

**ENVIRONMENTAL CONDITION DETECTING SYSTEM  
USING GEOSPATIAL IMAGES AND ASSOCIATED METHODS**

**Field of the Invention**

**[0001]** The present invention relates to the field of image processing, and, more particularly, to geospatial image processing and related methods.

**Background of the Invention**

**[0002]** As discussed in the background of U.S. Patent No. 6,654,690 to Rahmes et al. and assigned to the assignee of the present invention, topographical models of geographical areas may be used for many applications. For example, topographical models may be used in flight simulators and for planning military missions. Furthermore, topographical models of man-made structures (e.g., cities) may be extremely helpful in applications such as cellular antenna placement, urban planning, disaster preparedness and analysis, and mapping, for example.

**[0003]** Various types and methods for making topographical models are presently being used. One common topographical model is the digital elevation map (DEM). A DEM is a sampled matrix representation of a geographical area that may be generated in an automated fashion by a computer. In a DEM, co-ordinate points are made to correspond with a height value. DEMs are typically used for modeling terrain where the transitions between

different elevations (e.g., valleys, mountains, etc.) are generally smooth from one to a next. That is, DEMs typically model terrain as a plurality of curved surfaces and any discontinuities therebetween are thus "smoothed" over. For this reason, DEMs generally are not well suited for modeling man-made structures, such as skyscrapers in a downtown area, with sufficient accuracy for many of the above applications.

**[0004]** Another approach to producing topographical models has been developed by the Harris Corporation, assignee of the present invention, and is commercially referred to as RealSite®. RealSite® provides a semi-automated process for making three-dimensional (3D) topographical models of geographical areas, including cities, that have accurate textures and structure boundaries. Moreover, RealSite® models are geospatially accurate. That is, the location of any given point within the model corresponds to an actual location in the geographical area with very high accuracy (e.g., within a few meters). The data used to generate RealSite® models may include aerial and satellite photography, electro-optical, infrared, and light detection and ranging (LIDAR).

**[0005]** RealSite® models not only provide enhanced accuracy over prior automated methods (such as automated DEM generation), but since they are produced using a semi-automated computer process they may be created much more rapidly than comparable manually rendered models. Yet, even though the RealSite® model generation process begins with actual data of a geographic location, some user delineation may be required to distinguish objects within an input data set before automated computer algorithms can render the final models. Thus, producing RealSite® models

for large geometric areas of several kilometers, for example, may require a significant amount of time and labor.

**[0006]** Accordingly, U.S. Patent No. 6,654,690 discloses a significant advance of an automated method for making a topographical model of an area including terrain and buildings thereon based upon randomly spaced data of elevation versus position. The method may include processing the randomly spaced data to generate gridded data conforming to a predetermined position grid, processing the gridded data to distinguish building data from terrain data, and performing polygon extraction to make the topographical model of the area including terrain and buildings thereon.

**[0007]** Change detection is an important part of many commercial Geographic Information Systems (GIS)-related applications. Moreover, given the recent explosion of available imagery data and the increasing number of areas-of-interest throughout the world, the trend is towards rapid, automated change detection algorithms. To make effective use of these imagery databases care should generally be taken that the newly collected imagery match the existing/reference imagery's characteristics such as coverage, field-of-view, color, and most notably, sensor location and viewpoint.

**[0008]** Unfortunately, this presents a difficulty since in many cases it is time-consuming, very difficult or even impossible to replicate the original collection scenario due to: sensor-scheduling (in the case of space-based), cost of re-flying the sensor (in the case of aerial-based), or that the sensor is no longer in use (both cases). Thus large amounts of collected imagery may go underutilized in regards to change detection.

**[0009]** The current state of the art in change detection involves either: (1) geo-registering two images (reference and new collect images) together so that the automated change detection algorithms will have a high rate of success, or (2) performing sophisticated pixel-correlation change detection algorithms that tend to be slow, iterative in nature, and manually intensive, since the algorithms often need to be tweaked between runs. The first case requires a high degree of correlation in the location and parameters of the sensor, or sensors, if they are different between the two collects. The second case does not require as high a degree of correlation although some is still needed, but it is neither automated nor fast. Neither approach is satisfactory.

**[0010]** An article by Walter entitled "Automated GIS Data Collection and Update," pp. 267-280, 1999, examines data from different sensors regarding their potential for automatic change detection. Along these lines an article entitled "Automatic Change Detection of Urban Geospatial Databases Based on High Resolution Satellite Images Using AI Concepts" to Samadzadegan et al. discloses an automatic change detection approach for changes in topographic urban geospatial databases taking advantage of fusion of description and logical information represented on two levels. U.S. Patent No. 6,904,159 discloses identifying moving objects in a video using volume growing and change detection masks. U.S. Patent No. 6,243,483 discloses a mapping system for the integration and graphical display of pipeline information that enables automated pipeline surveillance.

**[0011]** Accordingly, although a growing body of geospatial scene model data exists, it has not yet been exploited in the area of automated change detection of

sensor images.

### **Summary of the Invention**

**[0012]** In view of the foregoing background it is therefore an object of the present invention to provided a environmental condition detecting system to detect at least one environmental condition associated with a collected geospatial image from a geospatial image sensor carried by an airborne platform, wherein the system is accurate and efficient.

**[0013]** This and other objects, features and advantages in accordance with the present invention are provided by an environmental condition detecting system comprising an image processor cooperating with a database for generating a reference geospatial image corresponding to the collected geospatial image, a change detector cooperating with the image processor for detecting a change between the collected geospatial image and the reference geospatial image, and an environmental condition detector.

Moreover, the environmental condition detector may cooperate with the change detector for detecting the at least one environmental condition associated with the collected geospatial image based upon the change between the collected geospatial image and the reference geospatial image.

**[0014]** The at least one environmental condition may comprise at least one weather condition, such as, for example, at least one of image obscuration and surface reflectivity. The at least one environmental condition may additionally or alternatively comprise at least one of a time of day and a time of year.

**[0015]** The database may comprise a geospatial scene model database, for example. In addition, the geospatial

scene model database may comprise three-dimensional (3D) scene model data, and the collected geospatial image and the reference geospatial image may each comprise respective two-dimensional (2D) image data.

**[0016]** The geospatial scene model database may comprise at least one of terrain data, building data, and foliage data. Moreover, the collected geospatial image may have at least one geospatial collection value associated therewith. Accordingly, the image processor may generate the reference geospatial image based upon synthetically positioning a virtual geospatial image sensor within a geospatial scene model based upon the at least one geospatial collection value. For example, the at least one geospatial collection value may comprise at least one of a geospatial collection position, a geospatial collection orientation, and a geospatial collection field-of-view.

**[0017]** A method aspect of the invention is directed to an environmental condition detecting method to detect at least one environmental condition associated with a collected geospatial image from a geospatial image sensor carried by an airborne platform. The environmental condition detecting method may comprise using an image processor cooperating with a database for generating a reference geospatial image corresponding to the collected geospatial image; detecting a change between the collected geospatial image and the reference geospatial image; and detecting the at least one environmental condition associated with the collected geospatial image based upon the change between the collected geospatial image and the reference geospatial image.

**Detailed Description of the Preferred Embodiments**

**[0018]** The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout, and prime notation is used to indicate similar elements in alternative embodiments.

**[0019]** Referring initially to FIG. 1, an image change detecting system **20** is initially described. As shown in the illustrated embodiment, the image change detecting system **20** comprises an image processor **25** cooperating with a geospatial scene model database **30** for generating a reference geospatial image **26** corresponding to the collected geospatial image **42**. The system **20** also includes a change detector **35** cooperating with the image processor **25** for detecting a change between the collected geospatial image **42** and the reference geospatial image **26**. The collected geospatial image **42** is generated by an image sensor carried by the schematically illustrated airborne platform **41**. As will be appreciated by those skilled in the art, the airborne platform **41** may be an airplane, helicopter, unmanned aerial device, lighter-than-air aircraft, satellite etc. Representative examples of collected and reference geospatial images **42**, **26** are described in greater detail below.

**[0020]** The geospatial scene model database **30** may

comprise three-dimensional (3D) scene model data, and the collected geospatial image and the reference geospatial image may each comprise respective two-dimensional (2D) image data. The geospatial scene model database **30** may be especially advantageous for providing accurate change detection in an efficient manner.

**[0021]** The collected geospatial image **42** may have at least one geospatial collection value associated therewith. Accordingly, the image processor **25** may generate the reference geospatial image **26** based upon synthetically positioning a virtual geospatial image sensor within a geospatial scene model extracted from the geospatial scene model database **30** based upon the at least one geospatial collection value. This type of model extraction and synthetic sensor positioning will be readily understood by those skilled in the art and needs no further discussion herein. For example, the at least one geospatial collection value may include at least one of a geospatial collection position, a geospatial collection orientation, and a geospatial collection field-of-view.

**[0022]** These geospatial collection values may be provided from the image sensor **40** and/or the airborne platform **41** as will also be appreciated by those skilled in the art. The particular collected geospatial image **42** will have such values associated therewith. Of course, as the airborne platform moves over its flight path above the ground **44**, a plurality of such collected geospatial images **42** may be generated. For clarity of explanation, the description provided herein is directed to a single collected geospatial image **42** and those skilled in the art will readily appreciate its application to multiple collected geospatial images. The airborne platform **41**



will typically include a GPS and/or inertial navigation equipment, not shown, that can provide the position and orientation information associated with the collected geospatial image **42**.

**[0023]** Alternatively or in addition to the geospatial collection value, the collected geospatial image may have at least one image sensor parameter associated therewith. Accordingly, the image processor may generate the reference geospatial image based upon synthetically positioning a virtual geospatial image sensor having the at least one image sensor parameter within a geospatial scene model. For example, the at least one image sensor parameter may include at least one of a sensor wavelength range, a sensor polarization, and a sensor pixel characteristic.

**[0024]** The sensor wavelength range may be in the visible, infrared, ultraviolet range, or RF ranges such as for synthetic aperture radar (SAR) image sensing, for example. The polarity may be selected to be horizontal or vertical or some combination thereof, such as to control reflections from certain types of surfaces. The sensor pixel characteristic may be a color assigned to a pixel value, for example, or may be a pixel size or aspect ratio. Those of skill in the art will appreciate yet further image sensor parameters that may be inherent or attributed to the collected geospatial image **42**. One or more of such image sensor parameters may be taken into account by the image processor **25**, such as by modifying the data extracted from the geospatial scene model database **30** to produce the reference geospatial image **26** that may more closely match the collected geospatial image **42**. Accordingly, the accuracy and efficiency of the image change detector **35** may be increased.

**[0025]** The geospatial scene model database **30** may comprise a light detection and ranging (LIDAR) geospatial scene model database, although other similar databases may also be used. Suitable models may include RealSite models, LiteSite (LIDAR and IFSAR) models, high-resolution digital elevation models (DEMS), etc. The geospatial scene model database **30** may comprise, for example, at least one of terrain data, building data, and foliage data as will be appreciated by those skilled in the art. As will be readily appreciated by those skilled in the art, the available pool of accurate, georeferenced 3D scene models is rapidly increasing.

**[0026]** Referring now additionally to FIG. 2, the change detecting system **20'** illustratively includes the image processor **25'** cooperating with the database **30'** for generating a reference geospatial image **26'** corresponding to the collected geospatial image **42'**, an image enhancer **50'** for enhancing the reference geospatial image **26'** that is supplied to the change detector **35'**. As will be appreciated by those skilled in the art, the change detector **35'** may now detect a change between the collected geospatial image **42'** and the reference geospatial image **26'** with the reference geospatial image enhanced by the image enhancer **50'** based upon the at least one environmental condition. Accordingly, the change detection accuracy is enhanced.

**[0027]** In the change detection system **20'**, the image enhancer **50'** illustratively acts upon the geospatial reference image, however, in other embodiments, the image enhancer may operate on just the collected geospatial image **42'** or both of these images as will be appreciated by those skilled in the art. In other words, one or both

of the collected geospatial image and the reference geospatial image may be enhanced to facilitate accurate change detection based upon at least one environmental condition.

**[0028]** The at least one environmental condition may comprise at least one weather condition, such as relating to image obscuration and surface reflectivity, for example. The at least one environmental condition may comprise at least one of a time of day and a time of year that may effect the intensity of the image, shadow lengths, etc.

**[0029]** The image change detection system **20'** may use a database **30'**, such as the geospatial scene model database described above with its attendant features and advantages. In other embodiments, the database **30'** may be provided by an image and/or video database, for example, as will be appreciated by those skilled in the art.

**[0030]** Referring now additionally to the flowchart **60** of FIG. 3, various method aspects relating to image change detection are now explained. From the start at Block **62** the image sensor may be used to generate the collected geospatial image (Block **64**) and the geospatial collection values, and/or image sensor parameters (Block **66**).

Thereafter, at Block **68** the model and model type may be extracted from the geospatial scene model database with the result fed to Block **74** that generates the reference geospatial image. Optionally, at Block **70** the best environmental condition(s) may be determined or extracted and applied to generate the reference geospatial image at Block **74**. At Block **72** the virtual geospatial image sensor is synthetically positioned with the geospatial scene model and its output also fed to Block **74** to generate the reference geospatial image. At Block **76** the collected

geospatial image from Block **64** and the reference geospatial image from Block **74** are compared by any of the commonly available hardware/software to perform the change detection before stopping at Block **78**.

**[0031]** Referring now additionally to FIGS. 4-6, representative examples of image change detection systems **120**, **120'** and **120''** are now explained in greater detail. As seen in FIG. 4, the image change detecting system **120** includes a visible image sensor **140** pictorially and schematically illustrated as a camera that generates the collected geospatial image **142**. The visible image sensor **140** also generates the sensor model/location information as described above which is used to select the correct model and model type represented by the model scene portion **131**. The virtual sensor is synthetically positioned within the model scene producing the 3D reference image data **127**. Thereafter the sensor parameters are considered to produce the reference geospatial image **126**, and this reference geospatial image along with the collected geospatial image are processed by the automatic image change detector **135**.

**[0032]** The image change detection system **120'** in FIG. 5 is similar, however, the image sensor **140'** is a SAR image sensor as will be appreciated by those skilled in the art. The remainder of the blocks and representative scenes and images are indicated with prime notation, are similar to those of the system **120** described above with reference to FIG. 4, and require no further discussion herein.

**[0033]** Similarly, the image change detection system **120'** in FIG. 5 is similar, however, the image sensor **140'** is an infrared (IR) image sensor as will be appreciated by those skilled in the art. The remainder of the blocks and

representative scenes and images are indicated with prime notation, are similar to those of the system **120** described above with reference to FIG. 4, and require no further discussion herein.

**[0034]** Referring now additionally to FIG. 7 an accuracy enhancing system **220** is now described incorporating and building upon the image change detection concepts described above. More particularly, the accuracy enhancing system **220** illustratively includes an image processor **225** cooperating with a database **230** for generating a reference geospatial image **226** corresponding to the collected geospatial image **242** from the image sensor **240** carried by the airborne platform **241**. The system **220** also includes an image change detector **235** cooperating with the image processor **225** for detecting a change between the collected geospatial image **242** and the reference geospatial image **226**. In addition, the system **230** also includes an accuracy enhancer **255** that may cooperate with the change detector **235** for generating at least one enhanced accuracy value corresponding to at least one geospatial collection value based upon the change detected between the collected geospatial image and the reference geospatial image.

**[0035]** The airborne platform **241** may traverse an actual flight path over the scene **244** based upon a planned flight path. Accordingly, the image processor **225** may generate the reference geospatial image **226** based upon correlation of the actual flight path with the planned flight path. For example, the image processor **225** may generate the closest reference image from the database **230** to the collected geospatial image **242** such as based upon receiving a GPS position from the airborne platform **241** as

will be appreciated by those skilled in the art. In other words, an alignment disparity may be minimized to determine the closest reference geospatial image **226**.

**[0036]** The at least one geospatial collection value may comprise a geospatial collection sensor position. This may be beneficial to correct a measured position of the airborne platform **241**, such as based upon its inertial navigation and/or GPS equipment. The at least one geospatial collection value may alternatively or additionally comprise a geospatial collection sensor orientation or a geospatial collection sensor field-of-view. Enhancement of one or both of these values in addition to the position, for example, may enhance sensor data collection accuracy as will be appreciated by those skilled in the art.

**[0037]** As noted above, the database **230** may comprise a geospatial scene model database in some advantageous embodiments. The geospatial scene model database may comprise three-dimensional (3D) scene model data, and the collected geospatial image and the reference geospatial image may each comprise respective two-dimensional (2D) image data. The geospatial scene model database may comprise at least one of terrain data, building data, and foliage data, as noted above. More particularly, the collected geospatial image may have at least one geospatial collection value associated therewith. Accordingly, the image processor **225** may generate the reference geospatial image based upon synthetically positioning a virtual geospatial image sensor within a geospatial scene model based upon the at least one geospatial collection value as also described above. The at least one geospatial collection value may include at least one of a geospatial collection position, a

geospatial collection orientation, and a geospatial collection field-of-view, for example.

**[0038]** The accuracy enhancing system is explained now in greater detail with exemplary images as shown in FIG. 8. The accuracy enhancing system **220** generates the collected image **242** from the image sensor **240**. In addition, the closest image is selected as the reference geospatial image **226** (location or position wise) by the image processor **225** (FIG. 7). This reference geospatial image **226** is selected from a series of pre-extracted geospatial images **226a-226n** within the database **230**. The pre-extracted geospatial images **226a-226n** may be from ground and/or airborne collection platforms as will be appreciated by those skilled in the art.

**[0039]** Referring now additionally to FIG. 9, another advantageous environmental condition detecting system **320** is now described and operates based upon the principles and features described above. In particular, the environmental condition detection system **320** may be considered as operating conversely to the image change detecting systems **20'**, **120**, **120'** and **120''** including an input for one or more environmental conditions, as described above with reference to FIGS. 2-6. In the illustrated environmental condition detecting system **320** the image sensor **340** aboard the airborne platform **341** generates the collected imaged **342**, and the image processor **325** cooperates with the database **330** for generating a reference geospatial image **326** corresponding to the collected geospatial image. The change detector **335**, in turn, cooperates with the image processor **325** for detecting a change between the collected geospatial image **342** and the reference geospatial image **326**. Lastly, an

environmental condition detector **367** may cooperate with the change detector **335** for detecting the at least one environmental condition associated with the collected geospatial image **342** based upon the change between the collected geospatial image and the reference geospatial image **326**.

**[0040]** As will be appreciated by those skilled in the art, the at least one environmental condition may comprise at least one weather condition, such as, for example, at least one of image obscuration and surface reflectivity. The at least one environmental condition may additionally or alternatively comprise at least one of a time of day and a time of year.

**[0041]** The database **330** may comprise a geospatial scene model database. The geospatial scene model database may comprise three-dimensional (3D) scene model data, and the collected geospatial image **342** and the reference geospatial image **326** may each comprise respective two-dimensional (2D) image data. As noted above, the geospatial scene model database **330** may comprise at least one of terrain data, building data, and foliage data. Also, the collected geospatial image **342** may have at least one geospatial collection value associated therewith. Accordingly, the image processor **325** may generate the reference geospatial image **326** based upon synthetically positioning a virtual geospatial image sensor within a geospatial scene model based upon the at least one geospatial collection value. For example, the at least one geospatial collection value may comprise at least one of a geospatial collection position, a geospatial collection orientation, and a geospatial collection field-of-view. Considered in slightly different terms, disclosed herein are automated systems and methods relating to



performing change detection algorithms whereby a collected geospatial image is compared to a reference geospatial image extracted from a pre-existing 3D scene model through a synthetic camera which is created and placed in the scene in such a way as to match the collected image sensor's location and parameterization (e.g. field-of-view, hyperspectral vs. monochromatic, etc.). Further, relevant known "real-world" phenomenology such as atmospheric and time-of-day effects, overall ground lighting/reflectivity properties (e.g. ocean vs. dense forest) can be simulated in the scene before the reference geospatial image is used for change detection to thereby improve results. The disclosed systems and methods may permit total freedom in virtual sensor positioning for reference image extraction, total freedom in sensor parameterization (i.e. sensor modeling) including spectral components. Other aspects of the systems and method disclosed herein may be understood with reference to related copending applications entitled: "ACCURACY ENHANCING SYSTEM FOR GEOSPATIAL COLLECTION VALUE OF AN IMAGE SENSOR ABOARD AN AIRBORNE PLATFORM AND ASSOCIATED METHODS", having attorney work docket no. 51450, "GEOSPATIAL IMAGE CHANGE DETECTING SYSTEM WITH ENVIRONMENTAL ENHANCEMENT AND ASSOCIATED METHODS", having attorney work docket no. 51452, and "GEOSPATIAL IMAGE CHANGE DETECTING SYSTEM AND ASSOCIATED METHODS", having attorney work docket no. 51451, the entire disclosures of each of which are incorporated herein by reference.

**[0042]** The various databases, image processors, change detectors, and other components described herein may be implemented using programmable digital computing hardware and software as will be readily appreciated by those skilled in the art. Of course, dedicated circuit

components may also be used in some embodiments. In addition, many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.