(12) UK Patent Application (19) GB (11) 2 447 258 (13) A

(43) Date of A Publication 10.09.2008

(21) Application No: 0704165.0

(22) Date of Filing: 05.03.2007

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(51) INT CL:
F16M 11/12 (2006.01) ***G03B 17/56*** (2006.01)
G03B 37/02 (2006.01)

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GB 2332531 A **AU 050200937 A**
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US 20040042783 A1
Realistic 3D reconstruction - combining laserscan data with RGB color information, Abmayr et al, Zoller + Frolish GmbH, Simoniusstr. 22, D-88239 Wangen, Germany,

(58) Field of Search:
UK CL (Edition X) **G2J**
INT CL **F16M, G03B**
Other: **EPODOC; WPI; TXTE; INTERNET**

(54) Abstract Title**: Camera mount for colour enhanced laser imagery**

(57) A camera mounting device for use in a true colour terrestrial laser scanner comprises a bracket 1 for attachment to a support structure 2 and a camera mounting member 20. The device provides for the position of the camera to be fixed with respect to the bracket in three orthogonal planes and to be selectively adjusted in at least two of those planes in order that the optical centre of the camera is coincident with the optical centre of a laser beam detector of a terrestrial laser scanner mountable on the support structure. The device further provides for the rotation of the camera in two orthogonal planes.

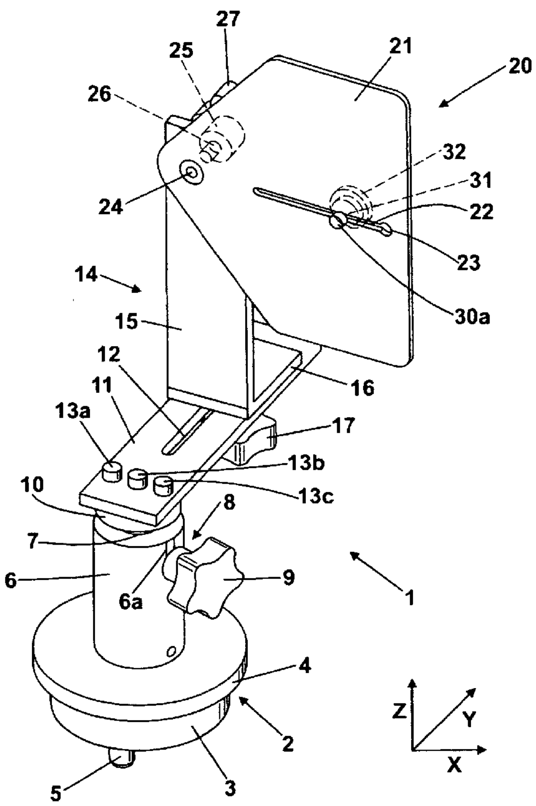

Fig. 1

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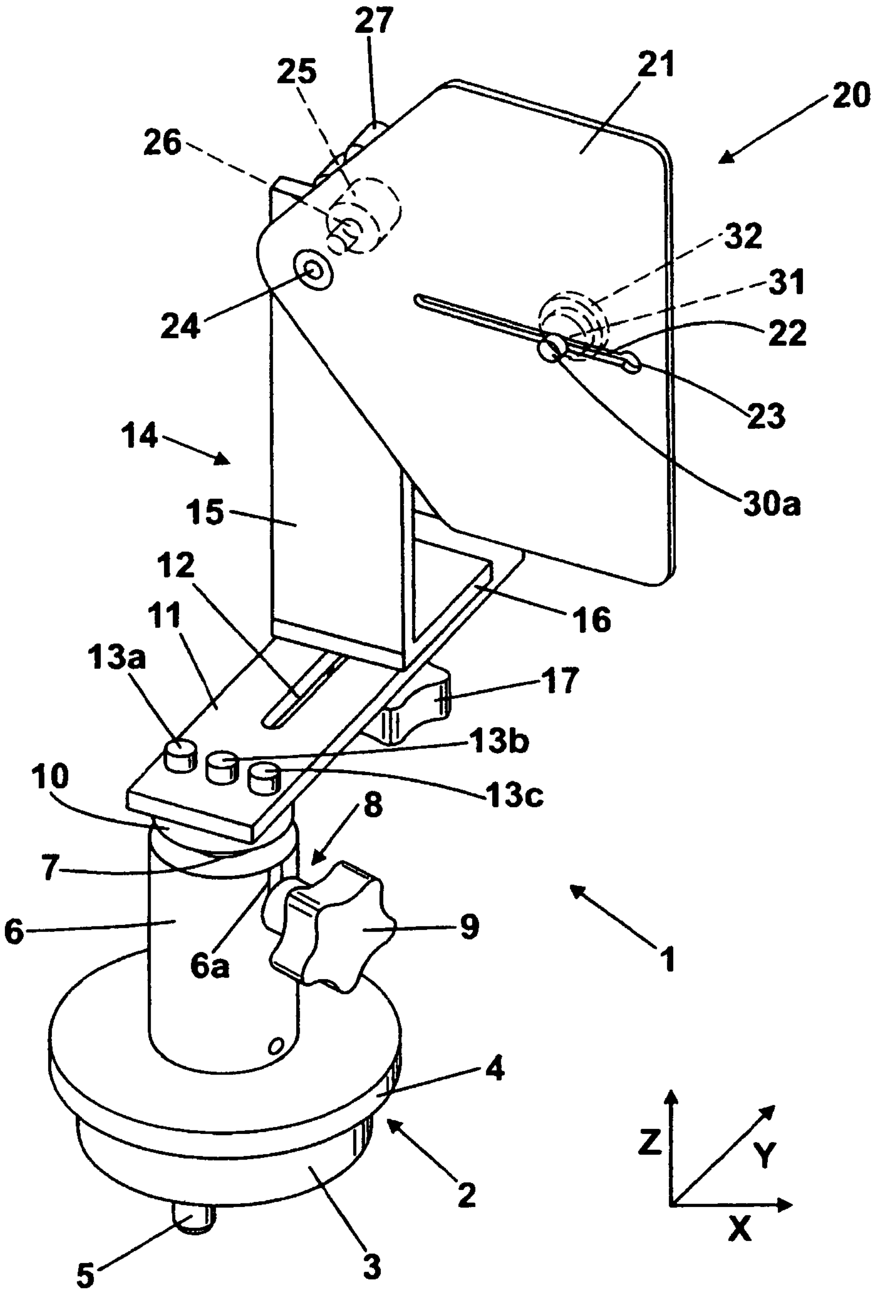
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Fig. 1

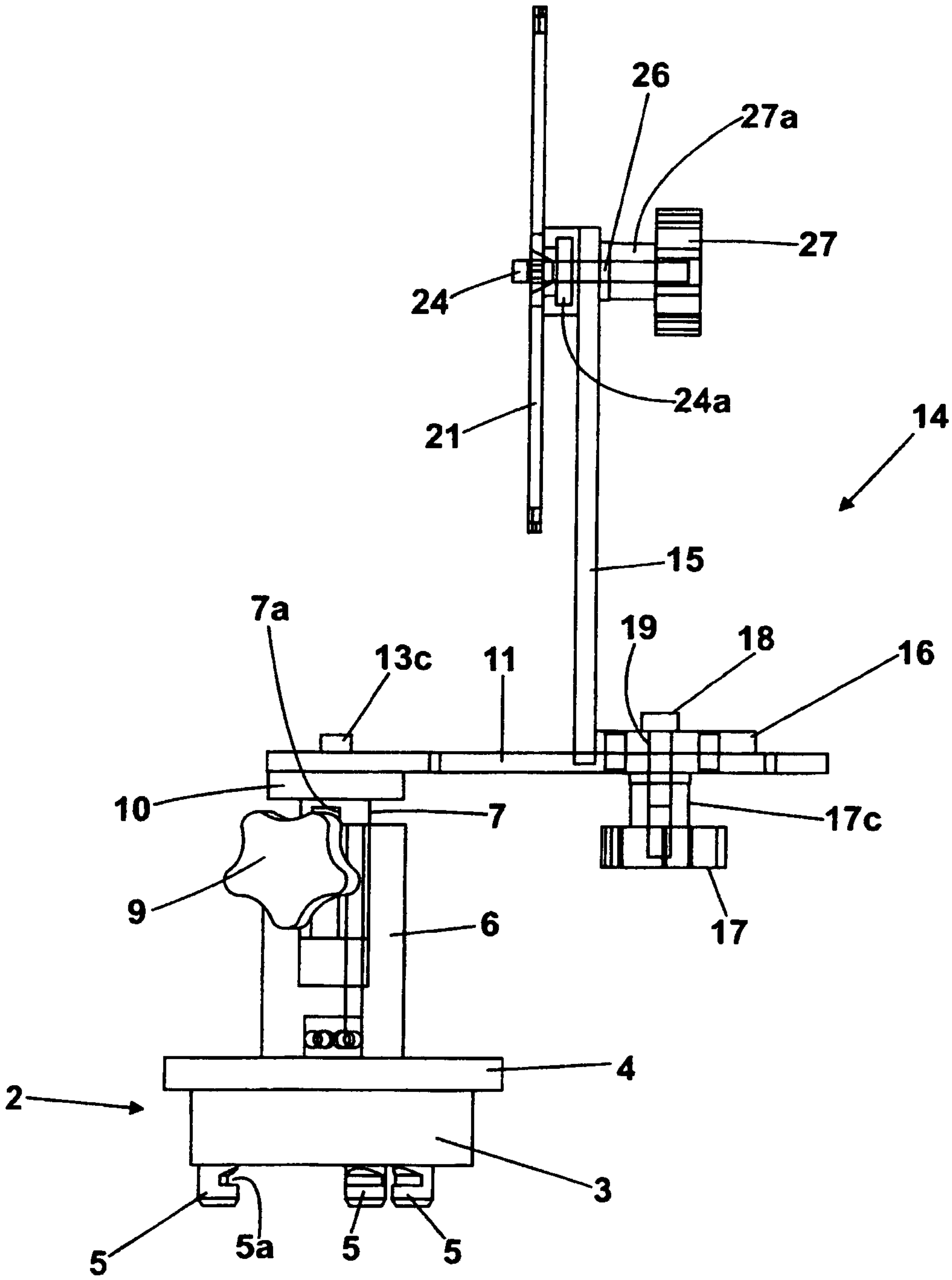

Fig. 2

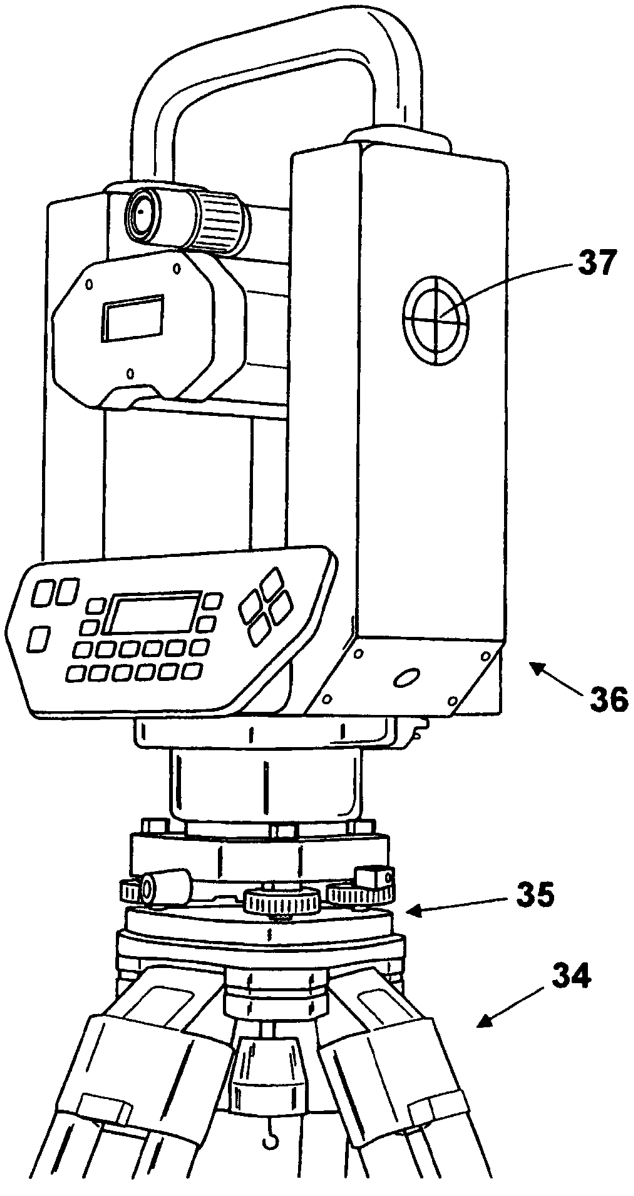

Fig. 3a

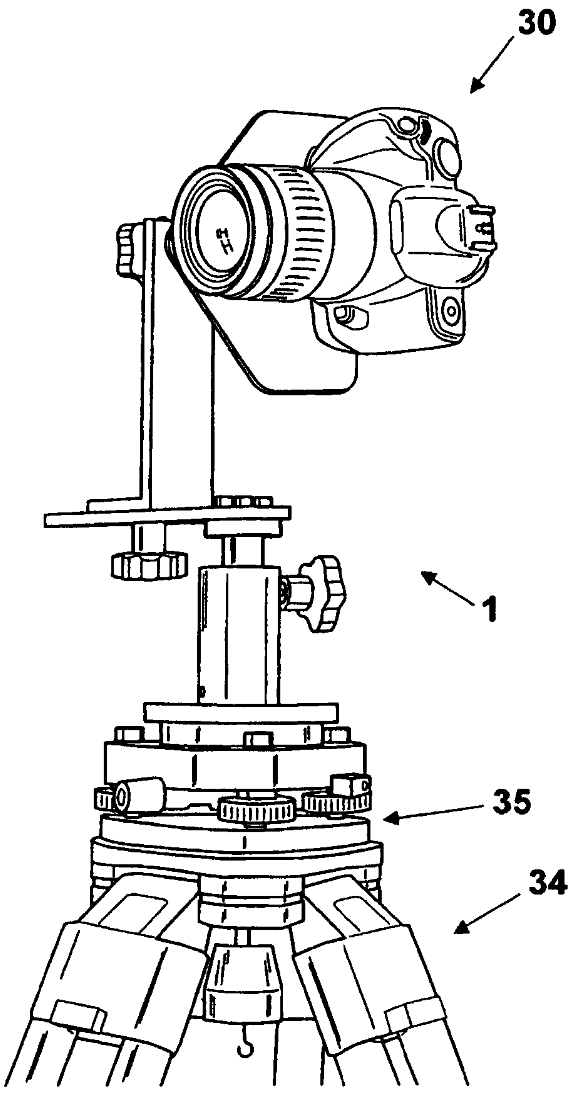

Fig. 3b

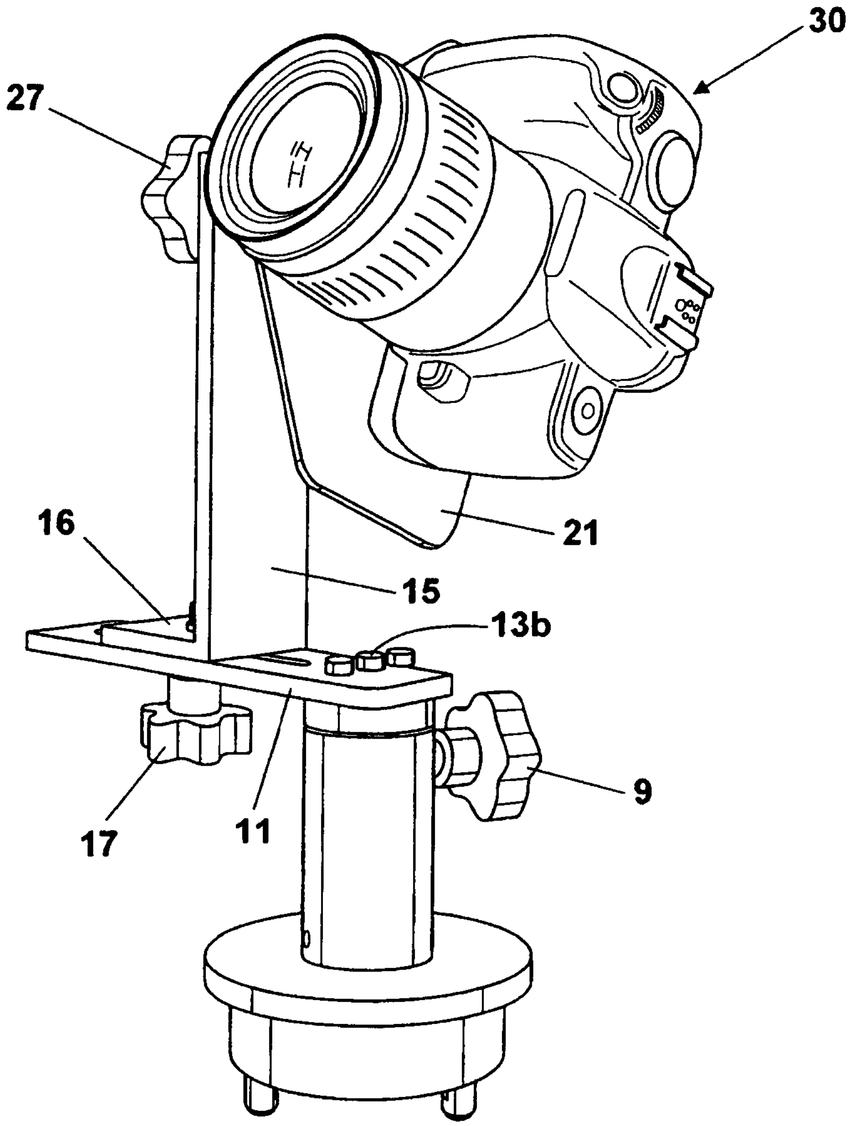

Fig. 4

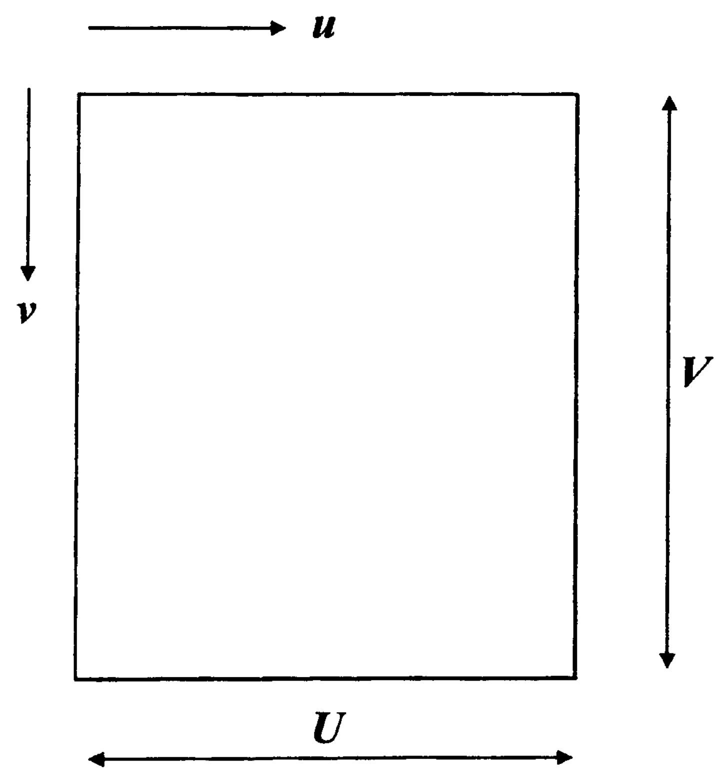

Fig. 5

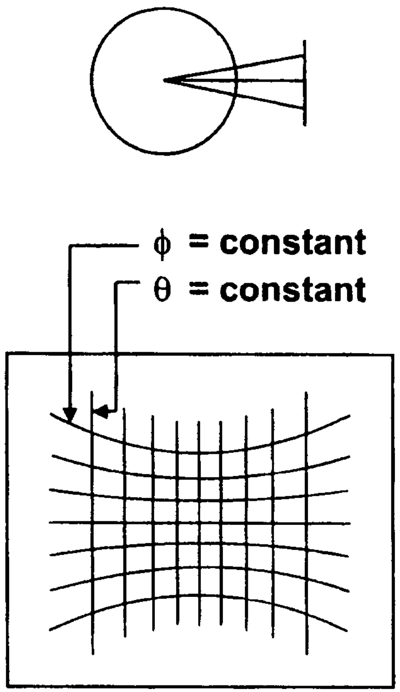

Fig. 6

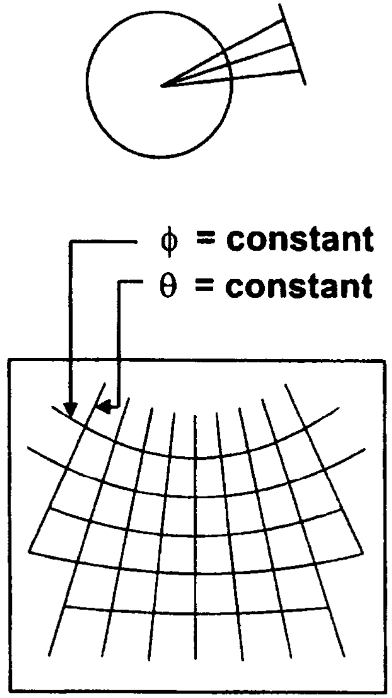

Fig. 7

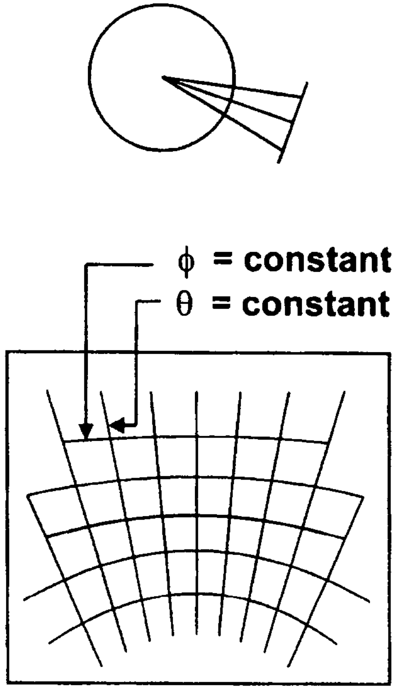

Fig. 8

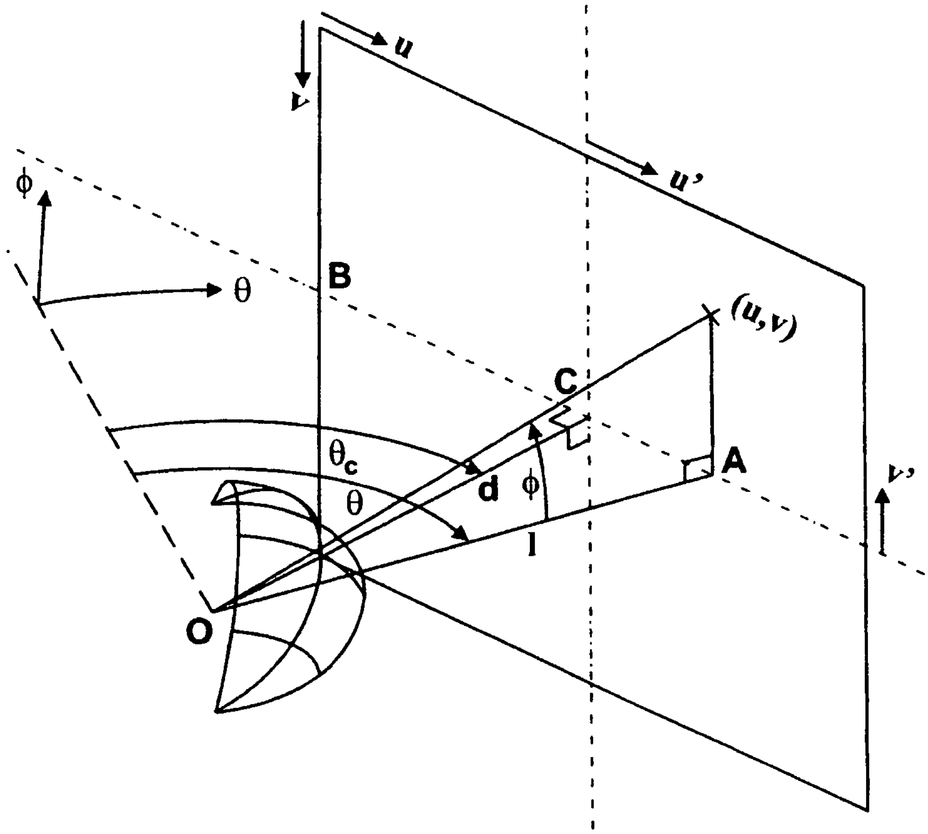

Fig. 9

Colour Enhanced Laser Imagery

Field of the Invention

The present invention relates to colour enhanced laser imagery and in particular to an apparatus and method applicable to a technique known as True Colour Terrestrial Laser Scanning.

Background of the Invention

The use of laser scanners has become widespread in surveying. The technique is often referred to as Terrestrial Laser Scanning (TLS) and is used for the acquisition of detailed positional data, with applications in many fields including civil engineering, geological survey, mining, architecture, as-built surveying, archaeology, city modelling and many others. In conventional TLS, the points in the resulting point cloud are attributed different shades of grey, depending upon the intensity of the reflected laser beam. The resulting false greyscale texture provides some help in interpreting the model, but is limited in its usefulness.

One method of improving the usefulness of TLS images is to apply false colour to the greyscale image. However, the improvement is only slight.

Another method of improving the usefulness of TLS images is to take, from arbitrary positions, a number of colour digital photographs of the object which has been the subject of the laser scan and map the colour photographs onto the laser scan. This technique requires complex mapping techniques, and the quality of the results is variable.

Another method of acquiring colour information that can be applied to the laser scan point cloud is to use on-board video mounted inside the laser scanner device. Such devices are available commercially under the brand names Leica® and Trimble®. The cameras used for this method are of significantly lower quality than separate digital Single Lens Reflex (SLR) cameras, and the resultant images are of lower resolution and poorer colour precision.

In order to provide colour more easily a technique known as True Colour Terrestrial Laser Scanning (TCTLS) has been developed. In TCTLS digital colour photographs are taken of the object which is the subject of the survey. The photographic images are then mapped onto the point cloud resulting from the laser scan producing a true colour three dimensional model which is much more interpretable than a TLS image. A number of TCTLS devices have been developed. One such device includes a digital camera which is mounted on top of a laser scanner and takes digital photographs of the subject while, or immediately after the scan is taking place. Such a device is available commercially under the brand name Riegl ®. It is understood that complex image mapping software is required to map the colour image information from the digital photograph onto the point cloud resulting from the laser scan. Since the digital camera and laser beam are not collinear, a source of error is introduced during the mapping. Typically, these devices are expensive.

Another means of providing TCTLS is described in the paper entitled "Realistic 3D Reconstruction – Combining Laserscan Data with RGB Colour Information", written by Abmayr T, et al. This document describes a device which comprises a laser scanner which is removably mounted on a tripod and a digital line scanner which is placed on the tripod when the laser scanner has been removed. The optical centre of the line scanning digital camera is described as being nearly identical with the optical centre of the laser scanner. The device described in this document uses a specialist camera developed by the German Aerospace Centre.

The present invention seeks to provide a TCTLS system at much lower cost than those systems currently known.

Summary of the Invention

According to the invention there is provided a mount for a camera as specified in Claim 1.

According to another aspect of the invention there is provided a true colour terrestrial laser scanning system as specified in Claim 14.

According to another aspect of the invention there is provided a method of producing a true colour terrestrial laser scan image as specified in Claim 31.

The present invention provides a particularly simple and economical solution to the problem of providing true colour terrestrial laser scans. Camera mounts can be provided so that any digital camera having suitable picture quality may be used. By providing for cameras which are mass produced to be used, the cost of the equipment required can be reduced drastically. Further, the colour mapping in the true colour terrestrial laser scan is very accurate. It does not suffer from some of the in-built registration problems which are encountered by some known systems, as the optical centres of the laser and the camera are coincident.

Brief Description of the Drawings

In the drawings, which illustrate preferred embodiments of the invention, and are by way of example:

Figure 1 is a schematic representation of a camera mounting bracket;

Figure 2 is a schematic representation of the camera mounting bracket illustrated in Figure 1;

Figure 3a is a schematic representation of a terrestrial laser scanner mounted on a tripod by means of a tribrach;

Figure 3b is a schematic representation of a digital camera mounted on a tripod by means of a camera mounting bracket according to the invention, the bracket being attached to the tripod by means of a tribrach;

Figure 4 is a schematic representation of the camera mounting bracket illustrated in Figures 1 and 2 with a camera mounted thereon;

Figure 5 is an illustration of the coordinate system of a rectified plane;

Figure 6 illustrates the projections of lines of constant azimuth and inclination onto a vertical plane;

Figure 7 illustrates the projections of lines of constant azimuth and inclination onto an inclined plane with the plane inclined upwards;

Figure 8 illustrates the projections of lines of constant azimuth and inclination onto an inclined plane with the plane inclined downwards; and

Figure 9 illustrates the relationship between the laser scanner and the virtual image plane in the case where the lens is pointing horizontally.

Detailed Description of the Preferred Embodiments

Referring now to Figures 1 and 2 there is shown a camera mounting bracket 1. The bracket is designed for attachment to a tribrach which is itself mounted on a tripod in normal use. It is common practice to mount surveying equipment on a tribrach, and in this particular case a laser scanner would also be mountable on the tribrach.

The bracket 1 includes a base 2, which itself comprises a lower plate 3 from which depend three elements 5 of a locking arrangement. The elements 5 are so shaped and located as to engage with corresponding elements in a tribrach. Such tribrachs are well known in the field and as such the detail of the locking arrangement will not be described in detail. The base 2 further includes an upper element 4 which is arranged to rotate with respect to the lower plate 3. Friction elements (not shown) are located between the upper and lower plates 3, 4. Due to the friction elements in the absence of a turning moment applied to the upper plate, there is no relative movement between the said upper and lower plates 3, 4. Extending from the upper plate 4 is a tubular element 6 which includes a slot 6a. A threaded screw 8 provided with a knob 9 extends through the slot 6a and into a shaft 7.

The bracket 1 further includes a plate 11. The shaft 7 extends downwardly from an end plate 10 to which the plate 11 is attached by means of three bolts 13a, 13b and 13c, so that in use the plate 11 is cantilevered off the shaft 7 which is held securely in position in the tubular element 6.

The plate 11 includes a slot 12 which extends along the longitudinal centre line of the plate 11. An L-shaped bracket 14 is mounted slidably on the upper surface of the plate 11. A part 16 of the bracket 14 lies on the upper surface of the plate 11. This part 16 is provided with a threaded bore 19 which is aligned with the slot 12. A threaded screw 18 co-operates with the threaded bore to lock the bracket 14 in a desired position on the plate 11. The free end of the screw 18 is provided with a knob 17 which provides for the easy slackening and tightening of the screw 18 and hence the locking of the bracket 14 in a desired position on the plate 11, or the releasing of the bracket 14 from a position on the plate 11.

Attached to the upwardly extending part 15 of the bracket 14 is a camera mounting bracket assembly 20. The assembly 20 comprises a plate 21 which is pivotally attached to the upwardly extending part 15 of the bracket 14 by means of a threaded screw 26 which engages with a correspondingly threaded bore 24 in an element 24a extending from the plate 21. The screw 26 passes through an unthreaded bore 25 located in the part 15 of the bracket 14. Turning the threaded screw 26 in one direction by means of the knob 27 causes the plate 21 to be pulled against the surface of the part 15 such that friction between the part 15 and the element 24a prevents rotation between the part 15 and the plate 21.

The plate 21 includes a slot 22 at one end of which includes an opening 23. A threaded screw comprising a threaded element 30a, a knob 32 and a portion of reduced diameter 31 is located in the slot 22. The opening 23 is of a dimension which allows the threaded element 30a to pass therethrough. The portion of reduced diameter 31 slides in the slot 22. The specification of the threaded element 30a, which in the present example is a ¼ inch Whitworth thread provides for the said element to attach to a standard tripod mount of an SLR camera.

With reference to Figure 3a, a conventional TLS scanner 36 is mounted on a tribrach 35 on a tripod 34. Cross-hairs 37 on the side of the scanner 36 mark a line that passes through the optical centre of the scanner.

Referring now to Figure 4, a camera 30 is mounted on the plate 21.

In use a TCTLS image is created by first performing a laser scan of an object, for example a cliff face, using a conventional TLS scanner mounted on a tribrach on a tripod. The Laser Ace 600 supplied by Measurement Devices Ltd is one such suitable scanner. When the laser scan is complete the TLS scanner is removed from the tribrach and the camera mounting bracket 1 is attached thereto. In order to simplify the task of mapping a colour image captured by a camera mounted on the bracket onto the point cloud produced by the TLS scanner it is essential that the optical centres of the camera and the laser of the TLS scanner are coincident.

The tripod mount of an SLR camera is usually aligned with the optical centre of the camera in one axis. The bracket 1 provides for the optical centre of the camera attached to plate 21 to be aligned with the optical centre of the laser of the TLS scanner.

This is achieved by performing a calibration routine.

Alignment in the X axis is achieved by aligning the SLR camera with a near object and a distant object. The bracket 14 is then turned about shaft 7 to pan the SLR camera. If during panning of the camera 30 there is movement between the near and far objects then the camera must be moved along the path defined by slot 22 until a point is reached where there is no movement between the near and far objects.

In order that the optical centres of the TLS scanner and the SLR camera may be aligned, in addition to alignment in the X axis, alignment must be achieved in the Y and Z axes.

Alignment in the Z axis is achieved by measurement. As the TLS scanner is attached to the tripod by means of the same tribrach on which the base 2 sits, on the TLS scanner the distance from the bottom edge of the lower plate 3 to the optical centre of the TLS scanner can be measured. The knob 9 is turned to slacken screw 8 in order that the bracket 11 may be moved up or down until the distance between the optical centre of the camera and the bottom edge of the lower plate 3 is equal to the distance between the optical centre of the TLS scanner and the bottom of its mounting plate. The knob 9 is then turned to tighten the screw 8 against the shaft 7 thereby locking the bracket 11 in the desired position.

Alignment in the Y axis is achieved by turning the knob 27 to slacken screw 26 in order that the plate 21 may be pivoted about the screw 26 such that the SLR camera is pointing downward towards the plate 11. The knob 27 is then turned to tighten the screw 26 thereby locking the plate 21 in position. The knob 17 is then turned to slacken screw 18 in order that the bracket 14 (and SLR camera mounted thereon) may be moved longitudinally with respect to the plate 11 along the path defined by slot 12. The bracket 14 is moved until the cross (+) on the lens of the SLR camera, which defines the optical centre of the camera is aligned with the central pin 13b.

In use, an image of a desired object is captured first using a TLS scanner mounted on a tribrach which is itself mounted on a tripod. The TLS scanner is then removed from the tribrach and the camera mounting bracket is attached to the tribrach. The calibration routine described above may be performed prior to the apparatus being brought to the field, in which case all that the surveyor need do is take pictures using the camera. If the object cannot be photographed using one picture, it will be necessary to pan and/or tilt the camera so that sufficient pictures can be taken to capture the whole object. The bracket 1 provides for both panning of the camera in the horizontal direction and tilting of the camera in the vertical direction. Panning in the horizontal is achieved by rotating the bracket 14 with respect to the base 2. Tilting in the vertical is achieved by turning the knob 27 to slacken off the screw 26. The plate 21 may then be rotated about the screw 26.

In an alternative embodiment of the invention, the camera mounting bracket may be provided with actuators such as stepper motors to rotate the camera in the vertical and horizontal planes. Actuators may also be used to control the camera mounting bracket during the calibration procedure.

The purpose of acquiring both a laser point cloud image using a TLS scanner and a digital colour image or images is to generate a True Colour Terrestrial Laser Scan. It is therefore necessary to map together the data from the laser scan and the digital camera imagery. In the invention processing of the data is conducted in the manner set out below:

First it is necessary to calibrate and rectify the images captured by the camera, the aim being to arrive at an image which appears to have been captured with a pinhole camera. The intrinsic parameters required to rectify the image to achieve the pinhole camera model are usually effective focal length, scale factor and image centre (principal point).

The images can be calibrated and rectified such that they appear to have been captured using a pinhole camera using known tools. One such tool is Bouguet's Camera Calibration Toolbox for

Matlab. However, the large image files produced by current digital cameras cannot be handled by this tool. Another tool, which again is freely distributed on the internet, is Vezhnevets and Velizhev's GML C++ Camera Calibration Toolbox (v. 0.31 or otherwise). In the present example, Vezhnevets and Velizhev's toolbox was chosen to perform the camera calibration and image rectification necessary before the photographic images could be registered with the laser scan point cloud.

Once the photographic images have been calibrated and rectified the photographic images must be registered with the laser scan point cloud. In order to register an image with a point cloud, a mapping must be determined which gives expressions for the image pixel coordinates, u and v, in terms of the azimuth (horizontal) and inclination (vertical) angles, θ and ϕ, respectively, from the laser scanner centre to the corresponding point in the cloud. Figure 5 illustrates the coordinate system of the rectified image plane, where u and v are the horizontal and vertical pixel coordinates, respectively, measured from the origin at the top left corner of the image, as is the convention in computer imaging. U and V refer to the total number of horizontal and vertical pixels in the image.

The laser scanner is an inherently spherical system using polar coordinates, whereas the camera sensor is a plane. The behaviour of the scanner-camera system is described in greater detail with reference to Figures 6 to 8.

The laser scanner measures the azimuth angle as the scanner rotates about the vertical axis. The azimuth is, therefore, the angle between the azimuth zero line in the horizontal plane passing through the scanner centre and the projection of the subject point onto the same plane. This is not the same as the horizontal angle between the vertical plane passing through the azimuth zero line and the point being scanned. The scanner measures the inclination angle with respect to the horizontal plane passing through the scanner centre. The inclination is simply the direct angle between the aforementioned plane and the point being scanned.

The implications of the method of operation of the laser scanner can be understood by considering the lines traced out by the laser-beam on the inside of a virtual sphere when θ or ϕ is kept constant, given that the laser scanner centre is at the centre of the sphere. If the inclination is kept constant while the azimuth is varied, a line of "latitude" is traced on the surface of the sphere. If, instead, the azimuth is kept constant while the inclination is varied, a line of "longitude" is traced on the surface.

The interaction of the laser scanner and the camera can be understood by imagining the projections of the lines of latitude and longitude onto a virtual plane by straight lines passing through the centre of the sphere. If the plane is vertical, the lines of latitude above the "equator" map to upwards curving lines on the plane, and those below the equator map to downwards curving lines. The lines of longitude, however, map to vertical lines on the plane as illustrated in Figure 6. If the plane is now tilted upwards, the projected lines of latitude now all curve upwards, as long as the bottom of the virtual plane is above the equatorial plane. The projections of the lines of longitude remain straight, but splay out towards the bottom of the plane as illustrated in Figure 7. If the plane is tilted downwards, the projected lines of latitude curve downwards and the projections of the lines of latitude splay out towards the top of the plane as illustrated in Figure 8.

Since the scanner is an inherently spherical system using polar coordinates, and a camera sensor is a plane, the scanner-camera system conforms to the behaviour described with reference to Figures 6 to 8, with the virtual image plane corresponding to the camera's sensor. When the virtual plane in Figure 6 is vertical, this corresponds to the case in which the camera's sensor is vertical, i.e. the longitudinal axis of the camera's lens is pointing horizontally. When the virtual plane is inclined, this corresponds to the situation in which the camera is tilted about a horizontal line passing through the laser-beam detector/camera optical centre.

In the case where the lens is pointing horizontally, the expression for *v* will be a function of both θ and ϕ, while *u* will be a function of θ only. In the tilted case, both *u* and *v* are functions of both θ and ϕ, as summarised in *Table 1*.

Camera Horizontal	**Camera Tilted**
$u = f(\theta)$	$u = f(\theta,\phi)$
$v = f(\theta,\phi)$	$v = f(\theta,\phi)$

Table 1

Figure 9 illustrates the relationship between the laser scanner and the virtual image plane in the case where the lens is pointing horizontally.

The laser scanner centre and the virtual image plane are separated by a virtual distance, *d*, perpendicular to the plane. θ_c is the angle from the azimuth zero line to the centre of the virtual image plane, and *u'* and *v'* define an alternative image coordinate system with respect to an origin at the centre of the virtual image plane.

Expressions for *u* and *v* are set out below:

i) $$u = \frac{U}{2} + \frac{d\tan(\theta - \theta_c)\sec\phi_c}{1 + \sec(\theta - \theta_c)\tan\phi\tan\phi_c}$$

ii) $$v = \frac{V}{2} - \frac{d(\sec(\theta - \theta_c)\tan\phi - \tan\phi_c)}{1 + \sec(\theta - \theta_c)\tan\phi\tan\phi_c}$$

In the present example, for each image, if the *u, v* coordinates of two points in the image and the corresponding θ, ϕ coordinates of the same two points (tie points) in the point cloud are known, and given the horizontal and vertical pixel dimensions of the image, then four equations can be formed containing only three unknown mapping parameters, θ_c, ϕ_c and *d*:

iii) $$u_1 = \frac{U}{2} + \frac{d\tan(\theta_1 - \theta_c)\sec\phi_c}{1 + \sec(\theta_1 - \theta_c)\tan\phi_1 \tan\phi_c}$$

iv) $$u_2 = \frac{U}{2} + \frac{d\tan(\theta_2 - \theta_c)\sec\phi_c}{1 + \sec(\theta_2 - \theta_c)\tan\phi_2 \tan\phi_c}$$

v) $$v_1 = \frac{V}{2} - \frac{d(\sec(\theta_1 - \theta_c)\tan\phi_1 - \tan\phi_c)}{1 + \sec(\theta_1 - \theta_c)\tan\phi_1 \tan\phi_c}$$

vi) $$v_2 = \frac{V}{2} - \frac{d(\sec(\theta_2 - \theta_c)\tan\phi_2 - \tan\phi_c)}{1 + \sec(\theta_2 - \theta_c)\tan\phi_2 \tan\phi_c}$$

Only three of the above equations are required to solve for the three mapping parameters.

The three simultaneous nonlinear equations iii, iv, and v are rearranged thus:

$$f(\theta_c, \phi_c, d) = \frac{U}{2} - u_1 + \frac{d\tan(\theta_1 - \theta_c)\sec\phi_c}{1 + \sec(\theta_1 - \theta_c)\tan\phi_1 \tan\phi_c}$$

$$g(\theta_c, \phi_c, d) = \frac{U}{2} - u_2 + \frac{d\tan(\theta_2 - \theta_c)\sec\phi_c}{1 + \sec(\theta_2 - \theta_c)\tan\phi_2 \tan\phi_c}$$

$$h(\theta_c, \phi_c, d) = \frac{V}{2} - v_1 - \frac{d(\sec(\theta_1 - \theta_c)\tan\phi_1 - \tan\phi_c)}{1 + \sec(\theta_1 - \theta_c)\tan\phi_1 \tan\phi_c}$$

which can be solved by using Newton's method in the following form:

$$\begin{bmatrix} \theta_c \\ \phi_c \\ d \end{bmatrix}_{n+1} = \begin{bmatrix} \theta_c \\ \phi_c \\ d \end{bmatrix}_n - J^{-1}(\theta_c, \phi_c, d) \begin{bmatrix} f(\theta_c, \phi_c, d) \\ g(\theta_c, \phi_c, d) \\ h(\theta_c, \phi_c, d) \end{bmatrix}_n$$

where J is the Jacobian matrix:

$$J(\theta_c, \phi_c, d) = \begin{bmatrix} \frac{\partial f}{\partial \theta_c} & \frac{\partial f}{\partial \phi_c} & \frac{\partial f}{\partial d} \\ \frac{\partial g}{\partial \theta_c} & \frac{\partial g}{\partial \phi_c} & \frac{\partial g}{\partial d} \\ \frac{\partial h}{\partial \theta_c} & \frac{\partial h}{\partial \phi_c} & \frac{\partial h}{\partial d} \end{bmatrix}$$

In the present example, the registration of a set of photographs with its associated point cloud is carried out using a set of tools created in Matlab7. The set of tools comprises nine individual programs collectively controlled through a common Graphical User Interface (GUI). The GUI program, registration_gui.m, was adapted from Bouguet's Camera Calibration Toolbox for Matlab.

The first tool, cloud_load.m loads a .txt file containing the point data in the following format:

x[space]y[space]z[space]intensity[new line]

Conversion of the point cloud from Cartesian to spherical coordinates is carried out using cloud_convert.m. This program assumes that the origin of the point cloud is at the laser scanner centre. If this is not the case, another tool, height_shift_and_save.m should be used to shift the point cloud vertically until the origin is at the scanner centre (the user is prompted to enter the required change in height in metres, with the upwards direction being positive). The azimuth and inclination coordinates are calculated from the *x*, *y* and *z* coordinates using the following formulae:

vii) $$azimuth = \arctan\left(\frac{x}{y}\right)$$

viii) $$inclination = \arctan\left(\frac{z}{\sqrt{x^2 + y^2}}\right)$$

The undistorted images, in .jpg format, are loaded using image_load.m. The user is asked how many images are to be mapped and the program reads and stores the 8-bit colour intensities for each pixel.

The main program in the toolbox is map.m, which solves the set of three simultaneous equations for each image; registers the images to the point cloud using the two mapping equations (i) and (ii); and combines the colour information from the different images. In each of the programs, computational efficiency was maximised by predefining vectors and matrices of the correct size, as well as optimising long mathematical expressions by splitting them into small reusable blocks.

The user inputs the resolution of the images and the coordinates of the tie-points. The program then calculates, for each image, initial guesses for the three unknown mapping parameters, θ_c, ϕ_c, d, in order to prime Newton's method with reasonable initial guesses and enable the correct roots to be obtained by taking the means of the two tie-point azimuth angles and the two tie-point inclination angles, respectively. The initial guess for d is calculated using the approximate equation:

$$d \approx \frac{U}{2}\cot\left(\frac{\psi_u}{2}\right)$$

where ψ_u is the approximate horizontal field of view of the lens after rectification. This equation cannot be used to determine d analytically since ψ_u varies as the camera is focused.

Newton's method is then used to solve iteratively for θ_c, ϕ_c and d for each image. The mapping equations are then used to assign to every point in the point cloud, the nearest image pixel from each image which covers the point in question. The colour information is extracted from the corresponding pixels and assigned to the cloud point, before removal of any duplicate colour information due to the overlap of images. Where images overlap, the order in which the images are loaded using image_load.m determines from which image the colour information is obtained. In the present example, the order of priority simply corresponds to the order in which the images are loaded, though more sophisticated strategies can be envisaged.

The tool for saving the output file is save.m. This function creates a .txt output file with a filename of the user's choice. The file is saved in the following format:

x[space]*y*[space]*z*[space]r[space]g[space]b[space]intensity[new line]

The point cloud data is now suitably coloured and can be imported into appropriate visualisation software, such as the open-source program ParaView.

The mapping procedure can be carried out without re-solving for the mapping parameters, using map_excl_solve.m. This function is the same as map.m, except that it uses whatever values of the mapping parameters are stored in Matlab's workspace. The user is, therefore, able to adjust the mapping iteratively to improve the accuracy of the registration if the tie-points were difficult to determine accurately. The values of the mapping parameters can be written to a .txt file at any time using the function save_parameters.m.

When identifying a tie-point in the point cloud using software such as ParaView, the position of the point is usually given in Cartesian coordinates. Cloud_convert.m is a useful tool for converting a point from Cartesian to spherical polar coordinates using expressions (vii) and (viii).

The use of tie points and the equations above sets out one way in which the relationship between the horizontal and vertical pixels and laser points can be established. In using tie points and the equations set out above, the computer software is working backwards from the tie points to arrive at the angle at which the camera was pointing with respect to the zero angle when the picture was taken. Alternatively, these angles may be measured electronically by including potentiometers in the mounting arrangement which measure the angles through which the camera has been panned horizontally and tilted vertically. An electronic output from the potentiometer is proportional to the angle through which the camera has been panned. The output could be recorded on each occasion that a picture is taken and subsequently used in the software. Another option would be to equip the mount with scales to measure the azimuth and inclination angles of the camera with respect to the zero angle when any picture is taken. The angles could be recorded manually following the operator reading off the angles from the scale.

In another embodiment of the invention the points in the point cloud are meshed together. The resulting surface is a mesh of triangles formed between points in the point cloud. After the colour image data has been registered with the points in the point cloud, colour information relating to respective triangles is applied to the mesh. This can provide a more detailed colour representation, as every pixel is applied to the surface of the mesh (except where photographs overlap), whereas without the creation of a mesh only the pixel closest to each point is used to colour the point cloud.

Claims

1. A camera mounting device suitable for use in a true colour terrestrial laser scanner, the mounting device comprising a bracket for attachment to a support structure and a camera mounting member, wherein the device provides for the position of the camera to be fixed with respect to the bracket in three orthogonal planes and to be selectively adjusted in at least two of those planes, in order that the optical centre of the camera is coincident with the optical centre of a laser beam detector of a terrestrial laser scanner mountable on the support structure, the device further providing for the rotation of the camera in two orthogonal planes.

2. A camera mounting device according to Claim 1, wherein the position of the camera may be selectively adjusted in at least three orthogonal planes.

3. A camera mounting device according to Claim 1, wherein the bracket is adapted to attach to a tribrach.

4. A camera mounting device as claimed in Claim 1 or 2, wherein the mounting device provides for the optical centre of a camera mounted on the camera mounting member to be aligned with the optical centre of another optical device supported by the said support structure.

5. A camera mounting device as claimed in any preceding claim, wherein the bracket comprises an arm and an upright member mounted on and extending perpendicular to the arm, and wherein the upright member is selectively movable with respect to the arm, thereby providing for adjustment of the position of the camera in one of the said three orthogonal planes.

6. A camera mounting device as claimed in any preceding claim, wherein the camera is mounted on a camera support and wherein the camera is

selectively movable with respect to the camera mount, thereby providing for adjustment of the position of the camera in another of the said three orthogonal planes.

7. A camera mounting device as claimed in Claim 5, wherein the mounting of the camera on the support provides for movement of the camera relative to the support along a line which passes through the axis of rotation of the camera support on the camera mount.

8. A camera mounting device as claimed in any preceding claim, wherein the camera mounting member is mounted in the bracket, and wherein the camera mounting member is selectively movable axially with respect to the bracket, thereby providing for adjustment of the position of the camera in another of the said three orthogonal planes.

9. A camera mounting device as claimed in any preceding claim, wherein the camera support is rotatably mounted on the camera mounting member, thereby providing for rotation of the camera in one of the said two orthogonal planes.

10. A camera mounting device as claimed in Claim 8, further comprising a fastener arranged to fasten the camera support in a position.

11. A camera mounting device as claimed in any preceding claim, wherein the camera mounting member is rotatably mounted in the bracket, thereby providing for rotation of the camera in the other of the said two orthogonal planes.

12. A camera mounting device as claimed in Claim 8, wherein the camera mount is mounted in the bracket on a friction bearing.

13. A camera mounting device as claimed in any preceding claim, further comprising an alignment marker, which the camera is aligned with to set the optical centre in one of the three orthogonal planes.

14. A true colour terrestrial laser scanner comprising:

i. a terrestrial laser scanner including a laser beam detector;

ii. a digital SLR camera;

iii. a support;

iv. and a camera mounting device as claimed in any of Claims 1 to 13;

wherein the camera mounting device provides for the position of the camera to be adjusted such that optical centres of the laser beam detector and the camera are coincident.

15. A true colour terrestrial laser scanner as claimed in Claim 14, wherein the support includes a tribrach and in use the terrestrial laser scanner and the camera mounting device are attached to the tribrach.

16. A true colour terrestrial laser scanner as claimed in Claim 14 or 15, further comprising at least one data recorder.

17. A true colour terrestrial laser scanner as claimed in any of Claims 14 to 16, further comprising image analysis software, wherein the image analysis software registers image data captured.by the camera with point cloud data captured by the terrestrial laser scanner.

18. A true colour terrestrial laser scanner as claimed in Claim 17, wherein registration of image data and point cloud data is performed by correlating the angles at which the camera was pointing relative to the azimuth zero and inclination zero lines when capturing a particular image data pixel with

the angles of the closest point in the laser point cloud relative to the azimuth zero and inclination zero lines.

19. A true colour terrestrial laser scanner as claimed in Claim 18, wherein the camera mount includes measuring devices for measuring the said pointing angles of the camera.

20. A true colour terrestrial laser scanner as claimed in Claim 19, wherein the angles are measured using transducers and the outputs of the transducers are inputs to the image analysis software.

21. A true colour terrestrial laser scanner as claimed in Claim 18, wherein the image analysis software derives the said angles from tie points identified in the camera capture image data and the point cloud wherein at each tie point a point in the laser point cloud is substantially coincident with a pixel in the image data.

22. A true colour terrestrial laser scanner as claimed in any of Claims 17 to 21, wherein the image analysis software registers images to point cloud data according to the equations:

$$u = \frac{U}{2} + \frac{d \tan(\theta - \theta_c) \sec\phi_c}{1 + \sec(\theta - \theta_c) \tan\phi \tan\phi_c}$$

$$v = \frac{V}{2} - \frac{d(\sec(\theta - \theta_c) \tan\phi - \tan\phi_c)}{1 + \sec(\theta - \theta_c) \tan\phi \tan\phi_c}$$

23. A true colour terrestrial laser scanner as claimed in Claim 22, wherein the image analysis software calculates values for the mapping parameters θ_c, ϕ_c and d: by solving at least three of the non-linear equations:

$$f(\theta_c,\phi_c,d)=\frac{U}{2}-u_1+\frac{d\tan(\theta_1-\theta_c)\sec\phi_c}{1+\sec(\theta_1-\theta_c)\tan\phi_1\tan\phi_c}$$

$$g(\theta_c,\phi_c,d)=\frac{U}{2}-u_2+\frac{d\tan(\theta_2-\theta_c)\sec\phi_c}{1+\sec(\theta_2-\theta_c)\tan\phi_2\tan\phi_c}$$

$$h(\theta_c,\phi_c,d)=\frac{V}{2}-v_1-\frac{d(\sec(\theta_1-\theta_c)\tan\phi_1-\tan\phi_c)}{1+\sec(\theta_1-\theta_c)\tan\phi_1\tan\phi_c}$$

$$k(\theta_c,\phi_c,d)=\frac{V}{2}-v_2-\frac{d(\sec(\theta_2-\theta_c)\tan\phi_2-\tan\phi_c)}{1+\sec(\theta_2-\theta_c)\tan\phi_2\tan\phi_c}$$

24. A true colour terrestrial laser scanner as claimed in Claim 23, wherein the three non-linear equations are solved using Newton's method and wherein the method is primed by introducing guessed values for unknown mapping parameters θ_c, ϕ_c and d.

25. A true colour terrestrial laser scanner as claimed in Claim 24, wherein the initial guessed values are the means of the two tie-point azimuth angles and the two tie-point angles respectively.

26. A true colour terrestrial laser scanner as claimed in Claim 24 or 25, wherein the image analysis software calculates the initial guess for d using the equation:

$$d\approx\frac{U}{2}\cot\left(\frac{\Psi_u}{2}\right)$$

27. A true colour terrestrial laser scanner as claimed in any of Claims 24 to 26, wherein the image analysis software runs Newton's method iteratively to solve values for θ_c, ϕ_c and d.

28. A true colour terrestrial laser scanner as claimed in any of Claims 17 to 27, wherein the image analysis software assigns to every point in the point

cloud the nearest image pixel, and the colour information is extracted from the said pixel and assigned to the said point in the point cloud.

29. A true colour terrestrial laser scanner as claimed in any of Claims 14 to 28, wherein the image analysis software meshes together the points in the point cloud to generate a mesh of triangles, and wherein colour from the colour image is applied to individual triangles in the mesh.

30. A true colour terrestrial laser scanner as claimed in any of Claims 17 to 28, wherein colour point cloud data is imported into visualisation software.

31. A method of obtaining a true colour terrestrial laser scanned image using a true colour laser scanner as claimed in any of Claims 14 to 30, comprising the steps of:

i) obtaining a laser point cloud using a laser scanner mountable on a support structure;

ii) removing the true colour laser scanner from the support structure and attaching a camera mounting device as claimed in any of Claims 1 to 13;

iii) adjusting the mounting device such that the optical centre of a camera mounted thereon is coincident with the optical centre of a laser beam detector of the true colour laser scanner;

iv) obtaining colour image data with the camera;

v) processing the laser scan point cloud data and image data using the image processing software.

32. A camera mounting device substantially as shown in and as described with reference to the drawings.

33. A true colour laser scanner substantially as shown in and as described with reference to the drawings.

Application No:	GB0704165.0	**Examiner:**	Donal Grace
Claims searched:	1 to 33	**Date of search:**	21 February 2008

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 at least	US 2006/0177215 A1 (JOHNSON) see figures 7 to 15
X	1 at least	US 5870642 A (MITTELSTAEDT et al) see column 3 line 58 to column 4 line 32
X	1 at least	US 2004/0042783 A1 (DIANA et al) see figure 6 and related description
X	1 at least	GB 2332531 A (LEHNER) see figure 5 and related description
X	1 at least	AU 050200937 A (MAPTEK) see figure 4 and related description
X	1 at least	Realistic 3D reconstruction - combining laserscan data with RGB color information, Abmayr et al, Zoller + Frolish GmbH, Simoniusstr. 22, D-88239 Wangen, Germany, <http://www.cartesia.org/geodoc/isprs2004/comm5/papers/549.pdf> see figure 8

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EPODOC; WPI; TXTE; INTERNET

International Classification:

Subclass	Subgroup	Valid From
F16M	0011/12	01/01/2006
G03B	0017/56	01/01/2006
G03B	0037/02	01/01/2006