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(54) Title of the Invention: **Hyperspectral imaging of a moving scene**
Abstract Title: **Hyperspectral imaging of a moving scene**

(57) An apparatus and method are disclosed for hyperspectral imaging of a scene along an imaging path, from a viewpoint, such as an aircraft 11, which is arranged to move relative to the scene. The method comprises acquiring hyperspectral image data of a portion of the scene 100 from the viewpoint, along a first viewing direction 14 relative to the viewpoint and redirecting the viewing direction from the first viewing direction to a second viewing direction 15 relative to the viewpoint, in dependence of the relative movement, to maintain a view of said portion of the scene as the viewpoint moves along a portion of the imaging path. The method may comprise further redirecting the viewing direction back to the first viewing direction 14. The hyperspectral image data may be acquired via a rotatable mirror (21a, Fig 2) arranged to reflect an image of the portion of the scene onto a hypespectral sensor (20, Fig 2). The second viewing direction 15 may be a rearward direction.

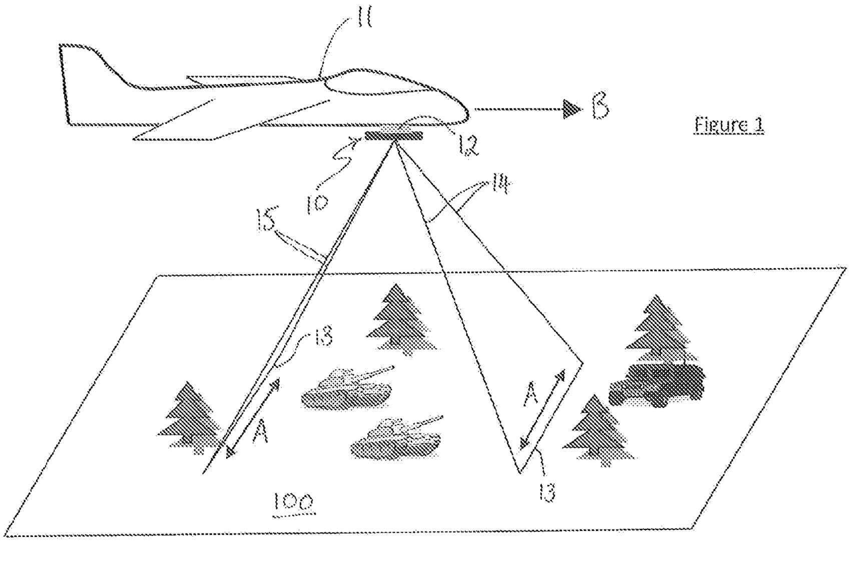

Figure 1

GB 2506687 A

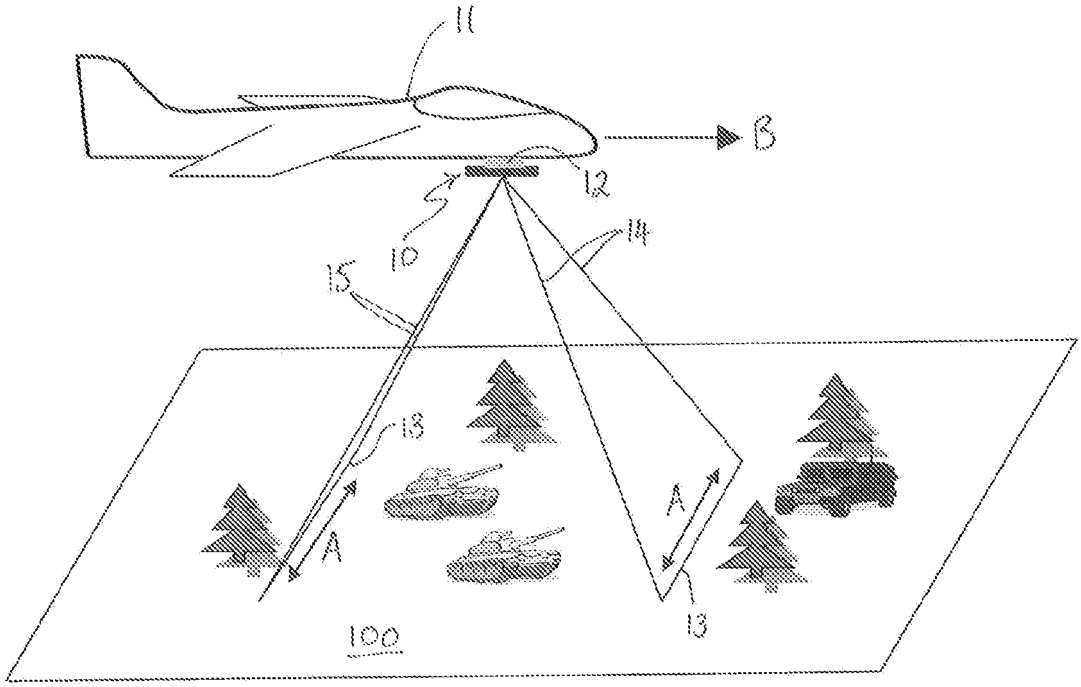

Figure 1

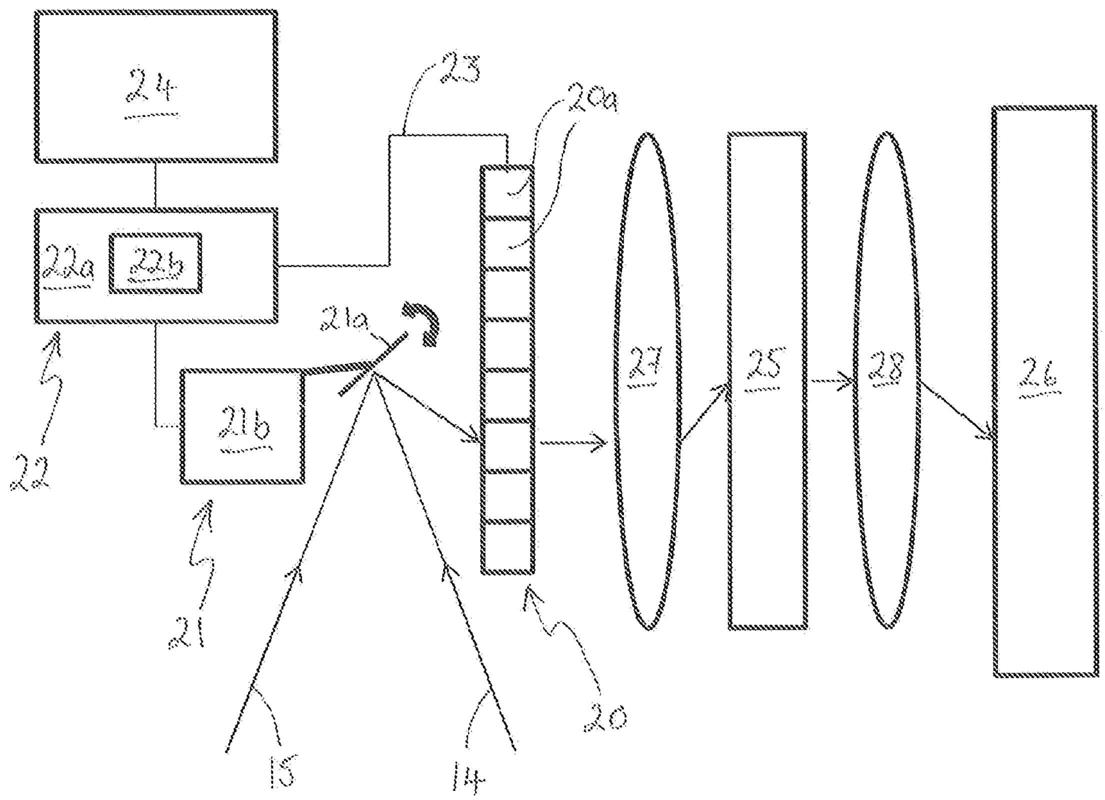

Figure 2

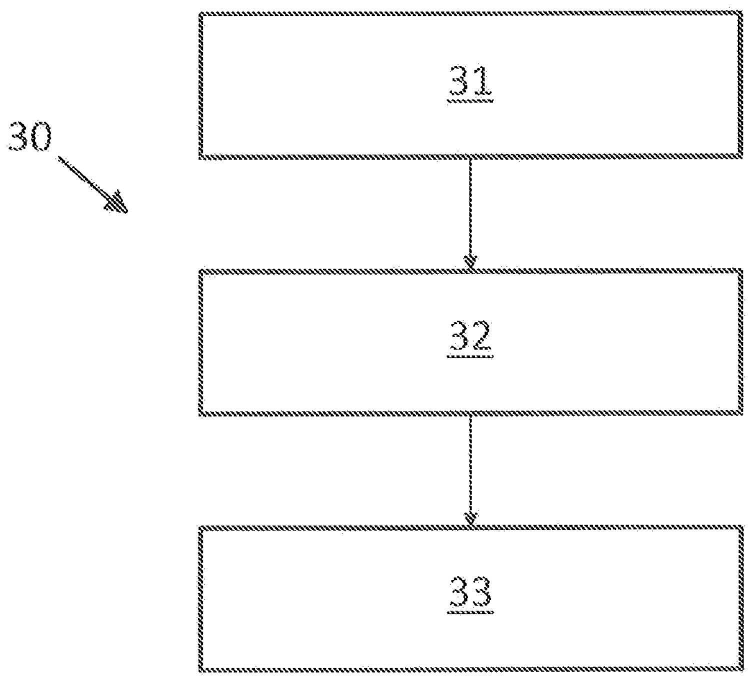

Figure 3

HYPERSPECTRAL IMAGING OF A MOVING SCENE

The present invention relates to a method and apparatus for hyperspectral imaging of a moving scene and particularly to imaging along an imaging path, from a viewpoint which is arranged to move relative to the scene.

Hyperspectral imaging sensors typically only register one thin line of an image at a time. The image is built up by scanning the sensor across the scene, e.g. using a motorised stage or using the motion of an aircraft to scan across the landscape (pushbroom scanning).

When incorporated with aircraft, pushbroom hyperspectral images are gathered using the forward motion of the aircraft to scan an image sensor across the ground in a swath direction, which is typically perpendicular to the forward motion (track direction). A slit and objective lens is used to project an image of a narrow line on the ground through a wavelength dispersive spectrometer. The geometry is arranged so that the images successively projected are spatial in one direction and spectral in the other.

The spatial resolution of aerial pushbroom hyperspectral images in the swath direction is determined by the characteristics of the lens optics and camera used. The spatial resolution in the track direction is determined by the speed and height of the aircraft. To create the highest quality imagery for subsequent analysis it is normal to match these two resolutions so that the pixels on the hyperspectral images are “square”.

Spectral resolution is principally determined by the extent of the dispersion produced by the spectrometer compared to the size of the sensor in the track direction. Hence to create well resolved images it is preferable to fly as low and as slow as practically possible.

Military surveillance aircraft cannot generally fly much lower than about 3km because of the threat from small arms fire and remotely piloted grenades. The stall speed of these types of aircraft is usually not less than about 45m/s (~90knots). In practice this puts a lower limit on the angular rate of scan of about 15mrad/s (0.86deg/s). For a frame rate of 50Hz, this is 0.3mrad (0.017deg), or 0.9m from 3km, and as such presents a limit to the spatial resolution attainable.

According to a first aspect of the present invention, there is provided a method for hyperspectral imaging of a scene along an imaging path, from a viewpoint which is arranged to move relative to the scene, the method comprising:

- acquiring hyperspectral image data of a portion of the scene from the viewpoint, along a first viewing direction relative to the viewpoint;
- redirecting the viewing direction from the first viewing direction to a second viewing direction relative to the viewpoint, in dependence of the relative movement, to maintain a view of said portion of the scene as the viewpoint moves along a portion of the imaging path.

Advantageously, the method provides for an increased spatial resolution of the scene by reducing the relative speed between the portion of the scene being viewed and the viewpoint, such as the aircraft, by tracking the location of the portion of the scene as the aircraft moves overhead.

The method preferably further comprises redirecting the viewing direction from the second viewing direction to the first viewing direction, for subsequent acquisition of further hyperspectral image data of a further portion of the scene from the viewpoint. In an embodiment, the method is arranged to acquire hyperspectral image data of a scene from an aerial position, for example using a hyperspectral sensor mounted upon an aircraft. In this respect, the first viewing direction is a forwardly direction relative to the aircraft and the second direction may be a less forwardly direction, or even a rearward direction.

The hyperspectral image data is preferably acquired via a reflecting member, which is arranged to reflect an image of the portion of the scene onto a hyperspectral sensor. The viewing direction may varied between the first and second viewing directions by rotating the reflecting member between first and second angular orientations, respectively.

According to a second aspect of the present invention, there is provided apparatus for hyperspectral imaging of a scene along an imaging path, from a viewpoint which is arranged to move relative to the scene, the apparatus comprising:

- a hyperspectral imaging sensor for acquiring hyperspectral image data
- an image steering arrangement for steering a view of a portion of the scene from a first viewing direction to a second viewing direction relative to the viewpoint, in dependence of the relative movement, so that the sensor can acquire hyperspectral image data of the portion of

the scene, as the viewpoint moves along a portion of the imaging path.

The image steering arrangement may comprise a mirror rotatably mounted for steering a view of the portion of the scene on the sensor.

The apparatus may further comprise one or more gimbals for mounting the sensor and steering arrangement to the viewpoint, such as an aircraft, to minimise rotational movements of the sensor and steering arrangement with corresponding movements of the viewpoint.

According to a third aspect of the present invention there is provided a computer program element comprising: computer code means to make the computer execute the methods of the first aspect. The element may comprise a computer program product.

According to a fourth aspect of the present invention there is provided apparatus comprising a processor configured to execute a method according to the first aspect.

Whilst the invention has been described above, it extends to any inventive combination of features set out above or in the following description. Although illustrative embodiments of the invention are described in detail herein with reference to the accompanying drawings, it is to be understood that the invention is not limited to these precise embodiments.

Furthermore, it is contemplated that a particular feature described either individually or as part of an embodiment can be combined with other individually described features, or parts of other embodiments, even if the other features and embodiments make no mention of the particular feature. Thus, the invention extends to such specific combinations not already described.

The invention may be performed in various ways, and, by way of example only, embodiments thereof will now be described, reference being made to the accompanying drawings in which:

Figure 1 is a schematic illustration of an aircraft embodying apparatus according to an embodiment of the present invention;

Figure 2 is a schematic illustration of the hyperspectral sensor; and,

Figure 3 is a flowchart outlining the steps associated with a method according to an embodiment of the present invention.

Referring to figure 1 of the drawings, there is illustrated an apparatus 10 according to an embodiment of the present invention mounted at the underside of an aircraft 11. The apparatus 10 comprises a hyperspectral sensor 20 for acquiring hyperspectral image data of a portion of a scene 100 to be imaged, and a steering arrangement 21, as illustrated in figure 2 of the drawings. The arrangement 21 may comprise a rotatably mounted mirror 21a and a motorised stage 21b for providing controlled rotations of the mirror 21a so that an image of the portion of the scene 100 can be suitably steered onto the sensor 20. Since the maximum angular velocity of the mirror 13a needs only to be small, of the order of 1deg/s, it is envisaged that this rotation may be controlled using a digitally controlled stepper motor.

The sensor 20 is in communication with a computing device 22 that is configured to receive hyperspectral image data from the sensor 20 and process it using an application. The computing device 22 can be any suitable computing device 22 having a processor 22a and memory 22b (e.g. a laptop or desktop personal computer) and can communicate with other devices, such as the sensor 20, using any suitable wired or wireless communications link 23, e.g. WiFi™, USB Link, etc.

The device 22 is also connected to, or includes, a display 24, such as an LCD monitor or any other suitable device, which can be used to display representations of the image data and/or other information relating to the results of the data processing. Although the components are shown as separate blocks in Figure 2, and can be located remotely of each other, it will be understood that in some embodiments, all or some of them could be integrated in a single device, e.g. a portable sensor with an onboard processing and/or display.

In order to minimise any blurring of the imaged scene due to aircraft movement and vibration, the apparatus may be mounted to the aircraft via gyroscopically stabilised gimbals 12. However, it is not generally necessary to do this with aerial hyperspectral imagers because their instantaneous field of view is relatively modest.

The hyperspectral image data of the scene 100 is acquired via the hyperspectral sensor 20 which comprises a linear array of sensing pixels 20a. The image data for the entire scene 100 is built up by combining scan lines 13 across the scene, namely the swath direction as indicated by arrow A, as the aircraft 11 moves along the scene 100, namely along the track direction, as indicated by arrow B. The image acquired at each sensing pixel 20a is dispersed using a spectrometer 25 onto a two-dimensional array of detectors 26 via collimating optics 27 and focussing optics 28 and the hyperspectra for each scan line are then stacked to form a three-dimensional hyperspectral data cube (not shown).

Referring to figure 3 of the drawings, in use, the aircraft 11 is flown over the scene 30 to be viewed and a portion of the image scene, namely a scan line 13 across the track direction is directed on the hyperspectral sensor 20 via the rotatable mirror 21a to acquire hyperspectral image data at step 31. As the aircraft 11 continues to move in the track direction, the mirror 21a is arranged to rotate from a first viewing direction 14 of the portion relative to the aircraft 11, which may be forwardly of the aircraft 11, to a second viewing direction 15 which may be less forwardly or even rearwardly of the aircraft 11, at step 32. This tracking of the portion of the scene 100 reduces the relative speed between the aircraft 11 and the portion and effectively increases the time spent acquiring the hyperspectral image data from the portion of the scene 100, thereby providing an increased image resolution of the scene portion.

Calculations have been carried out to show that the spatial resolution of aerial hyperspectral images can be improved by up to a factor of ten by tracking the instantaneous field of view backwards during flight. An instantaneous field of view of 0.03mrad can readily be achieved using commercial 7μm pixel hyperspectral imager, a 250mm lens, and a mirror 21a rotating at about 13.5mrad/s (0.08deg/s).

Once the rotatable mirror 21a has rotated to the second viewing direction 15 relative to the aircraft 11, the mirror 21a is required to return to the first viewing direction 14 for subsequent acquisition of image data from a further portion of the scene at step 33. During the recovery of the mirror 21a to its original position, the aircraft 11 will continue to move relative to the scene 100 and as such, this will result in portions of the scene being unimaged. In order to provide full pushbroom coverage of the scene 100 at high resolution, it is envisaged that several apparatus 10 according to the present invention may be mounted side by side and arranged to view different portions of the scene 100. By directing each mirror 21a in a slightly different direction, several lines could be scanned forward at the same time by an aircraft 11 travelling at a reasonable speed. In this manner, as one mirror 21a recovers to the original position, namely the first viewing direction 14, following a data acquisition, a further apparatus 10 may be used to acquire data from the portion which would have otherwise gone unimaged. Calculations show that with four apparatus 10 working in parallel, the ground resolution may be increased by a factor of four without any loss of image pixels.

CLAIMS

1. A method (30) for hyperspectral imaging of a scene (100) along an imaging path, from a viewpoint (11) which is arranged to move relative to the scene (100), the method comprising:

   - acquiring hyperspectral image data of a portion of the scene from the viewpoint, along a first viewing direction (14) relative to the viewpoint;
   - redirecting the viewing direction from the first viewing direction to a second viewing direction (15) relative to the viewpoint, in dependence of the relative movement, to maintain a view of said portion of the scene as the viewpoint moves along a portion of the imaging path.

2. A method according to claim 1, further comprising redirecting the viewing direction from the second viewing direction back to the first viewing direction, to acquire hyperspectral image data of a further portion of the scene from the viewpoint.

3. A method according to claim 1 or 2, wherein the hyperspectral image data is acquired via a reflecting member (21a), which is arranged to reflect an image of the portion of the scene onto a hyperspectral sensor (20).

4. A method according to claim 3, wherein the viewing direction is varied between the first and second viewing directions by rotating the reflecting member between first and second angular orientations, respectively.

5. Apparatus (10) for hyperspectral imaging of a scene along an imaging path, from a viewpoint (11) which is arranged to move relative to the scene, the apparatus (10) comprising:

- a hyperspectral imaging sensor (20) for acquiring hyperspectral image data;
- an image steering arrangement (21b) for steering a view of a portion of the scene (100) from a first viewing direction (14) to a second viewing direction (15) relative to the viewpoint, in dependence of the relative movement, so that the sensor can acquire hyperspectral image data of the portion of the scene, as the viewpoint moves along a portion of the imaging path.

6. Apparatus according to claim 5, wherein the image steering arrangement comprises a mirror (21a) rotatably mounted for steering a view of the portion of the scene on the sensor.

7. Apparatus according to claim 5 or 6, further comprising a gimbal (12) for minimising rotational movements of the sensor and steering arrangement with corresponding movements of the viewpoint.

8. A computer program element comprising: computer code means to make the computer execute a method (30) according to any of claims 1 to 4.

9. A computer program element according to claim 8, wherein the element comprises a computer program product.

10. Apparatus comprising a processor (22*a*) configured to execute a method according to any of claims 1 to 4.

INTELLECTUAL PROPERTY OFFICE

Application No:	GB1217997.4	**Examiner:**	Dr Susan Dewar
Claims searched:	1-10	**Date of search:**	9 January 2013

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-10	US 2006/0017816 A1 (GAT) See paragraphs 0031-0037

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

G01J; G06K; H04N

The following online and other databases have been used in the preparation of this search report

Online: EPODOC, WPI, TXTE, INSPEC

International Classification:

Subclass	Subgroup	Valid From
G01J	0003/28	01/01/2006
H04N	0005/225	01/01/2006