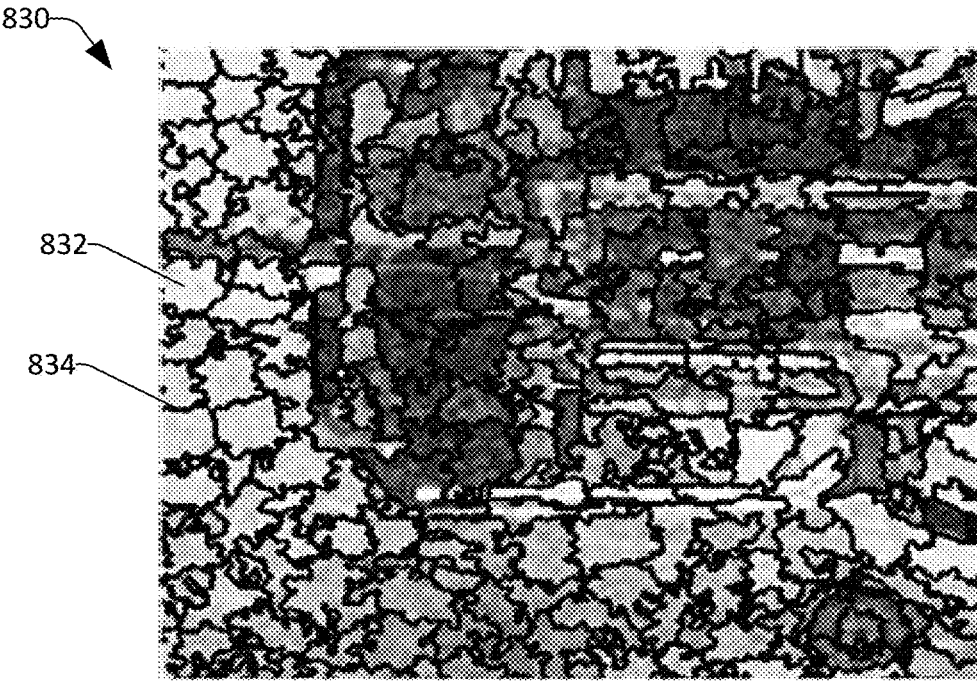


FIG. 8C

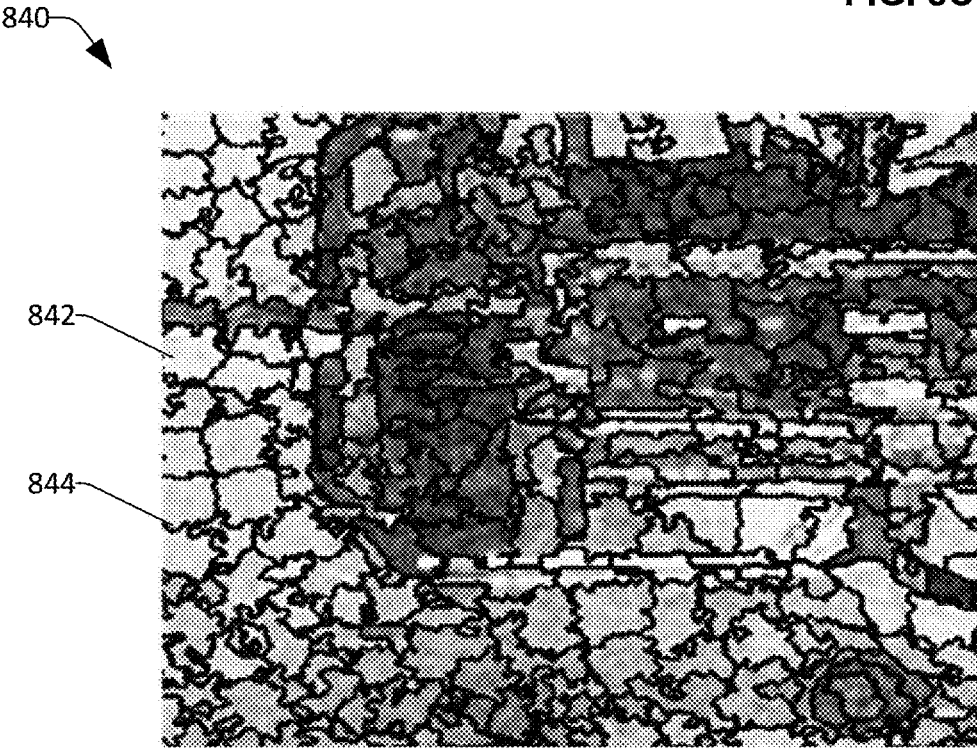


FIG. 8D

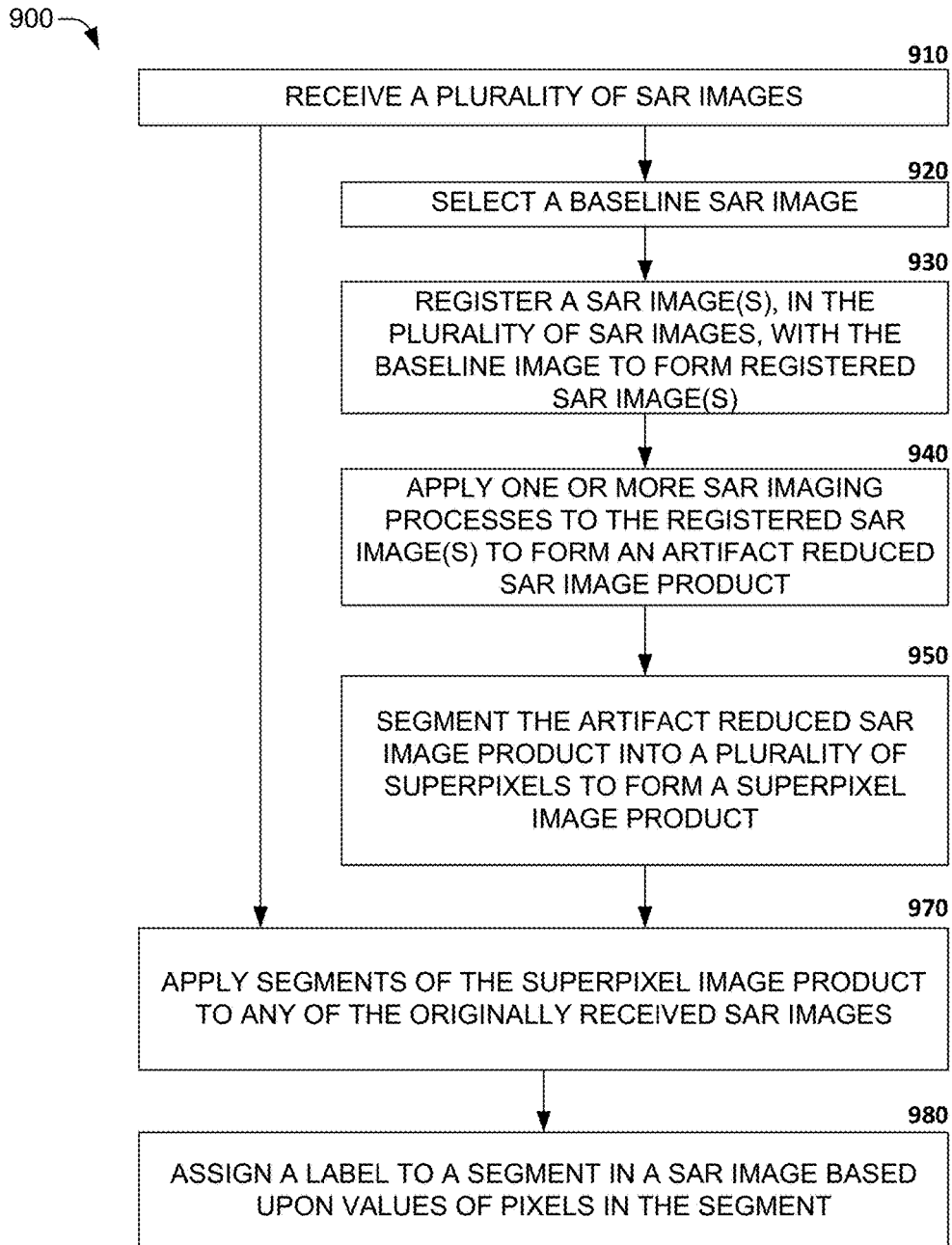


FIG. 9

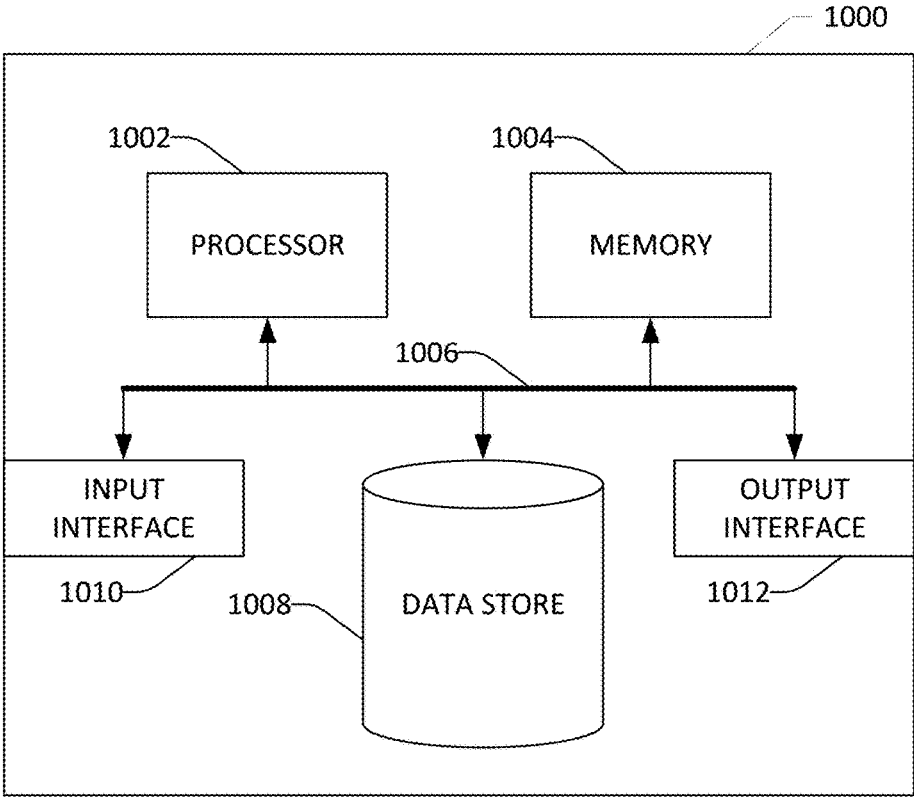


FIG. 10

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**SUPERPIXELS FOR IMPROVED
STRUCTURE AND TERRAIN
CLASSIFICATION USING MULTIPLE
SYNTHETIC APERTURE RADAR IMAGE
PRODUCTS**

RELATED APPLICATION

This application claims priority to U.S. Provisional Patent Application No. 61/942,532, filed on Feb. 20, 2014, and entitled "SUPERPIXELS FOR IMPROVED STRUCTURE AND TERRAIN CLASSIFICATION USING MULTIPLE SYNTHETIC APERTURE RADAR PRODUCTS", the entirety of which is incorporated herein by reference.

STATEMENT OF GOVERNMENTAL INTEREST

This invention was developed under contract DE-AC04-94AL85000 between Sandia Corporation and the U.S. Department of Energy. The U.S. Government has certain rights in this invention.

BACKGROUND

Synthetic aperture radar (SAR) images provide a wealth of information about structures and activities in an imaged scene. During the production of high-resolution, single-polarization SAR imagery, much more data and/or imagery is generated than available researchers and analysts can examine. Thus, automating the recognition of objects and features in SAR imagery is highly desired, e.g., to augment manual visual analysis. Superpixel segmentation (SPS) algorithms can be utilized to divide an image into small regions of close proximity pixels having similar intensities. Applying these SPS algorithms to optical images can reduce image complexity, enhance statistical characterization, and improve segmentation and categorization of scene objects and features. SPS algorithms typically require high signal-to-noise-ratio (SNR) images with low artifacts for accurate segmentation. SAR imagery, however, tends to include speckle, a product of coherent combining and cancelling of multi-path backscattered radar energy, which can complicate the extraction of superpixel segments and even preclude SPS usage.

SUMMARY

The following is a brief summary of subject matter that is described in greater detail herein. This summary is not intended to be limiting as to the scope of the claims.

Various embodiments presented herein relate to automating categorization of terrain and/or structure captured in radar imagery, such as, for example, synthetic aperture radar (SAR) imagery. A SAR image can include speckle, which is a deterministic artifact commonly found in SAR imagery. When a superpixel segmentation (SPS) algorithm is executed over the SAR image, the speckle in the SAR image impacts segmentation of the SAR image. That is, the speckle causes superpixels output by the SPS algorithm to be different from what the SPS algorithm would output if the SAR image were free of speckle. Accordingly, speckle can negatively impact operation of the SPS algorithm.

Therefore, the various embodiments presented herein relate to mitigating the deleterious effects of speckle during SPS. Prior to executing an SPS algorithm over the SAR image (e.g., in its original form), a speckle reduction process can be undertaken over the SAR image, resulting in a

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speckle-reduced SAR image product. Exemplary speckle-reduction processes include, but are not limited to, a sub-aperture multilook (SA-ML) process, a mean coherent change detection (MCCD) process, and a median radar cross section (MRCS) process. Other processes can also be executed, such as an interferometric height (IF-H) mapping process. One or more of these processes, in addition to reducing speckle, also reduces spatial resolution. Therefore, the speckle-reduced SAR image product can have a resolution that is lower than the resolution of the SAR image.

The SPS algorithm can then be executed over the speckle-reduced image product, resulting in segmentation of the speckle-reduced image product into a plurality of segments. Each segment comprises at least one pixel (and typically includes several pixels), where pixels in a segment have been found by the SPS algorithm to be related to one another. It can be ascertained that since the speckle-reduced image product has less speckle when compared to the original SAR image, the segmentation performed by the SPS algorithm will be less influenced by speckle. The segmented, reduced-speckle image product can be referred to as a superpixel image product.

In an embodiment, the superpixel image product can be formed from a speckle-reduced product that is registered with the original SAR image; accordingly, the superpixel image product is likewise registered with the original SAR image. Registration of the superpixel image product with the original SAR image causes the segments of the superpixel image product to be applicable to the original SAR image. Effectively, then, the original SAR image, and all other images registered with the superpixel image product, can be segmented into segments that respectively correspond to the segments of the superpixel image product. The segmented original SAR image is referred to as the segmented image.

Segments in the segmented image can subsequently be assigned labels based upon values of pixels in respective segments. With more particularity, a classifier can assign a label to a segment in the segmented image based upon values of pixels in the segment (without regard to values of pixels in other segments). For example, the classifier can be trained based upon labeled training data, such as manually identified segments that correspond to an object or feature of interest. Thus, for instance, the classifier can be trained based upon segments (of SAR images) manually identified as including a particular type of surface (e.g., a concrete building). The classifier, when provided with a segment from the segmented image, can output a value that is indicative of whether or not the segment includes a concrete building, and the classifier can label the segment as including (or not including) the concrete building based upon the value. The value output by the classifier, as noted above, is based upon values of pixels in the segment.

The above summary presents a simplified summary in order to provide a basic understanding of some aspects of the systems and/or methods discussed herein. This summary is not an extensive overview of the systems and/or methods discussed herein. It is not intended to identify key/critical elements or to delineate the scope of such systems and/or methods. Its sole purpose is to present some concepts in a simplified form as a prelude to the more detailed description that is presented later.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates an exemplary system for assigning labels to segments in a SAR image, where the segments are based upon a speckle-reduced SAR image product.

FIG. 2 presents an exemplary subaperture multilook (SA-ML) image product.

FIG. 3 presents an exemplary median-over-time of radar cross section (MRCS) image product.

FIG. 4 presents an exemplary mean coherent change detection (CCD) image product.

FIG. 5A presents an exemplary diagram of Parzen density estimate of spatial-intensity distance.

FIG. 5B presents an exemplary diagram of local search for higher-density, minimum-distance parent.

FIG. 5C presents an exemplary diagram of local search for parent-of-parent.

FIG. 6A presents an exemplary diagram of intensity gradient with initial cluster centers located at local minima.

FIG. 6B presents an exemplary diagram of finding a closest local cluster center in local k-means.

FIG. 7A presents an exemplary MRCS image product including a hand-labeled ground truth.

FIG. 7B is a depiction of an exemplary Quick-shift superpixel segmentation process over the MRCS image product shown in FIG. 7A.

FIG. 7C is a depiction of an exemplary simple linear iterative clustering (SLIC) superpixel segmentation process utilizing a SA-ML image product.

FIG. 7D is an exemplary depiction of a SLIC superpixel segmentation process utilizing a SA-ML image product in conjunction with interferometric height (IF-H) map data.

FIG. 8A presents an exemplary image segmentation formed by SLIC based upon an MRCS image product.

FIG. 8B presents an exemplary image segmentation formed by SLIC based upon an MCCD image product.

FIG. 8C presents an exemplary image segmentation formed by SLIC based upon SA-ML and MCCD image products.

FIG. 8D presents an exemplary image segmentation formed by SLIC based upon a combination of SA-ML, MCCD and IF-H image products.

FIG. 9 is a flow diagram illustrating an exemplary methodology for assigning labels to segments in a SAR image, where the SAR image is segmented based upon a speckle-reduced SAR image product.

FIG. 10 illustrates an exemplary computing device.

DETAILED DESCRIPTION

Various technologies pertaining to identifying an object or feature in a SAR image, wherein the SAR image may include speckle, are now described with reference to the drawings, wherein like reference numerals are used to refer to like elements throughout. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of one or more aspects. It may be evident, however, that such aspect(s) may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form in order to facilitate describing one or more aspects.

Further, the term “or” is intended to mean an inclusive “or” rather than an exclusive “or”. That is, unless specified otherwise, or clear from the context, the phrase “X employs A or B” is intended to mean any of the natural inclusive permutations. That is, the phrase “X employs A or B” is satisfied by any of the following instances: X employs A; X employs B; or X employs both A and B. In addition, the articles “a” and “an” as used in this application and the appended claims should generally be construed to mean “one or more” unless specified otherwise or clear from the

context to be directed to a singular form. Additionally, as used herein, the term “exemplary” is intended to mean serving as an illustration or example of something, and is not intended to indicate a preference.

As used herein, the terms “component”, “device”, and “system” are intended to encompass computer-readable data storage that is configured with computer-executable instructions that cause certain functionality to be performed when executed by a processor. The computer-executable instructions may include a routine, a function, or the like. It is also to be understood that a component or system may be localized on a single device or distributed across several devices. The terms “component”, “device”, and “system” are also intended to encompass hardware configured to cause certain functionality to be performed, where such hardware can include, but is not limited to including, Field-programmable Gate Arrays (FPGAs), Application-specific Integrated Circuits (ASICs), Application-specific Standard Products (ASSPs), System-on-a-chip systems (SOCs), Complex Programmable Logic Devices (CPLDs), etc.

SAR imaging systems deliver complex phase history data, which pass through Fourier transform processing to produce complex-valued backscatter images. Because multi-path backscattered energy can add and cancel coherently, resulting SAR images can include speckle, which can complicate application of standard image processing methods, such as superpixel segmentation (SPS), to SAR images.

FIG. 1 illustrates an exemplary system 100 that is configured to assign labels to one or more segments of a SAR image, where the segments are determined based upon a speckle-reduced SAR image product. FIG. 1 depicts an aircraft 110 navigating a scene 115, e.g., the aircraft 110 is flying in accordance with a known flight path(s) having a defined geometry relative to the scene 115.

The aircraft 110 has located thereon a radar system 120, which includes an antenna 122. The antenna 122 transmits radar signals 123, and the antenna 122 (or another antenna) receives radar echoes 124, which have been generated by reflection of the radar signals 123 from the scene 115. Transmission of the signals 123 can be performed in conjunction with a controller (not shown) incorporated into the radar system 120, wherein the controller can be a digital signal processor or other suitable circuit or processor.

For each pass of the aircraft 110 over the scene 115, data can be generated by the radar system 120, e.g., during a first pass of the aircraft 110 over the scene 115, the radar system 120 generates a first set of data 125, during a second pass of the aircraft 110 over the scene 115, the radar system 120 generates a second set of data 126, during an n^{th} pass of the aircraft 110 over the scene 115, the radar system 120 generates a n^{th} set of data 127, etc., where n is a positive integer. In an embodiment, the sets of data 125, 126, and 127 can be or include phase history data. Further, the sets of data 125, 126, and 127 can be in any suitable format, such as Ground-Based SAR Application Testbed File Format (GFF).

The system 100 comprises a classification device 150, which can be any suitable computing device, including but not limited to a desktop computing device, a laptop computing device, a mobile telephone, a wearable computing device, a server computing device, etc. The classification device 150 is in direct or indirect communication with the radar system 120, such that data generated by the radar system 120 (or data based upon data generated by the radar system 120) can be received at the classification device 150. For instance, the classification device 150 can be co-located with the radar system 120 on the aircraft. In another example, the classification device 150 can be located sepa-

rately from the radar system **120**. The classification device **150** comprises a data store **130**, and the respective sets of data **125-127** can optionally be stored in the data store **130** for subsequent retrieval.

The system **100** also includes a SAR image generator **140** that is configured to generate (complex) SAR images **141**, **142**, and **143**, based upon at least one of the data **125-127** (e.g., where the data **125-127** includes complex phase history data). The image generator **140** can exploit different phenomena of the complex backscatter data to produce the SAR images **141**, **142** and **143**. While shown as being separate from the classification device **150** and the radar system **120**, it is to be understood that the SAR image generator **140** may be included in either of the classification system **150** or the radar system **120**. The respective SAR images **141-143** can be stored in the data store **130** for subsequent retrieval.

The classification device **150** includes a processor **151** and a memory **152**. The memory **152** includes components that are executable by the processor, wherein functionalities of the process, when executing the components, are described below.

The memory **152** includes a registration component **153** that can be configured to register the SAR images **141-143**. In an embodiment, a SAR baseline image **145** can be selected from any of the SAR images **141-143** collected from the same scene **115**. The registration component **153** can be then be configured to register each of the remaining SAR images **141-143** with the baseline SAR image **145**, thereby forming a mapping between the baseline SAR image **145** and any of the SAR images **141-143**, and thereby producing registered SAR images **146**, **147**, and **148**, referred to collectively as a registered image stack **149**. It is to be appreciated that while the registration component **153** is shown as being separate from the radar system **120**, the registration component **153** may be included in either of the classification device **150** or the radar system **120**. As shown, the registered image stack **149** can be stored in the data store **130** for subsequent retrieval.

In a situation where any of the SAR images **141-143** has a different resolution to any of the other SAR images, the registration component **153** can optionally be configured to resample any of the SAR images to enable the SAR images to have a common resolution. For example, when the SAR image **141** comprises x pixels and the SAR image **142** comprises y pixels, the registration component **153** can resample the SAR image **141** such that the SAR image **141** comprises y pixels.

The memory **152** can also include an artifact reduction component **160**, wherein the artifact reduction component **160** is configured to generate an artifact-reduced image product **165** based upon at least one of the registered SAR images **146-148** in the registered image stack **149**. In a scenario where noise contamination may be an issue for processing of SAR images **141-143**, the artifact reduction component **160** can also be configured to reduce noise in at least one of the registered SAR images **146-148**. For purposes of explanation, functionality of the components in the memory **152** will be described with reference to the registered SAR image **146**, although it is to be understood that the functionality can be performed over other registered SAR images (e.g., registered SAR images **147**, **148**) in the registered image stack **149**. The artifact reduction component **160** can be configured to generate the artifact-reduced SAR image product **165** based upon the registered SAR image

in the registered SAR image **146**. The artifact-reduced SAR image product **165** can be perceived as an image comprising a plurality of pixels, wherein each pixel has a value or vector of values assigned thereto.

In a non-limiting example, the artifact reduction component **160** can be configured to perform at least one speckle-reduction operation over the registered SAR image **146**, such that the artifact-reduced SAR image product **165** is a speckle-reduced image product. Accordingly, an amount of speckle in the artifact-reduced SAR image product **165** can be less than an amount of speckle in the (original) registered SAR image **146**. Exemplary operations that can be performed by the artifact reduction component **160** include, but are not limited to, sub-aperture multilook imaging (SA-ML) **166**, mean-over-time of coherent change detection (MCCD) imaging **167**, and median-over-time of radar cross section (MRCS) imaging **168**. The artifact reduction component **160** can also be configured to perform other operations **169** over the registered SAR image **146**, such as an operation that generates interferometric height (IF-H) map data, which can be indicative of local height variations in the scene **115**, and can augment available backscatter and coherent change information. In an embodiment, the SA-ML imaging **166** can reduce spatial resolution to reduce speckle while MCCD imaging **167** and MRCS imaging **168** can average values over time rather than over space, hence spatial resolution is preserved while speckle is reduced. In another embodiment, MCCD imaging **167** and MRCS imaging **168** can have the same spatial resolution as an originally received image **141-143**, while SA-ML imaging **166** can have reduced spatial resolution from the originally received image **141-143**. The exemplary speckle reduction operations are described in greater detail below.

It is to be appreciated that the artifact reduction component **160** can generate the artifact-reduced SAR image product **165** using a single artifact reduction operation (e.g., any of operations **166-169**) or a combination of artifact reduction operations (e.g., a combination of operations **166-169**). For example, the artifact-reduced SAR image product **165** can be a plurality of image products that are registered to one another. For instance, conceptually, the artifact-reduced SAR image product **165** can have a plurality of pixels, with each pixel in the artifact-reduced SAR image product **165** having a vector of values, and each value in the vector corresponding to a respective artifact reduction operation. Thus, a pixel in the artifact-reduced SAR image product **165** can have the vector of values [A, B, C] assigned thereto, where A is based upon an output of a first artifact-reduction operation relative to the registered SAR image **146**, B is based upon an output of a second artifact-reduction operation relative to the registered SAR image **146**, and C is based upon an output of a third artifact reduction operation relative to the registered SAR image **146**. Additionally, each pixel in the artifact-reduced product **165** can have spatial values (e.g., range and azimuth coordinates) assigned thereto, which represent location of the pixel in the artifact-reduced SAR image product **165**. It is to be appreciated that, since the artifact-reduced SAR image product **165** was created from one or more registered images **146-148**, the artifact-reduced image product **165** is also registered to the baseline image **145** as well as all other registered images **146-148** in the stack **149**.

The memory **152** can further comprise a segmentation component **170** that is configured to segment the artifact-reduced SAR image product **165** into a plurality of segments based upon respective values of respective pixels of the artifact-reduced SAR image product **165**. For example, the

segmentation component **170** can be configured to perform a pixel clustering operation on the artifact-reduced SAR image product **165**, such that a plurality of pixel groupings (superpixels) are formed (and hence the artifact-reduced SAR image product **165** is segmented into the plurality of superpixels). The segmentation component **170** therefore divides (segments) the artifact-reduced SAR image product **165** into a plurality of segments, thus producing superpixel image product **175**. The superpixel image product **175**, as noted above, comprises a plurality of segments **176**, each comprising a respective boundary **177**, where each segment includes pixels of the artifact-reduced SAR image product **165** found to be correlated by the pixel clustering operation (e.g., proximate pixels having a similar value) performed by the segmentation component **170**. Exemplary pixel clustering algorithms that can be utilized by the segmentation component **170** when segmenting the artifact-reduced product **165** into a plurality of segments include, but are not limited to, a QUICK-SHIFT algorithm and a simple linear iterative clustering (SLIC) algorithm. It is to be appreciated that, since the superpixel image product **175** was created from the artifact reduced SAR image product **165**, that it too is registered to all other registered images **146-148**.

As the superpixel image product **175** is registered with the SAR images in the stack **149**, the segmentation component **170** can apply the boundaries **177** of the segments **176** of the superpixel image product **175** to all registered SAR images **146**, **147**, and **148** in the stack **149**. In an example, the segmentation component **170** can apply the segments to the registered SAR image **146** (and thus to the original SAR image **143**), thereby creating a segmented SAR image **185**. The segmented SAR image **185** has a plurality of segments **186**, bounded by boundaries **187**, that respectively correspond to the segments **176** (and boundaries **177**) in the superpixel image product **175**. Each segment in the segments **186** comprises a respective plurality of pixels, which have values corresponding thereto. As noted above, however, as the superpixel image product **175** is registered with SAR images in the stack **149**, the segments of the superpixel image product **175** can be applied to others of the registered SAR images in the stack **149**. Thus, the registered SAR images in the stack **149** can each be segmented in accordance with the boundaries of the superpixels.

The memory **152** additionally comprises a classifier component **190**, which can receive the segmented SAR image **185** and assign at least one label to at least one segment in the segmented SAR image **185** based upon values of pixels in the at least one segment (e.g., one label is assigned to each pixel in the segment(s) **186**). Further, since each SAR image in the registered stack **149** is segmented, the classifier component **190** can assign the at least one label to the at least one segment based upon a vector of pixel values, wherein a number of entries in the vector maps to a number of images in the stack **149**. Pursuant to an example, the classifier component **190** can be configured to determine if a segment represents a particular type of vegetation based upon pixel values in the segment. When the classifier component **190** determines that the segment represents the particular type of vegetation, the classifier component can assign a label to the segment in the segmented SAR image **185** that indicates that the segment represents the particular type of vegetation. It can be ascertained that the classifier component **190** can be configured to perform a classification based upon pixel values of a segment with respect to any suitable object, feature, or the like. For example, the classifier component

190 can be configured to determine whether a segment represents a body of water, a particular type of road surface, a ditch, etc.

The classifier component **190** can be trained to perform a classification based upon labeled training data. For example, analyst(s) can manually identify segments of SAR images that represent an object, feature, or the like that is to be classified. Likewise, negative training data can be considered, where analyst(s) manually identify segments of SAR images that do not represent the object, feature, or the like that is to be classified. Features of a segment that can impact whether the segment represents an object include, but are not limited to, size of the segment, shape of the segment, average intensity values of pixels in the segment, distribution of intensity values of pixels in the segment, etc. These features can be (inherently) identified when training the classifier component **190**, and the classifier component **190** can perform suitable computations with respect to pixel values in the segment when classifying the segment as representing an object or feature or not representing the object or feature.

It is to be understood that artifacts in the SAR image **143** would impact segmentation of the registered SAR image **143** if the segmentation component **170** were configured to directly segment the SAR image **143**. Thus, the segments **186** in the segmented SAR image **185** are different from segments that would be generated from directly segmenting the SAR image **143**. When the artifact reduction component **160** generates the artifact-reduced SAR image product **165** based upon the registered SAR image **146**, however, resolution of at least one dimension in the artifact-reduced SAR image product **165** may be less than resolution of the SAR image **143**. Accordingly, reducing artifacts in the registered SAR image **146** prior to segmenting is non-intuitive, as it may be expected that segmenting a lower resolution SAR image product may negatively impact classification performed based upon the segmented image product. In addition, the artifact-reduced SAR image product **165** utilized to generate the segments can be based on multiple SAR image products, which can be derived from different SAR backscatter phenomena. The segmentation component **170** facilitates the ability to generate the SAR image segments **176** from a particular SAR backscatter phenomenon and apply those segments to images or image products that exhibit an alternate SAR backscatter phenomenon. For example, an MCCD image product can capture a man-made structure with a high degree of accuracy, and accordingly segments generated based upon the MCCD image product (e.g., MCCD **167**) can be applied to a radar cross section image product, which includes characteristic distributions of pixel intensities for different surfaces but may include less well-defined edges for man-made structures.

Returning to the exemplary speckle reduction operations which can be performed by the artifact reduction component **160**, the following provides an overview of SA-ML **166**, MCCD **167**, and MRCS **168** techniques, which can be utilized by the artifact reduction component **160** when generating the artifact-reduced SAR image product **165**.

Forming a SA-ML image product can require transforming a complex-valued SAR image (e.g., registered SAR image **146**) back to the two-dimensional Fourier domain, partitioning the spectrum into non-overlapping pieces, and non-coherently averaging the images formed from each piece of the spectrum. As mentioned above, a SA-ML image product can have a coarser spatial resolution than an SAR backscatter magnitude image formed from the complete phase history, but also has reduced speckle. FIG. 2 presents

an example of an SA-ML image product **200** which can be formed by application of the SA-ML imaging algorithm **166** to a SAR image (e.g., registered SAR image **146**). The SA-ML image product **200** can be calibrated, and the log-magnitude computed, prior to the segmentation component **170** segmenting the artifact-reduced SAR image product **165** (which is based upon the SA-ML image product **200**). For example, the SA-ML image product **200** can be a $20 \log_{10}$ (SA-ML).

A MRCS image product can be formed by utilizing SAR images generated based upon multiple passes over the same scene (e.g., scene **115**). Thus, the artifact reduction component **160** receives multiple SAR images (e.g., from the registered images **146-148**) that are based upon SAR data generated from different passes over the scene, and utilizes the MRCS algorithm **168** to estimate image statistics for speckle reduction. The MRCS algorithm **168** can form a stack of co-registered Radar Cross Section (RCS) images of the same scene **115** and can compute a pixel-by-pixel median image product to form the MRCS image product, which is a temporal multilook product. The artifact reduction component **160** can compute the log-magnitude of the MRCS image product prior to the segmentation component **170** segmenting the artifact-reduced SAR image product **165**, wherein the artifact-reduced SAR image product **165** can be based upon the MRCS image product. In an exemplary embodiment, a MRCS image product can refer to $20 \log_{10}$ (MRCS). FIG. 3 shows an example of an MRCS image product **300**.

A complex-valued radar backscatter (BKS) image can provide not only magnitude of the backscattered radar return, but also a phase of the returned signal (e.g., return signal **124**), which can be utilized for determining coherence between multiple passes and for forming interferometric height maps. CCD image products, produced from co-registered images (e.g., registered SAR images **146-148**) of the same scene **115** collected at different times (e.g., formed from co-registering SAR images **141-143**), can exploit the phase information in the backscatter signal **124** to detect subtle changes such as tire tracks in a dirt road or breeze-induced shifts in vegetation. Collecting a large number of passes (e.g., 25 passes or more) from the same scene **115** enables characterization of patterns of change over time. The artifact reduction component **160** can utilize the M CCD algorithm **168** to generate CCD image products from pairs of images in the registered SAR images **146-148**, and further average a plurality of CCD image products together to create a M CCD image product. The M CCD image product represents the average change for different structures/terrains. For example, even a field of windblown grass can produce a smooth M CCD if the change from day to day is consistent.

FIG. 4 shows a M CCD image product formed from an average of 29 CCD image products, where a dark color indicates regions of low average coherence produced by physical scene changes between collection-times of the image pairs, shadows, or regions blocked from the radar signal. The surrounding desert **410** exhibits slightly more change over time than the packed dirt parking lot and driveway **420**. The gravel **430** to the right of the building exhibits relatively small change over time whereas the three trees **440** inside the oval planting area have moderate change likely a result of small displacements from wind and weather. A criterion for creating superpixels can be that structures made of the same material have similar change properties over time. The M CCD image product represents structures in the image in slightly different ways than do the products based on backscatter magnitude. Some structures

are more prominent and others are less so. Because different surface materials exhibit characteristic mean coherent changes over time, the segmentation component **170** can use M CCD to delineate segments of similar surface type, and the classifier component **190** can exploit M CCD to classify surface types.

In an embodiment, the artifact reduction component **160** can utilize one or more of the speckle reduction techniques SA-ML **166**, MRCS **167**, M CCD **168** (and optionally other techniques) to form the artifact-reduced SAR image product **165**. For example, the artifact-reduced SAR image product **165** can be based upon the three techniques mentioned above, such that each pixel in the artifact-reduced SAR image product **165** has a three-dimensional vector assigned thereto, where the artifact-reduced SAR image product **165** has a resolution of the SA-ML image product. Thus, as noted above, a value of a first dimension for a pixel can be based upon an SA-ML image product (generated by the artifact reduction component **160** through use of the SA-ML **166** technique), a value of a second dimension for the pixel can be based upon an MRCS image product (generated by the artifact reduction component **160** through use of the MRCS **167** technique), and a value of a third dimension for the pixel can be based upon an M CCD image product (generated by the artifact reduction component **160** through use of the M CCD technique **168**). The pixel can also have range and azimuth dimensions assigned thereto. Accordingly, the artifact reduction component **160** can generate the artifact-reduced image product **165** such that each pixel has values for an n-dimensional vector assigned thereto, where n is a positive integer.

As previously mentioned, the segmentation component **170** can segment the artifact-reduced SAR image product **165** based upon values of the n-dimensional vector for each pixel in the artifact-reduced SAR image product **165**. For example, the segmentation component **170** can employ a distance-based technique when segmenting the artifact-reduced SAR image product **165**, such as the QUICK-SHIFT algorithm. Execution of the QUICK-SHIFT algorithm over the artifact-reduced SAR image product **165** causes the artifact-reduced SAR image product **165** to be segmented into superpixels, where each superpixel in the superpixels represents a region of the artifact-reduced SAR image product **165** that comprises pixels having similar intensities in close spatial proximity.

The QUICK-SHIFT algorithm forms a Parzen density estimate of spatial and intensity distance relationships between neighboring pixels in the artifact-reduced SAR image product **165**. The distance between pixels i and j, as shown in Eqn. 1, accounts for both difference in intensity and difference in spatial proximity between the two pixels. Per Eqn. 1, r_i is the row index, c_i is the column index and I_i is the intensity of pixel i:

$$d_{ij}^2 = (r_i - r_j)^2 + (c_i - c_j)^2 + (I_i - I_j)^2 \quad (1)$$

Eqn. 2 shows the local Parzen density estimate for a pixel i over a neighborhood N_{ij} , where σ is the Gaussian window width and W is the search window width.

$$p_i = \sum_{j \in N_{ij}} e^{-d_{ij}^2 / 2\sigma^2} \quad (2)$$

The Parzen density estimate produces larger values for pixels whose close neighbors have similar intensities. FIG. 5A presents a conceptual representation of the Parzen density over the row and column grid space comprising a plurality of high intensity regions **510** and lower intensity regions **515**.

In contrast to gradient search algorithms, which iteratively compute gradients in the direction of a local maximum, a QUICK-SHIFT technique constrains its search to pass through image pixels. For each pixel in the artifact-reduced product **165**, QUICK-SHIFT searches a local region to find a “parent” pixel, one that has higher density than itself and closest distance within the search region. FIG. **5B**, image **520**, illustrates Parzen density contours with dots **525** that indicate the locations of image data pixels. The arrows **526** respectively indicate the association between each pixel, at the tail, and its parent, at the head. Some pixels are self-parents with no tails because they represent local density maxima. Then, each pixel follows parents-of-parents, creating a chain of associations, until it reaches a parent with largest local density. FIG. **5C** depicts an example of this second search step, which finds two parent-of-parent pixels indicated by boldface x’s, **535**. All pixels associated with each local maximum form the corresponding superpixel, where pixels labeled with “1” correspond to one local maximum and pixels labeled with “2” correspond to the other local maximum. By searching for local parent pixels with higher density, QUICK-SHIFT avoids computationally expensive gradient calculations, but still achieves a constrained locally optimal solution. Computational complexity of QUICK-SHIFT is $O(N^2)$.

The SLIC algorithm implements a localized k-means algorithm with a distance metric that depends on both spatial and intensity differences. The Euclidean spatial distance between pixels i and j is provided in Eqn. 3:

$$d_{ij} = \sqrt{(r_i - r_j)^2 + (c_i - c_j)^2} \quad (3)$$

Euclidean intensity distance for 3-channel intensities with weighting factors is provided in Eqn. 4:

$$d_{ij} = \sqrt{w_1(I_{1i} - I_{1j})^2 + w_2(I_{2i} - I_{2j})^2 + w_3(I_{3i} - I_{3j})^2} \quad (4)$$

In an example, $w_1 = w_2 = w_3 = 1$, although other values are possible, and more or fewer dimensions are contemplated. In an embodiment, per the foregoing, any combination of SA-ML **166** image product, the MRCS **167** image product, and/or the MCCD **168** image product can be selected by the segmentation component **170** as one, two, or three input channels for SLIC segmentation. The input channels can be scaled to similar magnitude ranges with equal weightings. If a particular channel(s) (e.g., any of the SA-ML **166** image product, the MRCS **167** image product, and/or the MCCD **168** image product) is deemed to be more important than another(s), the weightings can be adjusted accordingly. Further, the channel inputs can be weighted to scale a parameter (e.g., amplitude) to a similar range(s). When applying SLIC to either SA-ML or MRCS products, log-magnitude can be first computed. Applying the Euclidean distance in the log-magnitude domain is equivalent to a ratio-intensity distance in the magnitude domain.

As previously mentioned, an n -dimensional vector can also be generated with one of the input channels utilizing IF-H map data. To avoid IF-H map data dominating a superpixel segmentation operation, a weight can be assigned to the IF-H input channel (e.g., a weighting that is eight times smaller than applied to the other product input channels). MLIF indicates a combination of SA-ML and IF-H product inputs, and MLMCIF indicates a combination of SA-ML, MCCD and IF-H product inputs.

Eqn. 5 illustrates how a SLIC-based technique combines spatial and intensity distances together to create its distance measure, which depends on a compactness parameter, m , and an initial superpixel grid spacing parameter, S , where $S =$

$\sqrt{N/k}$, where N is a number of pixels in the artifact-reduced product **165** and k is an initial number of superpixels:

$$D_{ij} = d_{lij} + \frac{m}{S} d_{sij} \quad (5)$$

Because, the k-means algorithm can produce different cluster results with different cluster center initializations, SLIC-based technique deterministically initializes cluster centers to local minima of the intensity gradient. FIG. **6A**, image **600**, presents a conceptual representation of intensity gradient contours **610**. Dots **620** represent the pixel data locations and boldface x’s **630** indicate the initial cluster centers located at two local gradient minima. After initialization, the SLIC-based technique ignores the intensity gradient contours **610**. SLIC computes distances between every pixel **620** and every cluster center **630** within a local $2S \times 2S$ area. FIG. **6B**, image **6B**, illustrates that, for each pixel **620**, SLIC finds the closest local cluster center **630** and assigns the respective pixel **620** to it. The SLIC algorithm iterates between assigning pixels to closest clusters and updating cluster means. The SLIC algorithm iterates until the change in cluster center means falls below a preset threshold. Initializing cluster centers to the local intensity gradient facilitates speedy convergence, as does confining each search to a local area. Computational complexity of SLIC is $O(N)$.

Any suitable values can be utilized for the QUICK-SHIFT techniques and the SLIC-based techniques, wherein selected values can be a compromise between fidelity in representing various features in the scene **115** and sufficient size to provide accurate statistical estimates for later classification and reasonable computational complexity. For example, values of $\sigma=8$ and $w=10$ can be utilized for QUICK-SHIFT techniques. While, for example, values of $S=50K$, $25K$ or $10K$ can be utilized, along with $m=10$.

For understanding, FIGS. **7A-7D** pertain to analysis of a scene comprising a drainage ditch **712** located between a road **714** and a field **716**, wherein, per the MRCS image (FIG. **7A**, image **710**) the location of the drainage ditch **712** has been outlined by a hand-labelled ground truth **718**. FIGS. **7A-7D** indicate respective segmentation generated by way of different operations. FIG. **7B**, image **720**, illustrates superpixels **725** obtained by applying a QUICK-SHIFT-based technique, where $\sigma=8$ and $w=10$. FIG. **7C**, image **730**, illustrates superpixels **735** obtained by applying a SLIC-based technique, where $S=25K$ and $m=10$. As shown in FIG. **7C**, the SLIC-based technique produces more compact superpixels **735** that conform more readily to the shape of the drainage ditch **712** than the superpixels **725** which are generated via the QUICK-SHIFT-based technique (referenced in FIG. **7B**). Further, the superpixels **735** of FIG. **7C** are also more uniformly sized, which can be an advantage for making statistical comparisons.

To correctly map the roadside drainage ditch **712** can be a challenge owing to the drainage ditch **712** having low contrast compared to the background field **716**. Accordingly, superpixelation can be improved by including height information into the SPS segmentation. FIG. **7D**, image **740**, illustrates the resulting superpixels **745** achieved when the artifact-reduced product **165** is based upon both SA-ML and IF-H products, where $S=25K$ and $m=10$. As shown in FIG. **7D**, adding the interferometric height information improves the ability of the superpixels to represent two of the three

arms of the drainage ditch **712** when compared with the superpixels **725** and **735** in respective images **7B** and **7C**.

The artifact reduction component **160** and the segmentation component **170** can operate in unison to select and utilize one or more of the imaging processes SA-ML imaging **166**, MCCD imaging **167**, or MRCS imaging **16** (or other suitable data). For example, a product of SA-ML imaging **166** can contain lower spatial frequencies which yield superpixels having smoother edges, which can be advantageous when attempting to represent edges of a man-made structure(s) that may be included in the scene **115**. Further, it is possible to utilize SA-ML-derived superpixels to process data from any of the other image products, as long as they are co-registered. For example, if multiple images are not available from the same scene **115** to compute a temporal multilook MRCS image **168** products, it is possible to create superpixels from an SA-ML image **166** and then apply them to a co-registered MRCS image. In another example, it is possible to compute superpixel histograms from higher resolution MRCS pixels located inside SA-ML superpixels. Such histograms can be useful for classifying surfaces in a SAR image (e.g., any of SAR images **141-143**, registered SAR images **146-148**, etc.).

FIGS. **8A-8D** present respective images for comparison of superpixels derived from different SAR imaging inputs. FIG. **8A** presents a SPS image **810** formed with the segmentation component **170** utilizing SLIC processing in conjunction with MRCS imaging **168**, wherein the SPS image **810** comprises segments **812** having respective boundaries **814**, wherein the segments **812** are formed in conjunction with superpixels in a superpixel image **175**.

FIG. **8B** presents a SPS image **820** formed with the segmentation component **170** utilizing SLIC processing in conjunction with MCCD imaging **167**. Because a MCCD image product represents a different physical phenomenon than RCS-based image products, superpixel segmentation utilizing a MCCD image product can emphasize different structural features. The SPS image product **820** comprises segments **822** having respective boundaries **824**. Boundaries **824** of MCCD-based superpixels **822** can be contorted to conform to the local variability of the MCCD image product.

FIG. **8C** presents an SPS image **830** formed with the segmentation component **170** utilizing SLIC processing in conjunction with SA-ML imaging **166** combined with MCCD imaging **167** at two channels of the SLIC algorithm. The SPS image **830** comprises segments **832** having respective boundaries **834**. The SA-ML image product and the MCCD image product are scaled to similar ranges and equally weighted.

FIG. **8D** presents an SPS image **840** formed with the segmentation component **170** utilizing SLIC processing in conjunction with SA-ML imaging **166** combined with MCCD imaging **167** and further IF-H imaging **169** at three channels at the input of SLIC algorithm, wherein the IF-H imaging **169** enables height discrimination (e.g., for the previously mentioned drainage ditch). SPS image **840** comprises segments **842** having respective boundaries **844**.

FIG. **9** illustrates an exemplary methodology **900** relating to segmenting a SAR image. While the methodology is shown and described as being a series of acts that are performed in a sequence, it is to be understood and appreciated that the methodologies are not limited by the order of the sequence. For example, some acts can occur in a different order than what is described herein. In addition, an act can occur concurrently with another act. Further, in some instances, not all acts may be required to implement the methodology described herein.

Moreover, the acts described herein may be computer-executable instructions that can be implemented by one or more processors and/or stored on a computer-readable medium or media. The computer-executable instructions can include a routine, a sub-routine, programs, a thread of execution, and/or the like. Still further, results of acts of the methodology can be stored in a computer-readable medium, displayed on a display device, and/or the like.

At **910**, a plurality of SAR images can be received, wherein the plurality of SAR images have been generated based upon a plurality of aircraft flybys over a common scene.

At **920**, a baseline SAR image is selected from the plurality of received SAR images.

At **930**, respective images in the plurality of received SAR images can be registered with the baseline image to form one or more registered SAR images.

At **940**, one or more SAR imaging processes are applied to the one or more registered SAR images to product an artifact-reduced SAR image product. As previously described, an originally received SAR image can include speckle, wherein the speckle can impact segmentation of the original SAR image. Accordingly, any of a SA-ML technique, a MCCD technique, a MRCS technique, or other suitable technique can be applied to the registered SAR image (or images) to generate an artifact-reduced SAR image product. The plurality of registered SAR images can be arranged to form a registered SAR image stack.

At **950**, a SPS process can be performed on the artifact-reduced SAR image product to generate a segmented image product. The segmentation process can utilize any suitable SPS process such as SLIC, QUICK-SHIFT, etc.

At **970**, segments of the segmented superpixel image product can be applied to any of the originally received SAR images to segment the originally received SAR images into a plurality of segments.

At **980**, a segment in the originally received SAR image can be assigned a label based upon pixel values in the segment. For instance, a classifier can be trained to identify a particular object, feature, or the like, and can label a segment as including (or not including) the feature based upon pixel values in the segment.

Referring now to FIG. **10**, a high-level illustration of an exemplary computing device **1000** that can be used in accordance with the systems and methodology disclosed herein is illustrated. For example, the computing device **1000** may be utilized to generate any of an artifact-reduced product **165**, a segmented image product **175**, a segmented SAR image **185**, etc. For example, computing device **1000** can operate as the classification device **151**, or a controller (associated with) the radar system **120**. The computing device **1000** includes at least one processor **1002** that executes instructions that are stored in a memory **1004**. The instructions may be, for instance, instructions for implementing functionality described as being carried out by one or more components discussed above or instructions for implementing one or more of the methods described above. The processor **1002** may access the memory **1004** by way of a system bus **1006**. In addition to storing executable instructions, the memory **1004** may also store image products, SAR data, etc.

The computing device **1000** additionally includes a data store **1008** that is accessible by the processor **1002** by way of the system bus **1006**. The data store **1008** may include executable instructions, image products, SAR data, etc. The computing device **1000** also includes an input interface **1010** that allows external devices to communicate with the com-

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puting device **1000**. For instance, the input interface **1010** may be used to receive instructions from an external computer device, from a user, etc. The computing device **1000** also includes an output interface **1012** that interfaces the computing device **1000** with one or more external devices. For example, the computing device **1000** may display text, images, etc., by way of the output interface **1012**.

Additionally, while illustrated as a single system, it is to be understood that the computing device **1000** may be a distributed system. Thus, for instance, several devices may be in communication by way of a network connection and may collectively perform tasks described as being performed by the computing device **1000**.

Various functions described herein can be implemented in hardware, software, or any combination thereof. If implemented in software, the functions can be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Computer-readable media includes computer-readable storage media. A computer-readable storage media can be any available storage media that can be accessed by a computer. By way of example, and not limitation, such computer-readable storage media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. Disk and disc, as used herein, include compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk, and blu-ray disc (BD), where disks usually reproduce data magnetically and discs usually reproduce data optically with lasers. Further, a propagated signal is not included within the scope of computer-readable storage media. Computer-readable media also includes communication media including any medium that facilitates transfer of a computer program from one place to another. A connection, for instance, can be a communication medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio and microwave are included in the definition of communication medium. Combinations of the above should also be included within the scope of computer-readable media.

What has been described above includes examples of one or more embodiments. It is, of course, not possible to describe every conceivable modification and alteration of the above structures or methodologies for purposes of describing the aforementioned aspects, but one of ordinary skill in the art can recognize that many further modifications and permutations of various aspects are possible. Accordingly, the described aspects are intended to embrace all such alterations, modifications, and variations that fall within the spirit and scope of the appended claims. Furthermore, to the extent that the term “includes” is used in either the details description or the claims, such term is intended to be inclusive in a manner similar to the term “comprising” as “comprising” is interpreted when employed as a transitional word in a claim.

What is claimed is:

1. A system comprising:

an antenna that is configured to receive radar signals that have reflected off of a scene;
a processor; and

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memory that comprises components that are executed by the processor, the components comprising:

a registration component that is configured to register a baseline synthetic aperture radar (SAR) image with a plurality of SAR images to create a stack of co-registered SAR images, wherein the plurality of SAR images are generated based upon the radar signals received by the antenna;

an artifact reduction component that is configured to perform a speckle-reduction operation on at least one SAR image in the stack of co-registered SAR images to form an artifact-reduced SAR image product, a first number of artifacts in the artifact-reduced SAR image product is less than a second number of artifacts in the at least one SAR image;

a segmentation component that is configured to form a segmented SAR image product by segmenting the artifact-reduced SAR image product into a plurality of superpixels based upon values of pixels in the artifact-reduced SAR image product; and

apply boundaries of the superpixels to the at least one SAR image to segment the at least one SAR image into a plurality of segments, such that the plurality of segments respectively correspond to the plurality of superpixels in the segmented SAR image product; and

a classifier component that is configured to assign a label to a segment in the plurality of segments in the at least one SAR image based upon pixel values in the segment, the label indicative of an identity of an object or feature captured in the at least one SAR image.

2. The system of claim 1, the artifacts being speckle.

3. The system of claim 2, the artifact reduction component is configured to utilize at least one of a sub-aperture multi-look (SA-ML) imaging process, a mean-over-time of coherent change detection (MCCD) imaging process, or a median-over-time of radar cross section (MRCS) imaging process to form the artifact-reduced SAR image product.

4. The system of claim 3, the artifact reduction component further configured to form the artifact-reduced SAR image product such that each pixel in the artifact-reduced SAR image product is assigned values for an n-dimensional vector, the n-dimensional vector is formed based upon the SA-ML imaging process, the MCCD imaging process, or the MRCS imaging process.

5. The system of claim 1, the segmentation component is configured to utilize one of QUICK-SHIFT or simple linear iterative clustering (SLIC) to segment the artifact-reduced SAR image product into the plurality of superpixels.

6. The system of claim 5, the artifact-reduced SAR image product is further based upon application of an interferometric height (IF-H) mapping process to the at least one SAR image.

7. The system of claim 1, further comprising a radar system that comprises the antenna, the radar system is configured to generate SAR data as the radar system passes over the scene, the at least one SAR image is based upon the SAR data.

8. The system of claim 1, the classifier component assigns the label to the segment based upon comparing the pixel values in the segment with pre-classified data.

9. The system of claim 1, the registration component is further configured to resample a first SAR image in the plurality of SAR images to cause the first SAR image to

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comprise a same number of pixels as a second SAR image in the plurality of SAR images.

10. A method, comprising:

receiving, at an antenna of a radar system, radar signals that have reflected off of a scene, wherein a plurality of synthetic aperture radar (SAR) images are generated based upon the radar signals received at the antenna; registering the plurality of SAR images to form a stack of registered SAR images;

generating an artifact-reduced SAR image product based upon at least one registered SAR image from the stack of registered SAR images, the artifact-reduced SAR image product comprises fewer artifacts than the at least one registered SAR image;

segmenting the artifact-reduced SAR image product into a plurality of superpixels to form a superpixel image product;

applying boundaries of the superpixels to the at least one registered SAR image to form a segmented SAR image, the segmented SAR image comprises a plurality of segments that correspond to the superpixels of the superpixel image product; and

assigning a label to a segment in segmented SAR image based upon values of pixels in the segment, the label indicative of an identity of an object or feature captured in at least one image in the plurality of SAR images.

11. The method of claim **10**, the artifacts being speckle.

12. The method of claim **10**, wherein generating the artifact-reduced image product comprises performing at least one of a sub-aperture multilook (SA-ML) imaging process, a mean-over-time of coherent change detection (MCCD) imaging process, or a median-over-time of radar cross section (MRCS) imaging process to the at least one registered SAR image.

13. The method of claim **12**, each pixel in the artifact-reduced SAR image product has a n-dimensional vector assigned thereto, values of the n-dimensional vector are based upon at least one of the SA-ML imaging process, the MCCD imaging process, or the MRCS imaging process.

14. The method of claim **10**, wherein segmenting the artifact-reduced SAR image product into the plurality of superpixels comprises utilizing at least one of QUICK-SHIFT or simple linear iterative clustering (SLIC) to segment the artifact-reduced SAR image product into the plurality of superpixels.

15. The method of claim **10**, wherein generating the artifact-reduced SAR image product comprises:

acquiring interferometric height (IF-H) data for the at least one registered SAR image; and

generating the artifact-reduced SAR image product based upon the IF-H data.

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16. The method of claim **10**, wherein registering the plurality of SAR images comprises resampling a first SAR image in the plurality of SAR images to cause the first SAR image to comprise a same number of pixels as a second SAR image in the plurality of SAR images.

17. A non-transitory computer-readable storage medium comprising instructions that, when executed by a processor, cause the processor to perform acts comprising:

generating a plurality of synthetic aperture radar (SAR) images based upon radar signals received by an antenna of a radar system, wherein the radar signals have been directed towards a scene and have reflected off of the scene prior to being received by the antenna;

registering the plurality of SAR images to form a stack of registered SAR images;

applying a speckle reduction algorithm to at least one registered SAR image in the stack of registered SAR images to form an artifact-reduced SAR image product, the artifact-reduced SAR image product comprises fewer artifacts than the at least one registered SAR image;

segmenting the artifact-reduced SAR image product into a plurality of superpixels to form a superpixel image product;

applying boundaries of the superpixels in the superpixel image product to the at least one registered SAR image to form a segmented SAR image that comprises a plurality of segments, the plurality of segments respectively correspond to the plurality of superpixels; and assigning a label to a segment in the plurality of segments based upon values of pixels in the segment, the label indicative of an identity of an object or feature captured in at least one SAR image in the plurality of SAR images.

18. The computer-readable storage medium of claim **17**, the speckle reduction algorithm is one of a sub-aperture multilook (SA-ML) imaging algorithm, a mean-over-time of coherent change detection (MCCD) imaging algorithm, or a median-over-time of radar cross section (MRCS) imaging algorithm.

19. The computer-readable storage medium of claim **17**, the artifacts being speckle.

20. The computer-readable storage medium of claim **17**, wherein registering the plurality of SAR images comprises resampling a first SAR image in the plurality of SAR images to cause the first SAR image to comprise a same number of pixels as a second SAR image in the plurality of SAR images.

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