CLAIMS

1. An apparatus comprising:

a 3D dataset acquisition unit, configured to:

obtain from an imaging apparatus at a first position and orientation, a first 3D dataset of a first space at a first time, the first 3D dataset being a first point cloud in three dimensions, each point in the first point cloud representing a reading within the first space by the imaging apparatus; and

obtain from an imaging apparatus at a second position and orientation, a second 3D dataset of a second space at a second time, the second space and the first space overlapping, the second 3D dataset being a second point cloud in three dimensions, each point in the second point cloud representing a reading within the second space by the imaging apparatus;

a storage unit configured to store the first 3D dataset and the second 3D dataset as respective clouds of points in a common coordinate system; and

a rotational alignment processor configured to:

transform the stored first point cloud into a first set of vectors, and transform the stored second point cloud into a second set of vectors, wherein each member of the first set of vectors and each member of the second set of vectors represents the respective point and neighbouring points;

find at which angle of rotation of the second set of vectors relative to the first set in one or more of three axes of rotation, defined in the common coordinate system, the greatest degree of matching between the angular distribution of the first set of vectors and the angular distribution of the second set of vectors is obtained, the degree of matching being measured to compare the angular distributions of the first and second sets of vectors; and either:

output the angle of rotation about each of the one or more axis or axes of rotation for which the calculated degree of matching is greatest; or

rotate the second point cloud by the found angle of rotation about the respective one or more axes of rotation in the common coordinate system and output the rotated second point cloud in the common coordinate system;

wherein

the apparatus further comprises:

a translational alignment processor configured to:

for a line and a plane in the common coordinates system, wherein the line is at an angle to or normal to the plane:

record the position, relative to an arbitrary origin, of a projection onto the line of each point among the first point cloud and store the recorded positions as a first 1-dimensional array, and/or store one or more properties or readings of each point at the respective recorded position as the first 1-dimensional array;

record the position, relative to an arbitrary origin, of a projection onto the plane of each point among the first point cloud, and store the recorded positions as a first 2-dimensional array, and/or store one or more properties or readings of each point at the respective recorded position as the first 2-dimensional array;

record the position, relative to the arbitrary origin, of the projection onto the line of each point among the rotated second point cloud, and store the recorded positions as a second 1-dimensional array, and/or store one or more properties or readings of each point at the respective recorded position as the second 1-dimensional array;

record the position, relative to an arbitrary origin, of a projection onto the plane of each point among the rotated second point cloud, and store the recorded positions as a second 2-dimensional array, and/or store one or more properties or readings of each point at the respective recorded position as the second 2-dimensional array;

find a translation along the line of the second 1-dimensional array relative to the first 1-dimensional array at which a greatest degree of matching between the first 1-dimensional array and the second 1-dimensional array is computed, and record the translation at which the greatest degree of matching is computed; and

find a translation, in the plane, of the second 2-dimensional array relative to the first 2-dimensional array at which a greatest degree of matching between the first 2-dimensional array and the second 2-dimentional array is computed, and record said translation;

output either:

the first point cloud and the rotated second point cloud as a merged point cloud in the common coordinate system, with the rotated second point cloud translated along the line and in the plane in the common coordinates system by the respective recorded translation; and/or

a vector representation of the recorded translation along the line and in the plane, and a vector representation of the three axes of rotation and the respective found angles of rotation; and/or

the rotated second point cloud translated along the line and in the plane in the common coordinates system by the respective recorded translation.

2. An apparatus comprising:

a 3D dataset acquisition unit, configured to:

obtain from an imaging apparatus at a first position and orientation, a first 3D dataset of a first space at a first time, the first 3D dataset being a first point cloud in three dimensions, each point in the first point cloud representing a reading within the first space by the imaging apparatus; and

obtain from an imaging apparatus at a second position and orientation, a second 3D dataset of a second space at a second time, the second space and the first space overlapping, the second 3D dataset being a second point cloud in three dimensions, each point in the second point cloud representing a reading within the second space by the imaging apparatus;

a storage unit configured to store the first 3D dataset and the second 3D dataset as respective clouds of points in a common coordinate system; and

a rotational alignment processor configured to:

transform the stored first point cloud into a first set of vectors, and transform the stored second point cloud into a second set of vectors, wherein each member of the first set of vectors and each member of the second set of vectors represents the respective point and neighbouring points;

find at which angle of rotation of the second set of vectors relative to the first set in one or more of three axes of rotation, defined in the common coordinate system, the greatest degree of matching between the angular distribution of the first set of vectors and the angular distribution of the second set of vectors is obtained, the degree of matching being measured to compare the angular distributions of the first and second sets of vectors; and either:

output the angle of rotation about each of the one or more axis or axes of rotation for which the calculated degree of matching is greatest; or

rotate the second point cloud by the found angle of rotation about the respective one or more axes of rotation in the common coordinate system and output the rotated second point cloud in the common coordinate system;

wherein

the vectors of the first set of vectors and the vectors of the second set of vectors each comprise a plurality of subsets of vectors, each subset among the plurality representing the respective point cloud as vectors of a particular type, the particular type being different from that of the other subsets; wherein, the particular types include one or more from among:

- surface normal unit vectors, wherein the reading represented by each point in the first and second point clouds is a reading of a surface or interface between two materials,
- sum vectors,
- divergence vectors, a divergence vector being a vector in the same direction as the surface normal vector at the same point and having a magnitude proportional to the average divergence angle between the point and a set of neighbouring points, the angle deviation between each member of the set of neighbouring points and the point being the angle deviation between the normal at the member of the set of neighbouring points and the normal at the point;
- edge vectors, an edge vector representing an edge,
- cylinder vectors, a cylinder vector representing a cylinder, pipe, or column,
- plane vectors, a plane vector representing a plane area,
- point density gradient vectors, a point density gradient vector representing the direction of increase of point density,
- point density gradient divergence vectors, a point density gradient vector representing where the point density gradient vectors diverge, and
- gradient vectors;

wherein, in finding the greatest degree of matching:

between the angular distribution of the first set of vectors and the angular distribution of the second set of vectors; and/or

between the first 1-dimensional array and the second 1-dimensional array; and/or

between the first 2-dimensional array and the second 2-dimentional array;

degrees of matching between subsets of vectors of the same particular type are calculated on a type-by-type basis, and the degree of matching at any translation or angle of rotation, is a combination of the degrees of matching for the respective particular types, the combination being an average or a weighted average;

and wherein, in a case in which one of the particular types is sum vectors:

the vectors of the first set of vectors are sum vectors, and the vectors of the second set are sum vectors; and transforming the first point cloud into a first set

of sum vectors and transforming the second point cloud into a second set of sum vectors, comprises:

for each point cloud individually, for each point in the respective point cloud as an inquiry point: form a search radius sphere of predetermined radius around the inquiry point or find a specific number of nearest neighbour points; calculate vectors from the inquiry point to all other points within the search radius sphere or within the near neighbourhood; sum the calculated vectors to obtain the sum vector.

3. The apparatus according to claim 2, wherein

the apparatus further comprises:

a translational alignment processor configured to:

for each of three or more lines in the common coordinates system, wherein each pair of lines from among the three or more lines is non-parallel and at least one pair of lines from among the three or more lines is non-co-planar:

record the position, relative to an arbitrary origin, of a projection onto the line of each point among the first point cloud;

store the recorded positions as a first 1-dimensional array, and/or store one or more properties or readings of each point at the respective recorded position as the first 1-dimensional array;

record the position, relative to the arbitrary origin, of the projection onto the line of each point among the second point cloud;

store the recorded positions as a second 1-dimensional array, and/or store one or more properties or readings of each point at the respective recorded position as the second 1-dimensional array;

find a translation along the line of the second 1-dimensional array relative to the first 1-dimensional array at which a greatest degree of matching between the first 1-dimensional array and the second 1-dimensional array is computed, and record the translation at which the greatest degree of matching is computed; and

output either:

the first point cloud and the rotated second point cloud as a merged point cloud in the common coordinate system, with the rotated second point cloud translated along each of the three or more lines in the common coordinates system by the respective recorded translation; and/or

a vector representation of the three lines and recorded translation along each of the three or more lines, and a vector representation of the three axes of rotation and the respective found angles of rotation; and/or

the rotated second point cloud translated along each of the three or more lines in the common coordinates system by the respective recorded translation.

4. The apparatus according to claim 2, wherein

the apparatus further comprises:

a translational alignment processor configured to:

for a line and a plane in the common coordinates system, wherein the line is at an angle to or normal to the plane:

record the position, relative to an arbitrary origin, of a projection onto the line of each point among the first point cloud and store the recorded positions as a first 1-dimensional array, and/or store one or more properties or readings of each point at the respective recorded position as the first 1-dimensional array;

record the position, relative to an arbitrary origin, of a projection onto the plane of each point among the first point cloud, and store the recorded positions as a first 2-dimensional array, and/or store one or more properties or readings of each point at the respective recorded position as the first 2-dimensional array;

record the position, relative to the arbitrary origin, of the projection onto the line of each point among the rotated second point cloud, and store the recorded positions as a second 1-dimensional array, and/or store one or more properties or readings of each point at the respective recorded position as the second 1-dimensional array;

record the position, relative to an arbitrary origin, of a projection onto the plane of each point among the rotated second point cloud, and store the recorded positions as a second 2-dimensional array, and/or store one or more properties or readings of each point at the respective recorded position as the second 2-dimensional array;

find a translation along the line of the second 1-dimensional array relative to the first 1-dimensional array at which a greatest degree of matching between the first 1-dimensional array and the second 1-dimensional array is computed, and record the translation at which the greatest degree of matching is computed; and

find a translation, in the plane, of the second 2-dimensional array relative to the first 2-dimensional array at which a greatest degree of matching between the first 2-dimensional array and the second 2-dimentional array is computed, and record said translation;

output either:

the first point cloud and the rotated second point cloud as a merged point cloud in the common coordinate system, with the rotated second point cloud translated along the line and in the plane in the common coordinates system by the respective recorded translation; and/or

a vector representation of the recorded translation along the line and in the plane, and a vector representation of the three axes of rotation and the respective found angles of rotation; and/or

the rotated second point cloud translated along the line and in the plane in the common coordinates system by the respective recorded translation.

5. The apparatus according to claim 1 or 4, wherein

a 3D pattern matching algorithm is executed on the first point cloud and the second point cloud to recognise sets of points describing instances of features identifiable by said algorithm, to label the members of the sets of points as members of an instance of the respective identified feature, said label being a property of the labelled point; wherein

in finding a greatest degree of matching between the first 1-dimensional array and the second 1-dimensional array, and/or between the first 2-dimensional array and the second 2-dimensional array, degrees of matching for instances of the same feature are calculated on a feature-by-feature basis, and the degree of matching is a weighted combination of the feature-by-feature degrees of matching, weighted according to the number of labelled points labelled as members of an instance of the respective feature.

6. The apparatus according to any of claims 1 to 5, wherein:

the imaging apparatus from which one or both of the first 3D dataset and the second 3D dataset is obtained is either a LIDAR scanner, optical 3D scanning apparatus including photogrammetry, or a sonar scanner.

7. The apparatus according to any of the preceding claims, wherein

the imaging apparatus from which one or both of the first 3D dataset and the second 3D dataset is obtained is an electrical resistivity tomography scanner inserted into a ground surface and the imaged space is below the ground surface; or

the imaging apparatus from which one or both of the first 3D dataset and the second 3D dataset is obtained is an electrical impedance tomography scanner comprising electrodes for placement on a skin of a subject animal, and the imaged space is interior of the subject animal.

8. The apparatus according to any of the preceding claims, wherein

the imaging apparatus from which one or both of the first 3D dataset and the second 3D dataset is obtained is an MRI scanner or a scanner detecting nuclear quadrupole resonance, and the imaged space is the interior of a subject animal.

9. The apparatus according to any of the preceding claims, wherein

the 3D dataset acquisition unit comprises a denoising processor, wherein obtaining the first 3D dataset and obtaining the second 3D dataset includes the denoising processor executing a denoising algorithm on the first point cloud, and executing the denoising algorithm on the second point cloud.

10. The apparatus according to any of the preceding claims, wherein

the reading represented by each point in the first and second point clouds is a reading of a surface or interface between two materials; and

the vectors of the first set of vectors are surface normal unit vectors, and the vectors of the second set are surface normal unit vectors; and

transforming the first point cloud into a first set of surface normal vectors and transforming the second point cloud into a second set of surface normal vectors, comprises generating the first set of surface normal vectors and generating the second set of surface normal vectors by:

for each point cloud individually, for each point in the respective point cloud as an inquiry point: selecting a set of neighbour points, calculating a covariance matrix for the set of neighbour points and the inquiry point; solving the covariance matrix to find the three eigenvalues and three eigenvectors for the covariance matrix, determining the eigenvector with the smallest eigenvalue, normalising the eigenvector to a predetermined unit length, adding the normalised unit vector to the respective first or second set of normal vectors.

11. The apparatus according to claim 10, wherein

selecting the set of neighbour points for the inquiry point comprises either selecting each of the points within a sphere of a predefined radius with an origin coincident with the inquiry point, or selecting the N nearest points to the inquiry point; and

transforming the first point cloud into a first set of surface normal unit vectors and/or transforming the second point cloud into a second set of surface normal unit vectors further comprises:

storing the respective set of surface normal unit vectors as a reference set of normal unit vectors;

repeating the generating the respective set of surface normal unit vectors with a progressively smaller radius of the sphere until a minimum radius is reached, at which point the repeating is terminated and the reference set of surface normal unit vectors is set as the respective set of surface normal unit vectors, at each repetition:

determining a degree of confidence with which the respective set of surface normal unit vectors generated in the repetition match the reference set of surface normal unit vectors,

and

if the determined degree of confidence satisfies a predetermined criterion, setting the reference set of surface normal unit vectors as the respective set of surface normal unit vectors, and terminating the transforming, and

if the determined degree of confidence does not satisfy the predetermined criterion, replacing the stored reference set of surface normal unit vectors with the respective set of surface normal unit vectors generated in the repetition, and continuing the repeating.

12. The apparatus according to claim 1 or 2, wherein

edge detection is performed using the sum vectors, wherein the magnitude of the sum vectors are used to detect sum vectors representing edges and those representing corners, with larger magnitude indicating a vector representing an edge; and

surface feature detection is performed by calculating the vector dot product of the sum vector originating from a point of the point cloud and one or more nearby surface normal vectors, the angle having a cosine that is equal to the calculated vector dot product indicating the presence of a surface feature, and identifying the surface feature as an edge, a corner, or a hole or occlusion.

13. The apparatus according to any of claims 1 to 11, wherein

transforming the stored first point cloud into a first set of vectors, and transforming the stored second point cloud into a second set of vectors, wherein each member of the first set of vectors and each member of the second set of vectors represents the respective point and neighbouring points, includes executing an autoencoder on the stored first and second point clouds, or on a set of vectors representing said point clouds;

he autoencoder being an unsupervised deep learning algorithm for extracting features within the 3D space; wherein

the extracted features are represented by corresponding vectors in which position, orientation, and magnitude of the vector is determined by position, orientation, and dimension or dimensions of the extracted feature.

14. An apparatus according to claim 1 or 2, wherein transforming the stored first and second point clouds into first and second sets of vectors includes applying a non-linear filter to the point clouds or sets of vectors, wherein applying the non-linear filter comprises excluding from further processing any point from the point clouds, or any vectors from the sets of vectors, not recognised as representing edges by an edge detection algorithm.

15. An apparatus according to claim 1 or 2, wherein the rotational alignment processor is configured to transform the stored first and second point clouds into first and second sets of vectors, respectively, by,

for each point in the respective point cloud as an inquiry point:

calculating a surface normal;

calculating an angle deviation between the surface normal at the inquiry point compared to the surface normal of all of the near neighbour points within a small search radius sphere or for a specified number of nearest neighbour points;

calculating an average of the calculated angle deviations for the inquiry point;

obtaining, as the vector for the inquiry point in the respective set of vectors, a divergence vector, the divergence vector being a vector having the direction of the surface normal calculated for the inquiry point, and having a length proportional to the calculated average; and

filtering the first and second set of vectors by selecting those divergence vectors longer than a certain specified threshold value.

16. An apparatus according to claim 1 or 2, wherein transforming the stored first and second point clouds into first and second sets of vectors includes:

finding planes by one or more from among: RANSAC plane detection, Hough Transform plane detection, and region growing based on surface curvature, surface normal angle deviation, colour, reflectivity or roughness and distance from the plane;

finding the area of each plane;

awherein the respective set of vectors includes a vector for each found plane, the vector being a plane vector, which is a surface normal vector having a length equal to the area of the plane.

17. An apparatus according to claim 1 or 2, wherein,

the vectors of the first set of vectors include cylinder vectors, and the vectors of the second set include cylinder vectors; and transforming the first point cloud into a first set of cylinder vectors and transforming the second point cloud into a second set of cylinder vectors, respectively, comprises:

using a method for recognition of cylinders in the respective 3D dataset and finding the radius, position and orientation of each recognised cylinder;

aincluding in the respective set of vectors, a cylinder vector for each recognised cylinder, the cylinder vector for the recognised cylinder lying along, and parallel to, the orientation of the axis of the recognised cylinder, and having a length related to the radius of the recognised cylinder.

18. An apparatus according to claim 17, wherein

the method for recognition of cylinders in a 3D dataset comprises:

executing a segmentation algorithm to find potential cylinder candidates;

choose two random points lying within a certain distance of one another and lying on the same potential cylinder;

calculate a cylinder model for the potential cylinder on which the two points lie, the cylinder model comprising orientation, radius, and position;

based on surface curvature or surface angle deviation of the cylinder model, investigate points within a predetermined distance of the cylinder surface and, for any investigated points having a surface curvature or surface angle deviation within a predetermined threshold range of the surface curvature or

surface angle deviation of the cylinder model, region grow the cylinder model to include the investigated points.

19. The apparatus according to any of the preceding claims, wherein

finding at which angle of rotation of the second set of vectors relative to the first set in one or more of three axes of rotation defined in the common coordinate system the greatest degree of matching between the angular distribution of the first set of vectors and the angular distribution of the second set of vectors is obtained, comprises:

attributing a common origin to the vectors in the first and second sets of vectors;

dividing a notional sphere centred on the common origin into surface regions or volume regions;

finding at which angle of rotation of the second set of vectors relative to the first set in each of the one or more of the three axes of rotation defined in the common coordinate system the best match between the vector point distribution of vectors from the first set of vectors and the vector point distribution of vectors from the second set of vectors among the surface regions or volume regions is obtained.

20. The apparatus according to any of claims 1 to 14, wherein

the reading represented by each point in the first and second point clouds is a reading of a surface or interface between two materials;

the rotational alignment processor is further configured, before finding the best match between the angular distributions of the first and second sets of vectors, to:

filter the first and second sets of vectors by recognising, in both sets, surface normal unit vectors representing one of template shapes, and removing from the respective sets surface normal unit vectors not recognised as representing one of the template shapes.

21. The apparatus according to claim 8 or 20, wherein

the recognising is implemented by executing a segmentation algorithm on the first set of surface normal unit vectors and on the second set of surface normal unit vectors, respectively.

22. A system comprising:

a first imaging apparatus configured to generate, at a first position and orientation a first 3D dataset, the first 3D dataset of a first space at a first time;

a second imaging apparatus configured to generate, at a second position and orientation, a second 3D dataset, the second 3D dataset of a second space at a second time, the second space and the first space overlapping, wherein, either the second imaging apparatus is the first imaging apparatus and the second time is different from the first time, or the second imaging apparatus is different from the first imaging apparatus;

an apparatus according to claim 1 or 2, wherein the imaging apparatus at the first position and orientation is the first imaging apparatus, and the imaging apparatus at the second position and orientation is the second imaging apparatus.

23. A method comprising:

obtaining a first 3D dataset of a first space at a first time, the first 3D dataset being a first point cloud in three dimensions, each point in the first point cloud representing a reading within the first space by an imaging apparatus; and

obtaining a second 3D dataset of a second space at a second time, the second space and the first space overlapping, the second 3D dataset being a second point cloud in three dimensions, each point in the second point cloud representing a reading within the second space by an imaging apparatus;

storing the first 3D dataset and the second 3D dataset as respective clouds of points in a common coordinate system;

transforming the stored first point cloud into a first set of vectors, and transforming the stored second point cloud into a second set of vectors, wherein each member of the first set of vectors and each member of the second set of vectors represents the respective point and neighbouring points;

finding at which angle of rotation of the second set of vectors relative to the first set in one or more of three axes of rotation, defined in the common coordinate system, the greatest degree of matching between the angular distribution of the first set of vectors and the angular distribution of the second set of vectors is obtained, the degree of matching being measured to compare the angular distributions of the first and second sets of vectors; and either:

storing the angle of rotation about each of the one or more axis or axes of rotation for which the calculated degree of matching is greatest; or

rotating the second point cloud by the stored angle of rotation about the respective one or more axes of rotation in the common coordinate system, and outputting the rotated second point cloud in the common coordinate system,

wherein

the method further comprises:

for a line and a plane in the common coordinates system, wherein the line is at an angle to or normal to the plane:

recording the position, relative to an arbitrary origin, of a projection onto the line of each point among the first point cloud and store the recorded positions as a first 1-dimensional array, and/or store one or more properties or readings of each point at the respective recorded position as the first 1-dimensional array;

recording the position, relative to an arbitrary origin, of a projection onto the plane of each point among the first point cloud, and store the recorded positions as a first 2-dimensional array, and/or store one or more properties or readings of each point at the respective recorded position as the first 2-dimensional array;

recording the position, relative to the arbitrary origin, of the projection onto the line of each point among the rotated second point cloud, and store the recorded positions as a second 1-dimensional array, and/or store one or more properties or readings of each point at the respective recorded position as the second 1-dimensional array;

recording the position, relative to an arbitrary origin, of a projection onto the plane of each point among the rotated second point cloud, and store the recorded positions as a second 2-dimensional array, and/or store one or more properties or readings of each point at the respective recorded position as the second 2-dimensional array;

finding a translation along the line of the second 1-dimensional array relative to the first 1-dimensional array at which a greatest degree of matching between the first 1-dimensional array and the second 1-dimensional array is computed, and record the translation at which the greatest degree of matching is computed; and

finding a translation, in the plane, of the second 2-dimensional array relative to the first 2-dimensional array at which a greatest degree of matching between the first 2-dimensional array and the second 2-dimentional array is computed, and record said translation;

outputting either:

the first point cloud and the rotated second point cloud as a merged point cloud in the common coordinate system, with the rotated second point cloud

translated along the line and in the plane in the common coordinates system by the respective recorded translation; and/or

a vector representation of the recorded translation along the line and in the plane, and a vector representation of the three axes of rotation and the respective found angles of rotation; and/or

the rotated second point cloud translated along the line and in the plane in the common coordinates system by the respective recorded translation.

24. A method comprising:

obtaining a first 3D dataset of a first space at a first time, the first 3D dataset being a first point cloud in three dimensions, each point in the first point cloud representing a reading within the first space by an imaging apparatus; and

obtaining a second 3D dataset of a second space at a second time, the second space and the first space overlapping, the second 3D dataset being a second point cloud in three dimensions, each point in the second point cloud representing a reading within the second space by an imaging apparatus;

storing the first 3D dataset and the second 3D dataset as respective clouds of points in a common coordinate system;

transforming the stored first point cloud into a first set of vectors, and transforming the stored second point cloud into a second set of vectors, wherein each member of the first set of vectors and each member of the second set of vectors represents the respective point and neighbouring points;

finding at which angle of rotation of the second set of vectors relative to the first set in one or more of three axes of rotation, defined in the common coordinate system, the greatest degree of matching between the angular distribution of the first set of vectors and the angular distribution of the second set of vectors is obtained, the degree of matching being measured to compare the angular distributions of the first and second sets of vectors; and either:

storing the angle of rotation about each of the one or more axis or axes of rotation for which the calculated degree of matching is greatest; or

rotating the second point cloud by the stored angle of rotation about the respective one or more axes of rotation in the common coordinate system, and outputting the rotated second point cloud in the common coordinate system,

wherein

the vectors of the first set of vectors and the vectors of the second set of vectors each comprise a plurality of subsets of vectors, each subset among the plurality representing the respective

point cloud as vectors of a particular type, the particular type being different from that of the other subsets; wherein, the particular types include one or more from among:

- surface normal unit vectors, wherein the reading represented by each point in the first and second point clouds is a reading of a surface or interface between two materials,
- sum vectors,
- divergence vectors, a divergence vector being a vector in the same direction as the surface normal vector at the same point and having a magnitude proportional to the average divergence angle between the point and a set of neighbouring points, the angle deviation between each member of the set of neighbouring points and the point being the angle deviation between the normal at the member of the set of neighbouring points and the normal at the point;
- edge vectors, an edge vector representing an edge,
- cylinder vectors, a cylinder vector representing a cylinder, pipe, or column,
- plane vectors, a plane vector representing a plane area,
- point density gradient vectors, a point density gradient vector representing the direction of increase of point density,
- point density gradient divergence vectors, a point density gradient vector representing where the point density gradient vectors diverge, and
- gradient vectors;

wherein, in finding the greatest degree of matching:

between the angular distribution of the first set of vectors and the angular distribution of the second set of vectors; and/or

between the first 1-dimensional array and the second 1-dimensional array; and/or

between the first 2-dimensional array and the second 2-dimentional array;

degrees of matching between subsets of vectors of the same particular type are calculated on a type-by-type basis, and the degree of matching at any translation or angle of rotation, is a combination of the degrees of matching for the respective particular types, the combination being an average or a weighted average;

and wherein, in a case in which one of the particular types is sum vectors:

the vectors of the first set of vectors are sum vectors, and the vectors of the second set are sum vectors; and transforming the first point cloud into a first set of sum vectors and transforming the second point cloud into a second set of sum vectors, comprises:

for each point cloud individually, for each point in the respective point cloud as an inquiry point: form a search radius sphere of predetermined radius

around the inquiry point or find a specific number of nearest neighbour points; calculate vectors from the inquiry point to all other points within the search radius sphere or within the near neighbourhood; sum the calculated vectors to obtain the sum vector.

25. The method according to claim 23 or 24, wherein

the outputting comprises outputting the rotated second point cloud and the stored first point cloud defined in a common coordinate system and/or the first and second point clouds in their respective coordinate systems with the one or more stored angles of rotation.

26. The method according to claim 24 or 25, the method further comprising:

a translational alignment process comprising:

for each of three or more lines in the common coordinates system, wherein each pair of lines from among the three or more lines is non-parallel and at least one pair of lines from among the three or more lines is non-co-planar:

recording the position, relative to an arbitrary origin, of a projection onto the line of each point among the first point cloud;

storing the recorded positions as a first 1-dimensional array, and/or storing one or more properties or readings of each point at the respective recorded position as the first 1-dimensional array;

recording the position, relative to the arbitrary origin, of the projection onto the line of each point among the rotated second point cloud;

storing the recorded positions as a second 1-dimensional array, and/or storing one or more properties or readings of each point at the respective recorded position as the second 1-dimensional array;

finding a translation along the line of the second 1-dimensional array relative to the first 1-dimensional array at which a greatest degree of matching between the first 1D array and the second 1D array is computed, and recording the translation at which the greatest degree of matching is computed; and

outputting either:

the first point cloud and the rotated second point cloud as a merged point cloud in the common coordinate system, with the rotated second point cloud translated along each of the three or more lines in the common coordinates system by the respective recorded translation; and/or

a vector representation of the three or more lines and recorded translation along each of the three or more lines, and a vector representation of the three axes of rotation and the respective stored angles of rotation; and/or

the rotated second point cloud translated along each of the three or more lines in the common coordinates system by the respective recorded translation.

27. A method comprising:

obtaining a plurality of individual 3D datasets representing respective portions of a subject, the translational and rotational relations among the plurality of individual 3D datasets being unknown;

performing the method of claim 24, including,

for each combination of a pair of individual 3D datasets among the plurality of individual 3D datasets:

performing the storing, transforming, finding, and storing steps of the method of claim 24, and storing, in addition to the angle of rotation about the respective one or more axes of rotation, the magnitude of the corresponding greatest degree of matching between the angular distribution of the first set of vectors and the angular distribution of the second set of vectors;

for each individual 3D dataset among the plurality of individual 3D datasets:

of all pairs including the individual 3D dataset as a member of the pair, identifying the pair for which the stored greatest degree of matching is the maximum, and optionally any pair for which the stored greatest degree of matching is within a defined range of said maximum, and performing the translational alignment process of claim 26 on the or each identified pair;

performing the obtaining steps of claim 24 with the or each identified pair as the first and second 3D datasets, performing the rotating step of claim 24 on the identified pair with the angle of rotation about the respective one or more axes of rotation stored for the pair, with the rotated second point cloud translated along each of the three or more lines in the common coordinates system by the respective recorded translation from the translational alignment process of claim 26, thereby obtaining a pairwise point cloud representation of the pair of individual 3D datasets with a fixed rotational and translational relation between the pair;

merging the pairwise point cloud representations of the pairs into a single point cloud by co-locating instances of the same individual 3D dataset appearing in more than one of the pairwise point cloud representations.

28. A pair of point clouds defined in a common coordinate system obtained by the method according to any of claims 24 to 27.

29. An apparatus according to any of claims 1-4, wherein

rotational movement of the imaging apparatus is tracked with the angles of rotation output by the rotational alignment processor; and

movement of the imaging apparatus between obtaining the two point clouds is tracked with the vector representation of the three lines and the recorded translation along each of the three lines output by the translation processor.

30. An apparatus according to claim 29, wherein

the imaging apparatus is mounted to a vehicle, and a vehicle track is obtained from the vector representation of the three lines and the recorded translation along each of the three lines.

31. An apparatus according to claim 1 or 2, further comprising:

a translation alignment processor configured to find 3D objects and features in the first point cloud that match 3D objects and features in the second point cloud;

find the translation vectors which bring said 3D objects and features into alignment in the two point clouds;

find the most common translation vector from among said translation vectors by plotting histogram graphs of the lengths and angles of the translation vectors relative to three orthogonal axes, choosing the most common length and angles, and selecting any vectors within a small range of the most common vectors, and discarding the rest;

performing translational alignment of the two point clouds based on the most common translation vectors and the selected vectors.

32. An image processing method, comprising

obtaining a point-cloud representation of a subject, the point-cloud representation being composed of a plurality of individual scans, each scan being a point-cloud representation of a portion of the subject, each scan overlapping one or more other scans and

having a defined rotational and translational relation to said one or more other scans, wherein at least one of the scans is overlapping more than one other scan,

and characterised by executing a global alignment process comprising:

for each of the plurality of individual scans as a subject point cloud, setting the one or more other scans overlapping with the subject scan as a reference point cloud,

for each individual scan of the reference point cloud, executing a rotational alignment algorithm and translational alignment algorithm on the subject point cloud and the individual scan of the reference point cloud with the defined rotational and translation relation between the subject point cloud and the individual scan of the reference point cloud in the point-cloud representation of the subject as an initial estimation, to rotate and translate the subject point cloud relative to the individual scan of the reference point cloud until a process error criterion is met, to obtain a revised defined rotational and translational relation between the subject point cloud and the individual scan of the reference point cloud;

combining the revised defined rotational and translational relations between the subject point cloud and each of the individual scans in the reference point cloud;

implementing the combined revised defined rotational and translational relation between the subject point cloud and the reference point cloud in the point-cloud representation of the subject;

wherein

executing the rotational alignment algorithm comprises rotationally aligning the pair of scans, as first and second 3D datasets, in the apparatus according to any of claims 1 to 21, in the system of claim 22, by the method of any of claims 23-26;

the method further comprising:

repeating the global alignment process one or more times, with a progressively stricter process error criterion on each repetition.

33. The image processing method according to claim 32, further comprising

executing the translational alignment algorithm comprises aligning the pair of scans, as first and second 3D datasets, in the apparatus according to claim 3 or the method according to claim 26, the recorded translation being the defined translational relation.

34. The image processing method according to claim 32 or 33, wherein the process error criterion is a maximum allowable error.

35. A computer program which, when executed by a computing apparatus, causes the computing apparatus to execute a method according to any of claims 32-34.

36. An image processing apparatus, comprising memory hardware and processor hardware, the memory hardware storing processing instructions which, when executed by the processor hardware cause the processor hardware to perform an image processing method according to claim 32.