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DESCRIPTION

[0001] The present invention relates to a method for surveying of a city scape and for creation of a 3D city model of the surveyed city scape according to claim 1, to a hybrid 3D-imaging device for surveying of a city scape for creation of a 3D city model according to claims 7 and 14, and to a computer program product according to claim 13.

[0002] 3D city models, i.e. digital models of urban areas representing different terrain surfaces and infrastructure, are used in a large number of different application domains. Within a single framework 3D city models allow for displaying, managing, and analysing complex urban city scenarios. Typically, the 3D city models are generated at various levels of detail (LOD) and abstraction, and at multiple resolutions. For example, "CityGML" is a common information model for the representation of 3D urban objects which defines five LODs for building models:

- LOD 0: 2.5D footprints,
- LOD 1: buildings represented by block models,
- LOD 2: building models with standard roof structures,
- LOD 3: detailed (architectural) building models, and
- LOD 4: LOD 3 supplemented with interior features.

[0003] The models typically comprise of GIS data, in particular for creating digital terrain models (DTM), high-level CAD data for buildings and infrastructure elements, and BIM data for providing the highest level of detail for building components. Applications for 3D city models are multifarious, e.g. navigation systems, urban planning and architecture, archaeology, geodesign, emergency management, gaming or augmented reality applications, intelligent transportation systems, property management, and so forth.

[0004] Automatic creation of 3D city models (GIS ready buildings) and 3D meshes assists in providing up-to-date geospatial base layers for Smart City applications, wherein textured and GIS-ready 3D models are usually generated from stereo images and/or perspective views. In a first step, based on image based point matching, point clouds are generated using single global matching algorithms (SGM) or similar techniques. Specialized software is used, to extract 3D models out of these point clouds, e.g. based on additional input such as building footprints or data from multispectral cameras. For example, the Leica RCD30 with multispectral capability allows the generation of normalized difference vegetation index images (NDVI images) to eliminate vegetation and thus to improve the recognition rate of objects within the point cloud, e.g. by geometric or semantic classification.

[0005] 3D representation of landscapes and urban areas may also be achieved by creating meshes from point clouds, the point clouds being generated through the extraction from stereo images using SGM or similar techniques. In certain cases objects might also be extracted from lidar data, however in the case of city modelling objects such as buildings or infrastructure are

often not textured and of low resolution. Thus, for city modelling it is common practice however, that such meshes are more likely generated from nadir and/or oblique imaging as image data offers better resolution and thus more detail.

[0006] Point clouds generated from imaging, even for very dense overlaps (dense matching), typically show problem areas where efficient point extraction is not good enough. For example, this is the case for occlusions and canyons with low lighting conditions, for shadow areas exhibiting increased noise, for very inhomogeneous areas such as vegetation, and for very homogeneous surfaces such as water. In the case of automatic 3D building model creation this might cause wrong building identification, wrong ground height identification, and reduced accuracy. In the case of 3D mesh generation problems such as meltdown on building edges, wrong ground height, and modelling of trees inside the mesh may occur.

[0007] Point clouds from lidar data generally do not have such issues. However, due to the lower point density, meshes have far less detail and are often not textured.

[0008] The publication "AUTOMATED MODELING OF 3D BUILDING ROOFS USING IMAGE AND LIDAR DATA" (N. Demir and E. Baltsavias, ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume 1-4, 2012, XXII ISPRS Congress, 25 August - 01 September 2012, Melbourne, Australia) discloses an automated approach for 3D building roof modelling comprising roof detection and 3D geometric modelling. A combined approach of four methods is described using slope-based DSM filtering as well as classification of multispectral images, elevation data and vertical LiDAR point density, wherein the results are quantitatively assessed by comparing to ground truth.

[0009] The publication "The DGPF-Test on Digital Airborne Camera Evaluation - Overview and Test Design" (Michael Cramer, PFG 02/2010, Final Version (Status Jan 12, 2010)), incorporated by reference into above mentioned publication by Demir and Baltsavias, discloses a combination of imaging data with LiDAR data, wherein the imaging data and LiDAR data are acquired by separate data acquisition steps and the combination is carried out by offline processing.

[0010] The publication "Multi-scale solution for building extraction from LiDAR and image data" (T. Thuy Vu et al., International Journal of Applied Earth Observation and Geoinformation 11 (2009) 281 - 289) discloses a multi-scale solution based on mathematical morphology for extracting building features from remotely sensed elevation and spectral data, wherein elevation data are used as the primary data to delineate the structural information.

[0011] US 2012/0007982 A1 discloses a moving platform system, e.g. for remote sensing / aerial imaging to capture views of a geographic area and to be able to measure objects and structures within the images as well as to determine geographic locations of points within the image. The moving platform system includes a sensor capture system, a non-line of sight communication system, a high-speed line of sight communication system, and a computer system.

[0012] It is therefore an object of the present invention to improve creation of 3D city models and 3D meshes.

[0013] It is an object of the invention to generally improve the efficiency and accuracy of object extraction, particularly building extraction, from stereo images for creating a 3D city model, wherein it is a particular object to improve point cloud extraction from stereo images.

[0014] Another object of the invention is to reduce point mismatching in a stereo imaging method for creating a 3D city model, in particular caused by homogeneous surfaces, vegetation, occlusions, or low lighting conditions, e.g. caused by shadow areas.

[0015] It is a particular object of the invention to improve ground referencing, particularly to improve infrastructure height referencing and street modelling.

[0016] Those objects are achieved by realising the features of the independent claims. Features which further develop the invention in an alternative or advantageous manner are described in the dependent patent claims.

[0017] The invention relates to a method for surveying of a city scape and for creation of a 3D city model of the surveyed city scape, in particular from aerial mapping data. The method to which the invention relates is defined by claim 1.

[0018] According to an example not defining the invention, the method comprises

- acquisition of imaging data of an area of the city scape, the imaging data being adapted for generation of 3D information, and simultaneous acquisition of lidar data for the area of the city scape,
- generation of a 3D point cloud of the area of the city scape, based on the imaging and lidar data, and
- generation of a 3D city model with automated building model extraction, based on the 3D point cloud.

[0019] Here, simultaneous acquisition of the imaging and lidar data means an acquisition of the imaging and lidar data during the same measuring process, in particular from one combined device, i.e. in one go when surveying a city scape but not necessarily exactly time synchronous.

[0020] According to an example not defining the invention, the method is characterized in that the generation of the 3D point cloud of the area of the city scape is based on

- processing of the imaging data regarding generation of 3D information,
- a quality assessment of the imaging data based on data classification, wherein at least

part of the imaging data being assigned to a first class being defined by at least one of

- a defined first classification criterion for the imaging data, and
- a defined second classification criterion within a first auxiliary 3D point cloud solely based on the imaging data, in particular wherein the auxiliary 3D point cloud being generated solely by the imaging data fulfilling the first classification criterion,
- a combination of the imaging data of the first class with lidar data corresponding to the fraction of the area of the city scape defined by the imaging data of the first class, in the following called the critical area, in particular wherein the imaging data being replaced or supplemented by the lidar data.

[0021] The first and second classification criteria are based on semantic classification and, for example, on geometric classification, such as a classification into at least one of regions with shadowing, e.g. with low signal to noise (S/N), regions with occlusions, regions with specific surface texture, e.g. such as very homogeneous regions such as water, and regions with vegetation. Furthermore, classification might be based on statistical properties, e.g. such as noise background, particularly by means of a S/N threshold, and/or thresholds based on an error propagation model for point matching in a stereoscopic image processing method.

[0022] The combination of the imaging data and the lidar data might be based on at least one of a 3D mesh of two or more point clouds, the point clouds particularly being generated by a point matching algorithm such as single global matching (SGM), replacement of imaging data with lidar data, replacement of lidar data with imaging data, and a reference model generated based on the lidar data, in particular the reference model comprising at least one of a digital terrain model, a digital elevation model, and a digital surface model.

[0023] The generation of the 3D city model might be based on generic classification algorithms for extracting a 3D city model from a point cloud, particularly a point cloud generated by stereoscopic imaging, and the extraction and generation of the 3D city model might be further based on at least one of GIS data, in particular for creating digital terrain models (DTM), high-level CAD data for buildings and infrastructure elements, BIM data, and multispectral information, e.g. such as normalized difference vegetation index images (NDVI images).

[0024] Therefore, by combining the best of the two worlds of stereoscopic imaging and lidar, i.e. high resolution information by stereoscopic imaging and lighting independent information by lidar, the generation of a 3D city model is strongly improved, in particular regarding efficiency and accuracy of object extraction. Problems regarding wrong building extraction and wrong ground height identification of automatic 3D building model creation are strongly mitigated and in particular for 3D mesh generation a meltdown on building edges, wrong ground height, or modelling of trees inside the mesh are strongly prevented.

[0025] In a particular embodiment of the method according to the invention, the generation of the 3D point cloud is further based on a quality assessment of the lidar data, wherein at least part of the lidar data being assigned to a second class being defined by at least one of

- a defined third classification criterion within a second auxiliary 3D point cloud solely based on the lidar data, in particular solely based on the lidar data of the critical area, and
- a defined first comparison criterion for comparing the first auxiliary 3D point cloud solely based on the imaging data with a third auxiliary point cloud based on a combination of the imaging and the lidar data, in particular wherein the imaging and lidar data being solely data of the critical area,

wherein the imaging data of the first class is only combined with lidar data of the critical area where the critical area is overlapping the fraction of the area of the city scape defined by the lidar data of the second class.

[0026] Therefore, before combining the imaging data and the lidar data for the critical area, the quality of the lidar data might be assessed by inherent properties of the lidar data, e.g. such as a local resolution threshold, a local S/N threshold, and/or a semantic classification into objects particularly well suited for lidar observations, e.g. such as flat surfaces. On the other hand, there might be regions or objects which are not well suited for lidar observations, e.g. very low reflection surfaces, and thus a combination of the imaging data with lidar data would introduce additional noise or systematic errors. Furthermore, the first comparison criterion might provide a quality control in a sense that a combination of the imaging data with the lidar data actually leads to an improved 3D point cloud generation compared to a 3D point cloud solely based on the imaging data. For example such a comparison criterion might be based on a differential S/N threshold, a resolution threshold, and/or a differential threshold based on systematic error propagation.

[0027] Typically point clouds generated from lidar data have much lower point density and meshes have far less detail and are often not textured. Therefore, in most cases for 3D city modelling the point cloud generation is mainly based on stereoscopic imaging with much higher resolution, and, according to the present invention, the lidar data is only consulted for critical areas, e.g. where lighting conditions for classical imaging are not favourable. However, depending on the desired level of detail (LOD) of the 3D city model and/or the type of the imaging device, there might be applications where the desired LOD might only be achieved by a combination of imaging data with lidar data. On the other hand, for example for a quick look analysis of very low level of detail it might be preferred to replace as much of the imaging data by lidar data, e.g. because processing of lidar data might require less computing power, in particular since lidar data is inherently representing a point cloud.

[0028] Thus a main driver for combining the imaging data with the lidar data might also be based on the overall quality of the lidar data acquired for the area of the surveyed city scape, i.e. not only for critical areas of the imaging data. Therefore, in another embodiment of the invention the generation of the 3D point cloud is further based on a quality assessment of the

lidar data based on data classification, wherein at least part of the lidar data being assigned to a third class being defined by at least one of

- a defined fourth classification criterion within the second auxiliary 3D point cloud solely based on the lidar data, and
- a defined second comparison criterion for comparing the first auxiliary 3D point cloud solely based on the imaging data with the third auxiliary point cloud based on a combination of the imaging and the lidar data,

wherein the imaging data corresponding to the fraction of the area of the city scape defined by the lidar data of the third class being combined with the lidar data of the third class.

[0029] Again the quality of the lidar data might be assessed by inherent properties of the lidar data, e.g. such as a local resolution threshold, a local S/N threshold, and/or a semantic classification into objects particularly well suited for lidar observations, e.g. such as flat surfaces. On the other hand, there might be regions or objects which are not well suited for lidar observations, e.g. very low reflection surfaces, and thus a combination of the imaging data with lidar data would introduce additional noise or systematic errors. Similar to the case of the first comparison criterion above the second comparison criterion might provide a quality control in a sense that a combination of the imaging data with the lidar data actually leads to an improved 3D point cloud generation compared to a 3D point cloud solely based on the imaging data. For example such a comparison criterion might be based on a differential S/N threshold, a resolution threshold, and/or a differential threshold based on systematic error propagation.

[0030] A particular embodiment of the method is characterized in that at least one of the first to fourth classification criteria being based on a semantic classification, in particular wherein the semantic classification comprises semantic classifiers defining at least one of shadowing, a region with an occlusion, a region with vegetation, and a region with a homogeneous surface, in particular a water surface. For these regions even lower resolution lidar data may provide substantial support for point matching algorithms, e.g. by providing a digital surface model and lighting independent information. Semantic classification might comprise any generic semantic classification algorithms, e.g. based on identification of geometric 3D primitives, single point recognition and edge tracking algorithms, object extraction based on probabilistic algorithms, infrastructure models, and statistical models for different surface texture.

[0031] In a further embodiment at least one of the first to second comparison criteria is based on at least one of a signal to noise threshold, a resolution threshold, and a systematic error threshold, in particular based on an error propagation model for point mismatching. The thresholds may be based on the desired level of detail of the 3D city scape or they may be specifically tuned for efficient processing.

[0032] Since the lidar data is typically used as supporting data, e.g. for critical areas when generating a 3D point cloud based on stereoscopic imaging, the acquisition of the lidar data might be specifically tuned to be only taken for these critical areas of the city scape, e.g. to reduce requirements on data storage and processing power. Thus in another embodiment the

lidar data is acquired for a selected region of the area within the surveyed city scape, based on at least one of an a-priori model of the surveyed city scape, and an analysis of the imaging data, particularly the quality assessment of the imaging data, in particular the critical area. For many applications of city modelling a first estimate or a first 3D model of the city might be available before surveying. Thus, the scan pattern for acquiring the lidar data might be specifically tuned to cover only the critical areas, but e.g. with high resolution, in particular using a Palmer scanning lidar device or a lidar device with a fast sweeping mirror. Furthermore, the selection might also be based on a real-time analysis and information of the imaging data, e.g. by a 2D classification of the imaging data or the quality assessment of the imaging data for generating the 3D point cloud.

[0033] Another embodiment of the method according to the invention is described wherein the generation of the 3D point cloud for the 3D city model is based on a photogrammetric method, in particular a semi global matching algorithm, wherein the photogrammetric method being adapted for processing at least one of nadir and/or oblique images, particularly with oblique angles between 30-45 degrees, multispectral images, in particular RGB and/or RGBN images, normalized difference vegetation index images (NDVI images), building footprints, and a reference model comprising at least one of a digital terrain model, a digital elevation model, and a digital surface model.

[0034] Here, multispectral image information and NDVI images might be used for semantic discrimination of objects with specific wavelength and polarization dependent reflection properties, such as for example typical reflection signals for vegetation and water. Building footprints and the reference model might particularly provide a ground reference and thus improve infrastructure modelling. In particular the building footprints and the reference model might be automatically generated based on the lidar data.

[0035] According to the invention, the imaging data and the lidar data are acquired by one single hybrid 3D-imaging device, the hybrid 3D-imaging device comprising a nadir imaging camera, in particular exactly one nadir imaging camera, particularly with multispectral bands, four oblique imaging cameras, in particular comprising a RGB or RGBN camera, in particular exactly four oblique imaging cameras with oblique angles of 30-45 degrees, and a lidar device, in particular exactly one lidar device.

[0036] Thus, this setup provides an efficient and simultaneous acquisition of both imaging and lidar data, in a sense that the imaging and lidar data are acquired during the same surveying measurement, i.e. in one go, and wherein the imaging data can be readily processed within a stereoscopic method, e.g. by semi global matching, for creating the 3D point cloud for the generation of the 3D city model. In particular, such a hybrid 3D-imaging device might be installed in one standard aircraft hole, e.g. using a single stabilization system for stabilizing a common inertial system for the cameras and the lidar device, and being controlled by a single operator from a single controlling interface. Operation might be further supported by a dedicated mission planning software taking into account the surveyable city scape and making recommendations for operating both lidar and imaging devices to optimize data acquisition.

[0037] The invention further relates to a hybrid 3D-imaging device for surveying of a city scape, in particular an aerial hybrid 3D-imaging device, for creation of a 3D city model of the surveyed city scape. The hybrid 3D-imaging device to which the invention relates is defined by claim 7.

[0038] According to an example not defining the invention, the hybrid 3D-imaging device comprises

- an imaging device for generating imaging data for an area of the city scape, the imaging data being adapted for generation of 3D information, in particular wherein the area being imaged from at least two different image viewing angles,
- a lidar device for generating lidar data for the area of the city scape, simultaneously to the generation of the imaging data, and
- a control and processing unit being adapted for
 - controlling the imaging device and the lidar device,
 - generating a 3D point cloud for the area of the city scape based on the imaging and the lidar data, and
 - generating a 3D city model with automated building model extraction, based on the 3D point cloud.

[0039] Here, simultaneous acquisition of the imaging and lidar data means an acquisition of the imaging and lidar data during the same measuring process, i.e. in one go when surveying a city scape but not necessarily exactly time synchronous.

[0040] According to an example not defining the invention, the system is characterized in that the control and processing unit is adapted for generating the 3D point cloud with

- processing of the imaging data regarding generation of 3D information,
- assessing a quality of the imaging data based on data classification, wherein at least part of the imaging data being assigned to a first class being defined by at least one of
 - a defined first classification criterion for the imaging data, and
 - a defined second classification criterion within a first auxiliary 3D point cloud solely based on the imaging data, in particular wherein the auxiliary 3D point cloud being generated solely by the imaging data fulfilling the first classification criterion,
- combining the imaging data of the first class with lidar data corresponding to the fraction of the area of the city scape defined by the imaging data of the first class, in the following called the critical area, in particular wherein the imaging data being replaced or supplemented by the lidar data.

[0041] In a particular embodiment of the hybrid 3D-imaging device according to the invention, the control and processing unit is adapted for generating the 3D point cloud with a quality assessment of the lidar data, wherein at least part of the lidar data being assigned to a second class being defined by at least one of

- a defined third classification criterion within a second auxiliary 3D point cloud solely based on the lidar data, in particular solely based on the lidar data of the critical area, and
- a defined first comparison criterion for comparing the first auxiliary 3D point cloud solely based on the imaging data with a third auxiliary point cloud based on a combination of the imaging and the lidar data, in particular wherein the imaging and lidar data being solely data of the critical area,

wherein the imaging data of the first class is only combined with lidar data of the critical area where the critical area is overlapping the fraction of the area of the city scape defined by the lidar data of the second class.

[0042] In another embodiment of the hybrid 3D-imaging device the control and processing unit is adapted for generating the 3D point cloud with a quality assessment of the lidar data based on data classification, wherein at least part of the lidar data being assigned to a third class being defined by at least one of

- a defined fourth classification criterion within the second auxiliary 3D point cloud solely based on the lidar data, and
- a defined second comparison criterion for comparing the first auxiliary 3D point cloud solely based on the imaging data with the third auxiliary point cloud based on a combination of the imaging and the lidar data,

wherein the imaging data corresponding to the fraction of the area of the city scape defined by the lidar data of the third class being combined with the lidar data of the third class.

[0043] According to the invention, the hybrid 3D-imaging device is characterized in that the first and the second, and particularly at least one of the third and fourth, classification criteria being based on a semantic classification, wherein the semantic classification comprises semantic classifiers defining at least one of shadowing, a region with an occlusion, a region with vegetation, and a region with a homogeneous surface, in particular a water surface.

[0044] In a further embodiment of the hybrid 3D-imaging device at least one of the first to second comparison criteria is based on at least one of a signal to noise threshold, a resolution threshold, and a systematic error threshold, in particular based on an error propagation model for point mismatching.

[0045] In another embodiment the hybrid 3D-imaging device is adapted for acquiring lidar data

for a selected region of the area within the surveyed city scape, based on at least one of an a-priori model of the surveyed city scape, and an analysis of the imaging data, particularly the quality assessment of the imaging data, in particular the critical area.

[0046] In a particular embodiment of the hybrid 3D-imaging device the control and processing unit is adapted for generating the 3D point cloud for the 3D city model with a photogrammetric method, in particular a semi global matching algorithm, and wherein the control and processing unit is adapted for processing at least one of nadir and/or oblique images, particularly with oblique angles between 30-45 degrees, multispectral images, in particular RGB and/or RGBN images, normalized difference vegetation index images (NDVI images), building footprints, and a reference model comprising at least one of a digital terrain model, a digital elevation model, and a digital surface model. According to the invention, the hybrid 3D-imaging device is built as one single hybrid 3D-imaging device, comprising a nadir imaging camera, in particular exactly one nadir imaging camera, particularly with multispectral bands, four oblique imaging cameras, in particular comprising a RGB or RGBN camera, in particular exactly four oblique imaging cameras with oblique angles of 30-45 degrees, and a lidar device, in particular exactly one lidar device or two lidar devices.

[0047] The invention also relates to a computer program product for generating a 3D city model of a surveyed city scape according to the inventive method, the computer program product being stored on a control and processing unit, particularly being part of a hybrid 3D-imaging device according to the invention. The computer program product to which the invention relates is defined by claim 13.

[0048] According to an example not defining the invention, the computer program product comprises program code being configured for

- automatically communicating with a database comprising imaging and lidar data of a surveyed city scape,
- generating a 3D point cloud of the area of the city scape based on the imaging and lidar data, wherein the generation of the 3D point cloud being further based on
 - a quality assessment of the imaging data based on data classification, wherein at least part of the imaging data being assigned to a first class being defined by at least one of
 - a defined first classification criterion for the imaging data, and
 - a defined second classification criterion within a first auxiliary 3D point cloud solely based on the imaging data, in particular wherein the auxiliary 3D point cloud being generated solely by the imaging data fulfilling the first classification criterion,
- combining the imaging data of the first class with lidar data corresponding to the fraction of the area of the city scape defined by the imaging data of the first class, in the following called the critical area, in particular wherein the imaging data being replaced or supplemented by the lidar data,
 - in particular wherein the output is made available to a hybrid 3D-imaging device

according to the invention.

[0049] According to the invention, the hybrid 3D-imaging device comprises one single sensor platform supporting a nadir imaging camera, particularly with multispectral bands, four oblique imaging cameras, in particular comprising a RGB or RGBN camera, in particular with an oblique angle of 30-45 degrees, and a lidar device, wherein the nadir and oblique imaging cameras being arranged on the sensor platform on a circumferential area around the lidar device.

[0050] In a particular embodiment of the hybrid 3D-imaging device the sensor platform supports exactly one nadir camera, four oblique imaging cameras with oblique angles of 30-45 degrees with respect to the sensor platform, in particular RGB or RGBN cameras, in particular exactly four oblique cameras, and a lidar device, in particular being adapted for a Palmer lidar scan, in particular exactly one lidar device or exactly two lidar devices, wherein the four oblique imaging cameras all have different viewing directions from each other.

[0051] According to the invention, the four oblique imaging cameras and the nadir camera are placed circumferentially around the lidar device, with a mostly uniform angular separation and with a common distance from the center.

[0052] This device setup provides an efficient and simultaneous acquisition of both imaging and lidar data, in a sense that the imaging and lidar data are acquired during the same surveying measurement, i.e. in one go, and wherein the imaging data can be readily processed within a stereoscopic method, e.g. by semi global matching, for creating a 3D point cloud for the generation of a 3D city model. In particular, such a hybrid 3D-imaging device might be installed in one standard aircraft hole, e.g. using a single stabilization system for stabilizing a common inertial system for the cameras and the lidar device, and being controlled by a single operator from a single controlling interface. Operation might be further supported by a dedicated mission planning software taking into account the surveyable city scape and making recommendations for operating both lidar and imaging devices to optimize data acquisition.

[0053] Depending on the acquisition area, a variety of sensor platform configurations may be possible to best support the simplified generation of the model. Thus, the hybrid sensor setup may vary depending on the application and the area to be surveyed.

[0054] Devices, methods and setups and computer programs according to the invention are described or explained in more detail below, purely by way of example, with reference to working examples shown schematically in the drawing. Specifically,

Fig. 1a,b:

generic stereoscopic image processing steps for creating a 3D city model, based on stereoscopic imaging data (a) and in combination with additional building footprint data

(b);

Fig. 2:

generic 3D point cloud generated from stereoscopic imaging data, indicating point mismatching and other critical areas for a point matching algorithm;

Fig. 3:

exemplary embodiment of a hybrid 3D-imaging device according to the invention.

[0055] The diagrams of the figures should not be considered as being drawn to scale. Where appropriate, the same reference signs are used for the same features or for features with similar functionalities.

[0056] Figure 1 shows generic stereoscopic image processing steps for creating a 3D city model, here a 3D city model in LOD 2, based on stereoscopic imaging data and based on a combination of stereoscopic imaging data with additional model data, here building footprint data.

[0057] **Figure 1a** illustrates a general process for creating a 3D city model 1 from a 3D point cloud 2 generated from stereoscopic imaging data 3 with a point matching algorithm 4, e.g. such as a single global matching (SGM) algorithm or a similar technique. Based on the 3D point cloud 2 specialized extraction models 5 are used to extract a 3D city model 1 of a given level of detail (LOD). Typically such extraction models 5 are based on object classification algorithms, particularly based on geometric and semantic classification, and usually make use of additional input such as building footprints, GIS data for creating digital terrain models (DTM), high-level CAD data for buildings and infrastructure elements, and BIM data for providing the highest level of detail for building components. 3D city models might also be generated by creating meshes from point clouds, the point clouds being generated through the extraction from stereo images using SGM or similar techniques. In certain cases objects might also be extracted from lidar data, however in the case of city modelling objects such as buildings or infrastructure are often not textured and of low resolution. Thus, for city modelling it is common practice however, that such meshes are more likely generated from Nadir and/or oblique imaging as image data offers better resolution and thus more detail.

[0058] **Figure 1b** illustrates a generic creation of a 3D city model 1' from a 3D point cloud 2 generated from stereoscopic imaging data 3 with a point matching algorithm 4, wherein additional building footprint data 6 is used for the extraction model 5' to generate the 3D city model. Building footprints and/or reference models such as digital surface models might particularly provide a ground reference and thus improve infrastructure modelling. In particular the building footprints and the reference model might be automatically generated based on the lidar data.

[0059] **Figure 2** shows a generic 3D point cloud 2 generated from stereoscopic imaging data 3, for example by means of a point matching algorithm 4 such as a semi global matching

algorithm. Even for dense matching, i.e. for very dense image overlaps, there are areas within the point cloud 2 where point extraction efficiency is substantially worse (below average) than for the rest of the point cloud 2. This is for example the case for occlusions and canyons 7 with low lighting conditions, for shadow areas 8 exhibiting increased noise, for very inhomogeneous areas such as vegetation 9, e.g. because complex modelling is required, and for very homogeneous surfaces 10, e.g. due to a lack of defined reference structure for point matching. In the case of automatic 3D building model creation this might cause wrong building identification, wrong ground height identification, and reduced accuracy. In the case of 3D mesh generation problems such as meltdown on building edges, wrong ground height, and modelling of trees inside the mesh may occur.

[0060] Point clouds from lidar data generally do not have such issues. However, due to the lower point density, meshes have far less detail and are often not textured. Anyway, lidar data is not depending on lighting conditions and provides 1st, 2nd, and 3rd return to see through vegetation. Therefore, according to the invention, generic (stereoscopic) imaging data is combined with lidar data, in particular for compensating and addressing particular problem areas of generic stereoscopic image processing where the accuracy and efficiency of point matching and point extraction is below average.

[0061] According to the invention lidar data is for example used to provide ground reference in low lighting areas and occlusions, and for improving point matching for vegetation areas and homogeneous surface areas such as water.

[0062] In particular, according to the invention lidar data is acquired simultaneously with the acquisition of imaging data for stereoscopic imaging. Here, simultaneous acquisition of data means an acquisition of the imaging and lidar data during the same measuring process, i.e. in one go when surveying a city scape. Therefore, by combining the best of the two worlds of stereoscopic imaging and lidar, i.e. high resolution information by stereoscopic imaging and lighting independent information by lidar, the generation of a 3D city model is strongly improved.

[0063] Figure 3 shows a hybrid 3D-imaging device 11 according to the invention for surveying of a city scape and for acquiring data for a method according to the invention, i.e. combining an oblique imager with a lidar device in the same sensor for simultaneous acquisition of both data. Here, the hybrid 3D-imaging device 11 might be an airborne sensor device which can be installed in one standard aircraft hole, wherein the hybrid 3D-imaging device 11 comprises a single stabilizing platform 12 and its imaging and lidar subsystems can be controlled by one operator from a single control interface.

[0064] Here, the hybrid 3D-imaging device 11 comprises one single sensor platform 13 supporting exactly one nadir camera 14, particularly with multispectral bands, exactly four oblique RGB or RGBN cameras 15, in particular with oblique angles of 30-45 degrees, and exactly one lidar device 16, in particular wherein the lidar device is adapted for providing a Palmer scan. The four oblique imaging cameras 15 all have different viewing directions from

each other, and the four oblique imaging cameras 15 and the nadir camera 14 are placed circumferentially around the lidar device 16, in particular with a mostly uniform angular separation and with a common distance from the center.

[0065] Depending on the acquisition area, a variety of sensor platform configurations, which are not part of the invention, may be possible to best support the simplified generation of the model. Thus, according to examples that are not part of the invention, the hybrid sensor setup may vary depending on the application and the area to be surveyed.

REFERENCES CITED IN THE DESCRIPTION

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- **MICHAEL CRAMER**The DGPF-Test on Digital Airborne Camera Evaluation - Overview and Test DesignPFG 02/2010, Final Version, 2010, **[0009]**
- **T. THUY VU et al.**Multi-scale solution for building extraction from LiDAR and image dataInternational Journal of Applied Earth Observation and Geoinformation, 2009, vol. 11, 281-289 **[0010]**

Patentkrav

1. Fremgangsmåde til opmåling af et bylandskab og til skabelse af en 3D-by-model (1, 1') af det opmålte bylandskab, især ud fra luftkortdata, hvilken fremgangsmåde omfatter

- opnåelse af billeddannelsesdata (3) for et område af bylandskabet, hvilke billeddannelsesdata (3) er tilpasset til generering af 3D-information, nemlig til stereoskopisk billeddannelse, og samtidig opnåelse af lidardata for bylandskabets område, hvor billeddannelsesdataene (3) og lidardataene opnås under samme måleproces, nemlig på én gang under opmåling af bylandskabet, under anvendelse af en 3D-billeddannelsesindretning (11), der omfatter en enkelt stabiliseringsplatform (12), som understøtter en lidarindretning (16), et nadirkamera (14) og fire skrå billeddannelseskameraer (15), der alle har forskellige visningsretninger i forhold til hinanden, hvor de fire skrå billeddannelseskameraer (15) og nadirkameraet (14) er placeret periferisk omkring lidarindretningen (16) med en for det meste ensartet vinkeladskillelse og med en fælles afstand fra midten,
- generering af en 3D-punktsky (2) for bylandskabets område baseret på
 - o behandling af billeddannelsesdataene (3) inden for en stereoskopisk fremgangsmåde til generering af 3D-information,
 - o en kvalitetsvurdering af billeddannelsesdataene (3) baseret på dataklassifikation, hvor i det mindste en del af billeddannelsesdataene tildeles til en første klasse, idet den første klasse angiver et kritisk område for behandlingen af billeddannelsesdataene, idet den første klasse defineres ved hjælp af mindst én af
- et defineret første klassifikationskriterium for billeddannelsesdataene (3), og

5 ▪ et defineret andet klassifikationskriterium inden for en første hjælpe-3D-punktsky udelukkende baseret på billeddannelsesdataene, idet det første og det andet klassifikationskriterium er baseret på semantisk klassifikation, hvor den semantiske klassifikation omfatter semantiske klassifikatorer, der definerer mindst én af skygge, en region med en okklusion, en region med vegetation og en region med en homogen overflade,

10 o en kombination af billeddannelsesdataene for den første klasse med lidardata svarende til den del af bylandskabets område, der defineres af den første classes billeddannelsesdata, hvor lidardataene kun konsulteres for det kritiske område,

15 • generering af en 3D-bymodel (1, 1') med automatiseret bygningsmodeldekstraktion, baseret på 3D-punktskyen (2), ved at oprette en maske ud fra 3D-punktskyen (2).

15

2. Fremgangsmåde ifølge krav 1,

kendetegnet ved, at

20 genereringen af 3D-punktskyen (2) endvidere baseres på en kvalitetsvurdering af lidardataene, hvor i det mindste en del af lidardataene tildeles til en anden klasse, der defineres ved hjælp af mindst én af

25 • et defineret tredje klassifikationskriterium inden for en anden hjælpe-3D-punktsky udelukkende baseret på lidardataene, især udelukkende baseret på lidardataene for det kritiske område, og

30 • et defineret første sammenligningskriterium til sammenligning af den første hjælpe-3D-punktsky, udelukkende baseret på billeddannelsesdataene, med en tredje hjælpepunktsky baseret på en kombination af billeddannelses- og lidardataene, især hvor billeddannelses- og lidardataene udelukkende er data for det kritiske område,

30 hvor billeddannelsesdataene for den første klasse kun kombineres med lidardata for det kritiske område, hvor det kritiske område overlapper

den del af bylandskabets område, der defineres af den anden klasses lidardata.

3. Fremgangsmåde ifølge krav 2,

5 kendetegnet ved, at

genereringen af 3D-punktskyen (2) endvidere baseres på en kvalitetsvurdering af lidardataene baseret på dataklassifikation, hvor i det mindste en del af lidardataene tildeles til en tredje klasse, der defineres ved hjælp af mindst én af

- 10 • et defineret fjerde klassifikationskriterium inden for den anden hjælpe-3D-punktsky udelukkende baseret på lidardataene, og
- et defineret andet sammenligningskriterium til sammenligning af den første hjælpe-3D-punktsky, udelukkende baseret på billeddannelsesdataene, med en tredje hjælpepunktsky baseret på en kombination af bil-
- 15 leddannelses- og lidardataene,

hvor de billeddannelsesdata, der svarer til den del af bylandskabet, som defineres af lidardataene for den tredje klasse, kombineres med lidardataene for den tredje klasse.

20 4. Fremgangsmåde ifølge krav 3,

kendetegnet ved, at

mindst ét af det tredje og det fjerde klassifikationskriterium er baseret på en semantisk klassifikation, især hvor den semantiske klassifikation omfatter semantiske klassifikatorer, der definerer mindst en af

- 25 • skygge (8),
- en region med en okklusion (7),
- en region med vegetation (9), og
- en region med en homogen overflade (10), især en vandoverflade.

5. Fremgangsmåde ifølge et hvilket som helst af kravene 3 og 4,

kendetegnet ved, at

mindst ét af de første til anden sammenligningskriterier er baseret på mindst
5 én af

- en signal/støj-tærskelværdi,
- en opløsningstærskelværdi, og
- en systematisk fejltærskelværdi, især baseret på en fejludbredelses-model for punktfejltilpasning.

10

6. Fremgangsmåde ifølge et hvilket som helst af de foregående krav,

kendetegnet ved, at

billeddannelsesdataene (3) og lidardataene opnås ved hjælp af én enkelt hybrid 3D-billeddannelsesindretning (11), især hvor

15

- den hybride 3D-billeddannelsesindretning (11) omfatter
 - præcis ét nadirbilleddannelseskamera, særlig med multispektrale bånd,
 - præcis fire skrå billeddannelseskameraer med skrå vinkler på 30-45 grader, og

20

- præcis én lidarindretning,
- lidardataene opnås for en udvalgt region af området inden for det opmålte bylandskab, baseret på mindst én af

25

- en a priori-model af det opmålte bylandskab, og
- en analyse af billeddannelsesdataene (3), særlig kvalitetsvurderingen af billeddannelsesdataene, især det kritiske område, og/eller

- genereringen af 3D-punktskyen (2) baseres på en fotogrammetrisk fremgangsmåde, især en semiglobal tilpasningsalgoritme, hvor den fotogrammetriske fremgangsmåde er tilpasset til behandling af mindst én af

- 5
 - nadir- og/eller skrå billeder, særlig med skrå vinkler på mellem 30-45 grader,
 - multispektrale billeder, især RGB og/eller RGBN,
 - normaldifferencevegetationsindeksbilleder,
 - bygningsaftryk, og

- 10
 - en referencemodel, der omfatter mindst én af en digital terrænmodel, en digital højdemodel og en digital overflademodel.

7. Hybrid 3D-billeddannelsesindretning (11) til opmåling af et bylandskab, især en hybrid luft-3D-billeddannelsesindretning, til skabelse af en 3D-bymodel (1, 1') af det opmålte bylandskab, hvilken hybrid 3D-billeddannelsesindretning (11) omfatter

- 15
 - en billedannelsesindretning (14, 15), der er konfigureret til at generere billedannelsesdata (3) for et område af bylandskabet, idet billedannelsesdataene (3) er tilpasset til generering af 3D-information, nemlig til stereoskopisk billedannelse,
- 20
 - en lidarindretning (16), der er konfigureret til at generere lidardata for bylandskabets område, samtidig med genereringen af billedannelsesdataene (3), hvor den hybride 3D-billeddannelsesindretning (11) er konfigureret således, at billedannelsesdataene og lidardataene opnås under samme måleproces, nemlig på én gang under opmåling af bylandskabet, og
- 25
 - en kontrol- og behandlingsenhed, der er indrettet til

- kontrol af billeddannelsesindretningen (14, 15) og lidarindretningen (16),
 - generering af en 3D-punktsky (2) for bylandskabets område baseret på billeddannelses- og lidardataene, og
- 5 ◦ generering af en 3D-bymodel (1, 1') med automatiseret bygningsmodelekstraktion, baseret på 3D-punktskyen (2), ved at oprette en maske ud fra 3D-punktskyen (2),
hvor kontrol- og behandlingsenheden er indrettet til at generere 3D-punktskyen (2) med
- 10 • behandling af billeddannelsesdataene (3) inden for en stereoskopisk fremgangsmåde til generering af 3D-information,
- vurdering af en kvalitet af billeddannelsesdataene (3) baseret på dataklassifikation, hvor i det mindste en del af billeddannelsesdataene tildeles til en første klasse, idet den første klasse angiver et kritisk område
- 15 for behandlingen af billeddannelsesdataene, idet den første klasse defineres ved hjælp af mindst én af
- et defineret første klassifikationskriterium for billeddannelsesdataene (3), og
- et defineret andet klassifikationskriterium inden for en første
- 20 hjælpe-3D-punktsky udelukkende baseret på billeddannelsesdataene,
idet det første og det andet klassifikationskriterium er baseret på semantisk klassifikation, hvor den semantiske klassifikation omfatter semantiske klassifikatorer, der definerer mindst én af skygge,
- 25 en region med en okklusion, en region med vegetation og en region med en homogen overflade,
- kombination af billeddannelsesdataene for den første klasse med lidardata svarende til den del af bylandskabets område, der defineres af den første classes billeddannelsesdata, hvor lidardataene kun

konsulteres for det kritiske område,
 hvor den hybride 3D-billeddannelsesindretning (11) omfatter en enkelt
 stabiliseringsplatform (12), der understøtter

- et nadirbilleddannelseskamera (14),
- 5 ◦ fire skrå billeddannelseskameraer (15), der alle har forskellige
 visningsretninger i forhold til hinanden, og
- lidarindretningen (16),
 hvor de fire skrå billeddannelseskameraer (15) og nadirkame-
 raet (14) er placeret periferisk omkring lidarindretningen (16) med
 10 en for det meste ensartet vinkeladskillelse og med en fælles af-
 stand fra midten.

8. Hybrid 3D-billeddannelsesindretning (11) ifølge krav 7,

kendetegnet ved, at

- 15 kontrol- og behandlingsenheden er indrettet til generering af 3D-punkt-
 skyen (2) med en kvalitetsvurdering af lidardataene, hvor i det mindste en del
 af lidardataene tildeles til en anden klasse, der defineres ved hjælp af mindst
 én af
- et defineret tredje klassifikationskriterium inden for en anden hjælpe-
 20 3D-punktsky udelukkende baseret på lidardataene, især udelukkende
 baseret på lidardataene for det kritiske område, og
 - et defineret første sammenligningskriterium til sammenligning af den
 første hjælpe-3D-punktsky, udelukkende baseret på billeddannelsesda-
 taene, med en tredje hjælpepunktsky baseret på en kombination af bil-
 25 leddannelses- og lidardataene, især hvor billeddannelses- og lidardata-
 ene udelukkende er data for det kritiske område,

hvor billeddannelsesdataene for den første klasse kun kombineres med li-
 dardata for det kritiske område, hvor det kritiske område overlapper den del af

bylandskabets område, der defineres af den anden klasses lidardata.

9. Hybrid 3D-billeddannelsesindretning (11) ifølge krav 8,

kendetegnet ved, at

5 kontrol- og behandlingsenheden er indrettet til generering af 3D-punktskyen (2) med en kvalitetsvurdering af lidardataene baseret på dataklassifikation, hvor i det mindste en del af lidardataene tildeles til en tredje klasse, der defineres ved hjælp af mindst én af

- 10 • et defineret fjerde klassifikationskriterium inden for den anden hjælpe-3D-punktsky udelukkende baseret på lidardataene, og
- et defineret andet sammenligningskriterium til sammenligning af den første hjælpe-3D-punktsky, udelukkende baseret på billeddannelsesdataene, med en tredje hjælpepunktsky baseret på en kombination af billeddannelses- og lidardataene,

15 hvor de billeddannelsesdata, der svarer til den del af bylandskabet, som defineres af lidardataene for den tredje klasse, kombineres med lidardataene for den tredje klasse.

10. Hybrid 3D-billeddannelsesindretning (11) ifølge krav 9,

kendetegnet ved, at

20 mindst ét af det tredje og det fjerde klassifikationskriterium er baseret på en semantisk klassifikation, især hvor den semantiske klassifikation omfatter semantiske klassifikatorer, der definerer mindst en af

- skygge (8),
- 25 • en region med en okklusion (7),
- en region med vegetation (9), og
- en region med en homogen overflade (10), især en vandoverflade.

11. Hybrid 3D-billeddannelsesindretning (11) ifølge et hvilket som helst af kravene 9 og 10,

kendetegnet ved, at

mindst ét af de første til anden sammenligningskriterier er baseret på mindst én af

- en signal/støj-tærskelværdi,
- en opløsningstærskelværdi, og
- en systematisk fejltærskelværdi, især baseret på en fejludbredelsesmodel for punktfejltilpasning.

10

12. Hybrid 3D-billeddannelsesindretning (11) ifølge et hvilket som helst af kravene 7 til 11,

kendetegnet ved, at

den hybride 3D-billeddannelsesindretning (11) er bygget som én enkelt hybrid 3D-billeddannelsesindretning, hvor

15

- den hybride 3D-billeddannelsesindretning omfatter
 - o præcis ét nadirbilleddannelseskamera, særlig med multispektrale bånd,
 - o præcis fire skrå billeddannelseskameraer med skrå vinkler på 30-45 grader, og
 - o præcis én lidarindretning eller to lidarindretninger,
- den hybride 3D-billeddannelsesindretning (11) er indrettet til opnåelse af lidardata for en udvalgt region af området inden for det opmålte bylandskab, baseret på mindst én af
 - o en a priori-model af det opmålte bylandskab, og

20

25

o en analyse af billeddannelsesdataene (3), særlig kvalitetsvurderingen af billeddannelsesdataene, især det kritiske område, og/eller

5 • kontrol- og behandlingsenheden er indrettet til generering af 3D-punktskyen (2) med en fotogrammetrisk fremgangsmåde, især en semiglobal tilpasningsalgoritme, og er indrettet til behandling af mindst én af

o nadir- og/eller skrå billeder, særlig med skrå vinkler på mellem 30-45 grader,

10 o multispektrale billeder, især RGB og/eller RGBN,

o normaldifferencevegetationsindeksbilleder,

o bygningsaftryk, og

o en referencemodel, der omfatter mindst én af en digital terrænmodel, en digital højdemodel og en digital overflademodel.

15

13. Computerprogramprodukt til generering af en 3D-bymodel (1, 1') af et opmålt bylandskab ifølge et af kravene 1 til 6,

kendetegnet ved, at

20 computerprogramproduktet er lagret på en kontrol- og behandlingsenhed, der især er en del af en hybrid 3D-billeddannelsesindretning (11) ifølge et af kravene 7 til 12, og som omfatter programkode, der er konfigureret til

• automatisk kommunikation med en database, der omfatter billeddannelses- (3) og lidardata for et opmålt bylandskab,

25 • generering af en 3D-punktsky (2) for bylandskabets område baseret på billeddannelses- (3) og lidardataene, hvor genereringen af 3D-punktskyen (2) endvidere er baseret på

- o behandling af billeddannelsesdataene (3) inden for en stereoskopisk fremgangsmåde til generering af 3D-information,
- o en kvalitetsvurdering af billeddannelsesdataene (3) baseret på dataklassifikation, hvor i det mindste en del af billeddannelsesdataene tildes til en første klasse, idet den første klasse angiver et kritisk område for behandlingen af billeddannelsesdataene, idet den første klasse defineres ved hjælp af mindst én af
- et defineret første klassifikationskriterium for billeddannelsesdataene, og
 - et defineret andet sammenligningskriterium inden for en første hjælpe-3D-punktsky udelukkende baseret på billeddannelsesdataene, især hvor hjælpe-3D-punktskyen udelukkende genereres ved, at billeddannelsesdataene opfylder det første klassifikationskriterium, idet det første og det andet klassifikationskriterium er baseret på semantisk klassifikation, hvor den semantiske klassifikation omfatter semantiske klassifikatorer, der definerer mindst én af skygge, en region med en okklusion, en region med vegetation og en region med en homogen overflade,
 - o kombination af billeddannelsesdataene for den første klasse med lidardata svarende til den del af bylandskabets område, der defineres ved hjælp af den første classes billeddannelsesdata, hvor lidardataene kun konsulteres for det kritiske område, især hvor billeddannelsesdataene erstattes af eller suppleres med lidardataene,
 - især hvor outputtet gøres tilgængeligt for en hybrid 3D-billeddannelsesindretning (11) ifølge et af kravene 7 til 12.

DRAWINGS

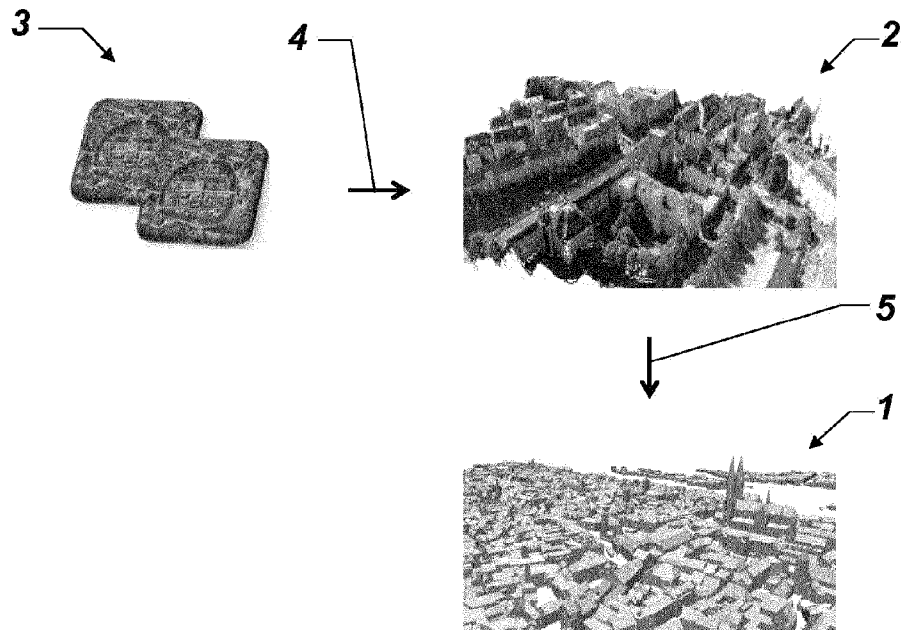


Fig.1a

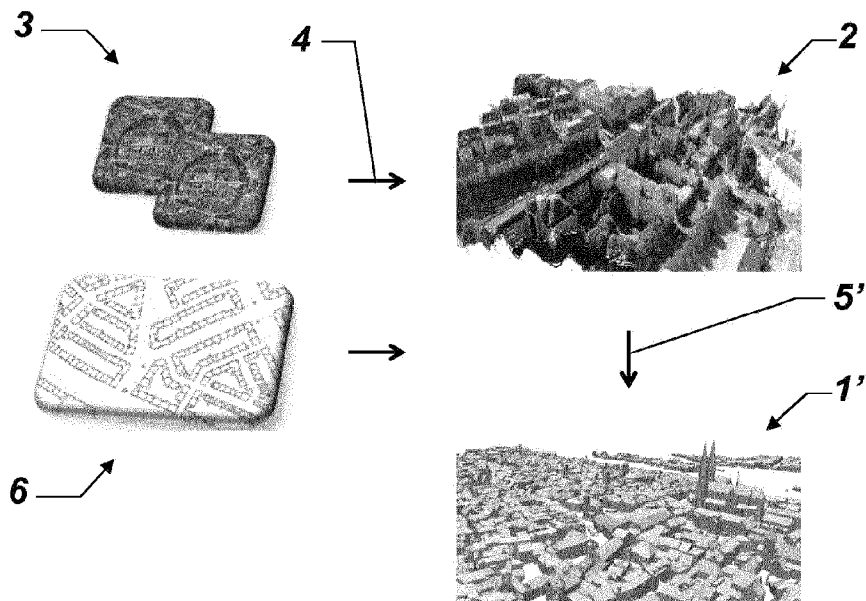


Fig.1b

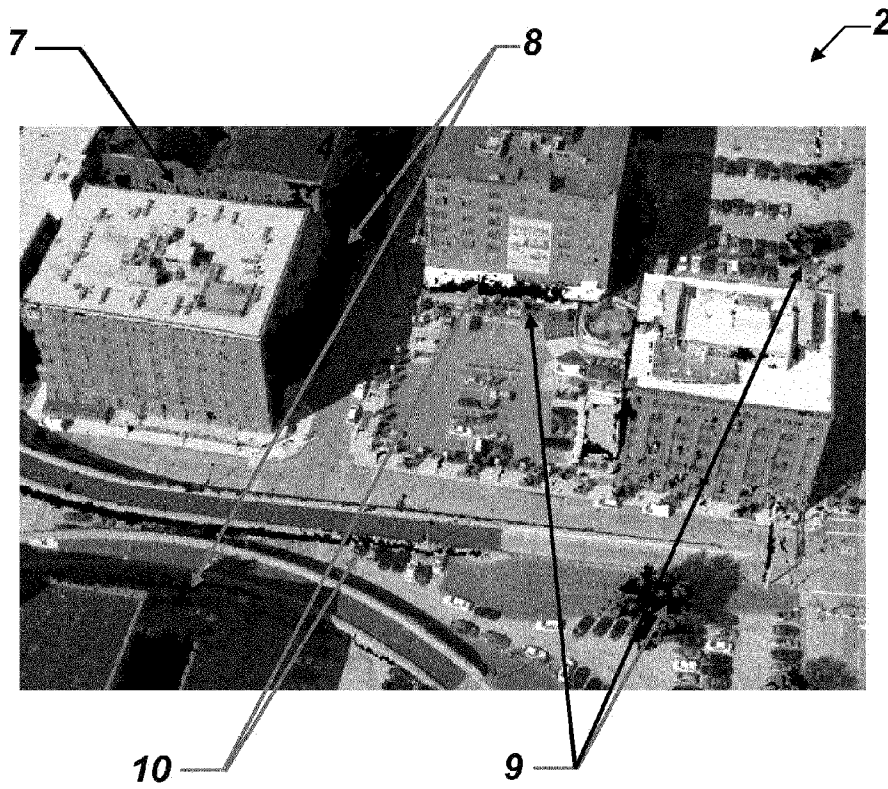


Fig.2

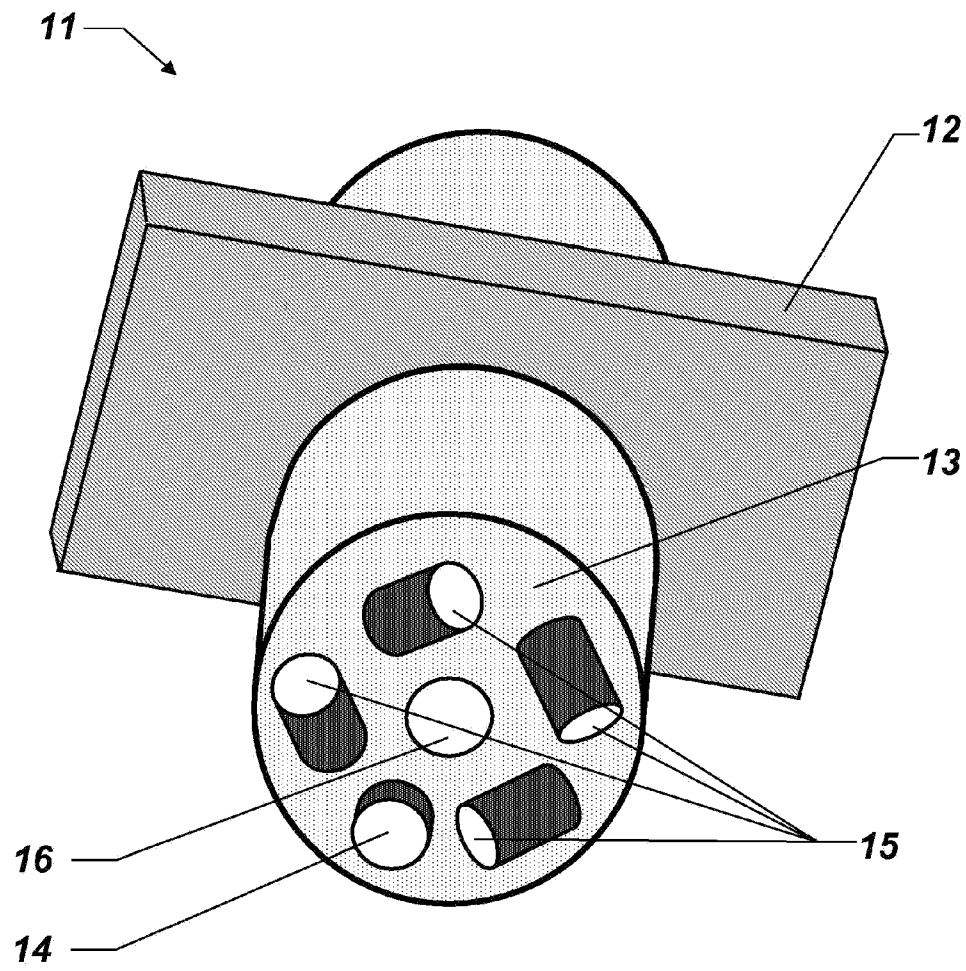


Fig.3