CLAIMS

1. A system comprising:

a sensor array comprising a plurality of magnetic field sensors configured to provide measurements of ambient magnetic fields in an environment;

a mapping module configured to receive the ambient magnetic fields and determine rotation-invariant ambient magnetic field vectors, based on the received ambient magnetic fields, to build a magnetic map representative of the environment,

wherein the magnetic map comprises coordinates established for each of a plurality of locations in the environment; and a rotation-invariant ambient magnetic field fingerprint at each location,

wherein the rotation-invariant ambient magnetic field fingerprint is to be determined based on rotation-invariant ambient magnetic field vectors at that location, each rotation-invariant ambient magnetic field vector to be determined by:

representing the ambient magnetic field measured by one or each of the plurality of magnetic field sensors at a position within the environment or within a working distance of the one or each of the plurality of magnetic field sensors from an edge boundary of the environment as an ambient magnetic field vector in a local coordinate system;

inferring, based on the ambient magnetic field vector, an orientation of the one or each of the plurality of magnetic field sensors; and

aligning, based on the inferred orientation, the ambient magnetic field vector in the local coordinate system to a global coordinate system to generate the rotation-invariant ambient magnetic field vector, the rotation-invariant ambient magnetic field vector comprising two orthogonal components and an integrated intensity of the measured ambient magnetic field; and

a localization module configured to

based on ambient magnetic fields measured over a period of time by either the plurality of magnetic field sensors of the sensor array or a different group of magnetic field sensors, that are releasably coupled with a mobile device, infer candidate initial poses of the mobile device from candidate locations in the magnetic map,

based on the candidate initial poses and variations in the measured ambient magnetic fields over the period of time, infer a fine pose of the mobile device, and

evaluate a joint probabilistic distribution based on a probability distribution of the candidate initial poses and a probability distribution of the fine pose to estimate a specific pose of the mobile device.

2. The system as claimed in claim 1, wherein the mapping module is further configured to:

estimate the coordinates for each of the plurality of locations in the environment;

collect the rotation-invariant ambient magnetic field vectors at each location;

determine, based on the collected rotation-invariant ambient magnetic field vectors, an ambient magnetic field fingerprint for each location; and

for more than one of the plurality of locations, select the respective ambient magnetic field fingerprints and associate each of the respective ambient magnetic field fingerprints with the corresponding coordinates.

3. The system as claimed in claim 2, wherein each location is either:

a grid location, and the coordinates are 2-dimensional grid coordinates; or

a cubic location, and the coordinates are 3-dimensional cubic coordinates.

4. The system as claimed in claim 2 or 3, further comprising an auxiliary sensor in communication with the mapping module, the auxiliary sensor configured to provide measurements to establish the coordinates.

5. The system as claimed in claim 4, wherein the auxiliary sensor comprises a GNSS/GPS receiver, a LiDAR system, or a camera.

6. The system as claimed in any one of claims 2 to 5, wherein the ambient magnetic field fingerprint comprises a rotation-invariant ambient magnetic field fingerprint.

7. The system as claimed in any one of claims 2 to 6, wherein the mapping module is further configured to determine the ambient magnetic field fingerprint for each location by averaging the collected rotation-invariant ambient magnetic field vectors within the location.

8. The system as claimed in any one of claims 2 to 7, wherein the mapping module is further configured to fill at least one vacancy between one of the collected rotation-invariant ambient magnetic field vectors and an adjacent collected rotation-invariant ambient magnetic field vector.

9. The system as claimed in claim 8, wherein the mapping module is further configured to fill the at least one vacancy by performing interpolation on the collected rotation-invariant ambient magnetic field vectors.

10. The system as claimed in any one of claims 2 to 7, wherein the mapping module is further configured to fill at least one vacancy between one of the measured ambient magnetic fields and an adjacent measured ambient magnetic field.

11. The system as claimed in claim 10, wherein the mapping module is further configured to fill the at least one vacancy by performing interpolation on the measured ambient magnetic fields.

12. The system as claimed in any one of claims 1 to 11, wherein the localization module is configured to infer the candidate initial poses by calculating the probability distribution of the candidate initial poses based on a normalization constant for coarse localization, a prior distribution of the candidate initial poses and an observation model for coarse localization.

13. The system as claimed in claim 12, wherein the prior distribution of the candidate initial poses is a uniform distribution.

14. The system as claimed in claim 12 or 13, wherein the observation model for coarse localization is denoted by $p(\mathbf{z}_0|\mathbf{x}_0, \mathbf{M}^{\mathrm{B}})$, where

$$p(\mathbf{z}_0|\mathbf{x}_0, \mathbf{M}^{\mathrm{B}}) \propto \prod_{i=1}^{N} \frac{\exp\left(-\frac{1}{2}(\mathbf{B}_{\mathbf{O}_i}^0 - \mathbf{B}_{\mathbf{M}_{k,i}}^0)^T (\boldsymbol{\Sigma}_{\mathbf{x}_i^k}^0)^{-1} (\mathbf{B}_{\mathbf{O}_i}^0 - \mathbf{B}_{\mathbf{M}_{k,i}}^0) \right)}{(\sqrt{2\pi})^3 \sqrt{|\boldsymbol{\Sigma}_{\mathbf{x}_i^k}^0|}},$$

z_0 denotes ambient magnetic field observations of the plurality of magnetic field sensors at initial timestep,

x_0 denotes the candidate initial poses,

$\mathbf{M}^{\mathrm{B}}$ denotes the magnetic map,

N denotes the number of magnetic field sensors utilized for localization,

$\mathbf{B}_{\mathbf{O}_i}^0 = [B_{O_i}^{h,0}, B_{O_i}^{v,0}, F_{O_i}^0]^T$ and denotes measured ambient magnetic field data of the i^{th} magnetic field sensor,

$\mathbf{B}_{\mathbf{M}_{k.i}}^0 = [B_{M_{k.i}}^{h,0}, B_{M_{k.i}}^{v,0}, F_{M_{k.i}}^0]^T$ and denotes corresponding ambient magnetic field data relative to the i^{th} magnetic field sensor at the k^{th} candidate location in the magnetic map, and

$\Sigma_{\mathbf{x}_i^k}^0$ is a diagonal covariance matrix of the measured ambient magnetic field data of the i^{th} magnetic field sensor at the k^{th} candidate location at the initial timestep, diagonal elements of the diagonal covariance matrix being shown as variances $\sigma_{\mathbf{x}_i^k}^{h,0}$, $\sigma_{\mathbf{x}_i^k}^{v,0}$, and $\sigma_{\mathbf{x}_i^k}^{F,0}$.

15. The system as claimed in any one of claims 1 to 14, further comprising an assistant localization apparatus in communication with the localization module, wherein the assistant localization apparatus is configured to expedite the inference of the candidate initial poses of the mobile device from the candidate locations in the magnetic map.

16. The system as claimed in claim 15, wherein the assistant localization apparatus comprises a laser-based localization apparatus, a vision-based localization apparatus, or a GNSS/GPS-based localization apparatus.

17. The system as claimed in any one of claims 1 to 16, wherein the localization module is configured to infer the fine pose of the mobile device by calculating the probability distribution of the fine pose based on a normalization constant for fine localization, an observation model for fine localization, and a motion model for fine localization.

18. The system as claimed in claim 17, wherein the observation model for fine localization is derived from a multidimensional ambient magnetic field sequential matching module for aligning two time-series ambient magnetic field sequences with substantially similar patterns and amplitudes.

19. The system as claimed in claim 18, wherein the multidimensional ambient magnetic field sequential matching module is configured to:

estimate an orientation of the mobile device,

take rotation-invariant ambient magnetic field vectors, determined from the measured ambient magnetic fields at predetermined time intervals over the period of time and the estimated orientation of the mobile device, as one of the two time-series ambient magnetic field sequences;

derive, by the motion model for fine localization, the other of the two time-series ambient magnetic field sequences at the predetermined time intervals and at one of the candidate locations in the magnetic map, and

derive the observation model for fine localization based on a multivariate multi-dimensional Gaussian distribution by utilizing the two time-series ambient magnetic field sequences and positive covariances of the two time-series ambient magnetic field sequences at the respective candidate location.

20. The system as claimed in claim 19, wherein the multidimensional ambient magnetic field sequential matching module is configured to estimate the orientation of the mobile device by averaging yaw angles of the plurality of magnetic field sensors,

wherein for each magnetic field sensor, the yaw angle represents an orientation of the magnetic field sensor that is inferred based on an ambient magnetic field vector, the ambient magnetic field vector being representative of the ambient magnetic field measured by the magnetic field sensor.

21. The system as claimed in any one of claims 17 to 20, wherein the motion model for fine localization is based on a probability distribution utilizing the inferred fine pose, the candidate initial poses and a control input for fine localization.

22. The system as claimed in any one of claims 17 to 21, wherein the observation model for fine localization is denoted by

$p(\mathbf{z}_t|\mathbf{x}_t, \mathbf{M}^{\mathrm{B}})$

, where

$$p(\mathbf{z}_t|\mathbf{x}_t, \mathbf{M}^{\mathrm{B}}) \propto \prod_{i=1}^{N} \frac{\exp\left(-\frac{1}{2}(\mathbf{B}_{\mathbf{O}_i} - \mathbf{B}_{\mathbf{M}_{k,i}})^T \boldsymbol{\Sigma}_{\mathbf{x}_i^k}^{-1} (\mathbf{B}_{\mathbf{O}_i} - \mathbf{B}_{\mathbf{M}_{k,i}})\right)}{(\sqrt{2\pi})^3 \sqrt{|\boldsymbol{\Sigma}_{\mathbf{x}_i^k}|}}$$

z_t denotes ambient magnetic field observations of the plurality of magnetic field sensors at timestep t,

x_t denotes the specific pose of the mobile device at timestep t,

$\mathbf{M}^{\mathrm{B}}$ denotes the magnetic map,

N denotes the number of magnetic field sensors utilized for localization,

$\mathbf{B}_{\mathbf{O}_i} = \{\mathbf{B}_{\mathbf{O}_i}^{t-n}, \mathbf{B}_{\mathbf{O}_i}^{t-n+1}, \ldots, \mathbf{B}_{\mathbf{O}_i}^{t}\}$ and denotes measured ambient magnetic field sequence of the i^{th} magnetic field sensor,

$\mathbf{B}_{\mathbf{O}_i}^{t} = [B_{O_i}^{h,t}, B_{O_i}^{v,t}, F_{O_i}^{t}]^T$ and denotes rotation-invariant 3-D ambient magnetic field vector measured at time t,

$\mathbf{B}_{\mathbf{M}_{k,i}} = \{\mathbf{B}_{\mathbf{M}_{k.i}}^{t-n}, \mathbf{B}_{\mathbf{M}_{k.i}}^{t-n+1}, \ldots, \mathbf{B}_{\mathbf{M}_{k.i}}^{t}\}$ and denotes corresponding ambient magnetic field sequence derivated from the motion model of the i^{th} magnetic field sensor at the k^{th} candidate location for fine localization,

$\mathbf{B}^{t}_{\mathbf{M}_{k.i}} = [B^{h,t}_{M_{k.i}}, B^{v,t}_{M_{k.i}}, F^{t}_{M_{k.i}}]^T$ and denotes corresponding rotation-invariant 3-D ambient magnetic field vector at time t,

$\Sigma_{\mathbf{x}^k_i} = \{\Sigma^{t-n}_{\mathbf{x}^k_i}, \Sigma^{t-n+1}_{\mathbf{x}^k_i}, \ldots, \Sigma^{t}_{\mathbf{x}^k_i}\}$ and is a sequence of diagonal covariance matrix of the measured ambient magnetic field of the i^{th} magnetic field sensor at the k^{th} candidate location, diagonal elements of the diagonal covariance matrix at time t being shown as variances $\sigma^{h,t}_{\mathbf{x}^k_i}$, $\sigma^{v,t}_{\mathbf{x}^k_i}$, and $\sigma^{F,t}_{\mathbf{x}^k_i}$.

23. The system as claimed in any one of claims 17 to 22, wherein the localization module is further configured to:

calculate an estimated pose of the mobile device at timestep t+1 based on the specific pose at timestep t and data provided by the motion model for fine localization during the timestep t to the timestep t+1;

select an area in the magnetic map based on the estimated pose;

match, in terms of substantially similar patterns and amplitudes, a first time-series ambient magnetic field sequences corresponding to locations within the selected area and a second time-series ambient magnetic field sequences associated with rotation-invariant ambient magnetic field vectors determined from the measured ambient magnetic fields to identify candidate subsequent locations; and

infer a subsequent pose based on the identified candidate subsequent locations, thereby enabling substantially continuous tracking of poses of the mobile device.

24. The system as claimed in claim 23, wherein the subsequent pose of the mobile device at timestep t+1 is estimated by:

$$\frac{\sum_{k=1}^{R'}\left(\mathrm{x}^k_{t+1}\cdot p\left(\mathrm{x}^k_t\middle|\mathrm{z}_t,\mathrm{M}^{\mathrm{B}}\right)\cdot p\left(\mathrm{x}^k_{t+1}\middle|\mathrm{x}^k_t,\mathrm{z}_{1:t+1},\mathrm{u}_{1:t+1},\mathrm{M}^{\mathrm{B}}\right)\right)}{\sum_{k=1}^{R'}\left(p\left(\mathrm{x}^k_t\middle|\mathrm{z}_t,\mathrm{M}^{\mathrm{B}}\right)\cdot p\left(\mathrm{x}^k_{t+1}\middle|\mathrm{x}^k_t,\mathrm{z}_{1:t+1},\mathrm{u}_{1:t+1},\mathrm{M}^{\mathrm{B}}\right)\right)}$$

where R' comprises the identified candidate subsequent locations,

k corresponds to the k^{th} candidate subsequent location,

$\mathbf{z}_t$ denotes ambient magnetic field observations of the plurality of magnetic field sensors at timestep t,

$\mathbf{z}_{1:t+1}$ denotes multidimensional ambient magnetic field sequential observations from timestep 1 to t+1,

x_t^k denotes a candidate pose based on the k^{th} candidate subsequent location at timestep t,

x_{t+1}^k denotes a candidate pose based on the k^{th} candidate subsequent location at timestep t+1,

$\mathbf{u}_{1:t+1}$ is a control input from timestep 1 to t+1, and

M^B is the magnetic map.

25. The system as claimed in any one of claims 1 to 24, wherein the specific pose of the mobile device at timestep t is estimated by:

$$\frac{\sum_{k=1}^{R}\left(\mathbf{x}_t^k \cdot p(\mathbf{x}_0^k|\mathbf{z}_0, M^B) \cdot p(\mathbf{x}_t^k|\mathbf{x}_0^k, \mathbf{z}_{1:t}, \mathbf{u}_{1:t}, M^B)\right)}{\sum_{k=1}^{R}\left(p(\mathbf{x}_0^k|\mathbf{z}_0, M^B) \cdot p(\mathbf{x}_t^k|\mathbf{x}_0^k, \mathbf{z}_{1:t}, \mathbf{u}_{1:t}, M^B)\right)}$$

where R comprises selected candidate locations,

k corresponds to the k^{th} candidate location,

$\mathbf{z}_0$ denotes ambient magnetic field observations of the plurality of magnetic field sensors at initial timestep,

$\mathbf{z}_{1:t}$ denotes multidimensional ambient magnetic field sequential observations from timestep 1 to t,

x_0^k denotes a candidate pose based on the k^{th} candidate location at the initial timestep,

x_t^k denotes a candidate pose based on the k^{th} candidate location at timestep t,

$\mathbf{u}_{1:t}$ is a control input from timestep 1 to t, and

M^B is the magnetic map.

26. A system comprising:

a plurality of magnetic field sensors releasably coupled with a mobile device, wherein the plurality of magnetic field sensors is configured to measure ambient magnetic fields over a period of time and provided by a sensor array; and

a localization module configured to

based on the measured ambient magnetic fields, infer candidate initial poses of the mobile device from candidate locations in a magnetic map,

wherein the magnetic map comprises coordinates established for each of a plurality of locations in an environment; and a rotation-invariant ambient magnetic field fingerprint at each location,

wherein the rotation-invariant ambient magnetic field fingerprint is to be determined based on rotation-invariant ambient magnetic field vectors at that location, each rotation-invariant ambient magnetic field vector to be determined by:

representing the ambient magnetic field measured by one or each of the plurality of magnetic field sensors at a position within the environment or within a working distance of the one or each of the plurality of magnetic field sensors from an edge boundary of the environment as an ambient magnetic field vector in a local coordinate system;

inferring, based on the ambient magnetic field vector, an orientation of the one or each of the plurality of magnetic field sensors; and

aligning, based on the inferred orientation, the ambient magnetic field vector in the local coordinate system to a global coordinate system to generate the rotation-invariant ambient magnetic field vector, the rotation-invariant ambient magnetic field vector comprising two orthogonal components and an integrated intensity of the measured ambient magnetic field,

based on the candidate initial poses and variations in the measured ambient magnetic fields over the period of time, to infer a fine pose of the mobile device, and

evaluate a joint probabilistic distribution based on a probability distribution of the candidate initial poses and a probability distribution of the fine pose to estimate a specific pose of the mobile device.

27. The system as claimed in any one of claims 1 to 26,

wherein the plurality of magnetic field sensors of the sensor array is configured to operate simultaneously for building the magnetic map representative of the environment,

wherein each magnetic field sensor of the plurality of magnetic field sensors is configured to measure the ambient magnetic field at the position of the magnetic field sensor, the position being within the environment or within the working distance of the magnetic field sensor from the edge boundary of the environment,

the ambient magnetic field comprises infrastructure-free characteristics that do not depend on pre-installed infrastructures,

each magnetic field sensor is arranged spaced apart from a neighbouring magnetic field sensor at a distance such that the respective ambient magnetic fields measured by the magnetic field sensor and the neighbouring magnetic field sensor are disambiguated in a manner where the respective ambient magnetic fields do not cause interference to one another.

28. The system as claimed in any one of claims 1 to 27, wherein the plurality of magnetic field sensors comprises at least one of the followings:

a plurality of magnetometer sensors,

a plurality of digital compasses,

a plurality of magnetoresistive sensors,

a plurality of magnetoinductive sensors,

a plurality of Hall effect sensors, or

a plurality of superconducting quantum interference devices.

29. The system as claimed in any one of claims 1 to 28, wherein the plurality of magnetic field sensors is arranged at substantially regular spatial intervals.

30. The system as claimed in any one of claims 1 to 29, wherein the sensor array is a q-dimensional sensor array, where q is 1, 2 or 3.

31. The system as claimed in any one of claims 1 to 30, wherein the plurality of magnetic field sensors is calibrated to obtain calibration parameters to facilitate building the magnetic map.

32. A method for determining a rotation-invariant ambient magnetic field vector to build a magnetic map of an environment, the method comprising:

for a plurality of magnetic field sensors provided by a sensor array, representing an ambient magnetic field measured by one or each of the plurality of magnetic field sensors at a position within the environment or within a working distance of the one or each of the plurality of magnetic field sensors from an edge boundary of the environment as an ambient magnetic field vector in a local coordinate system, wherein the plurality of magnetic field sensors is releasably coupled with a mobile device moved to the position;

inferring, based on the ambient magnetic field vector, an orientation of the one or each of the plurality of magnetic field sensors; and

aligning, based on the inferred orientation, the ambient magnetic field vector in the local coordinate system to a global coordinate system to generate the rotation-invariant ambient magnetic field vector, the rotation-invariant ambient magnetic field vector comprising two orthogonal components and an integrated intensity of the measured ambient magnetic field.

33. The method as claimed in claim 32, wherein the measured ambient magnetic field is dependent on the orientation of the one or each of the plurality of magnetic sensors, and represented by:

$$W\,R_z(\gamma)\,R_y(\theta)\,R_x(\phi)\,\mathrm{B}_e + V$$

where $R_z(\gamma)$, $R_y(\theta)$, and $R_x(\phi)$ are corresponding rotation matrices in yaw, pitch, and roll, respectively;

W and V are a soft-iron effect matrix and a hard-iron effect offset vector of the one or each of the plurality of magnetic field sensors, respectively; and

$B_e = [B_e^x, B_e^y, B_e^z]^T$ within the global coordinate system, B_e^x, B_e^y, and B_e^z being orthogonal components representing magnetic field intensities in Geographic North, Geographic East and vertical downward directions, respectively, and B_e^z being parallel with a unit vector of the Earth's gravity field.

34. The method as claimed in claim 32 or 33, wherein the ambient magnetic field vector comprises three orthogonal components in the local coordinate system and the integrated intensity of the measured ambient magnetic field, represented by: $\begin{bmatrix} B_m^x \\ B_m^y \\ B_m^z \\ F_m \end{bmatrix}$

where B_m^x is a x-direction component;

B_m^y is a y-direction component;

B_m^z is a z-direction component; and

$F_m = \sqrt{(B_m^x)^2 + (B_m^y)^2 + (B_m^z)^2}$.

35. The method as claimed in claim 34, wherein the inferred orientation of the one or each of the plurality of magnetic field sensors is represented by a yaw angle, ψ, where

$$\psi = \begin{cases} 2\pi - \alpha, & \text{if } B_m^x > 0, B_m^y > 0 \\ -\alpha, & \text{if } B_m^x > 0, B_m^y < 0 \\ \pi - \alpha, & \text{if } B_m^x < 0, B_m^y > 0 \\ \pi - \alpha, & \text{if } B_m^x < 0, B_m^y < 0 \end{cases},$$

α = arctan ($|B_m^y|$ / $|B_m^x|$), and

ψ ranges between 0 radian and 2π radian, the 0 radian being defined with respect to a direction of Magnetic North.

36. The method as claimed in claim 34 or 35, wherein one of the two orthogonal components of the rotation-invariant ambient magnetic field vector is a vertical component parallel with a unit vector of the Earth's gravity field, and the other is a rotation-invariant horizontal component orthogonal to the vertical component.

37. The method as claimed in claim 36, wherein the rotation-invariant horizontal component is $\sqrt{(B_m^x)^2 + (B_m^y)^2}$, and the vertical component is B_m^z.

38. A method for building a magnetic map representative of an environment, the method comprising:

establishing coordinates for each of a plurality of locations in the environment;

collecting rotation-invariant ambient magnetic field vectors at each location, the rotation-invariant ambient magnetic field vectors being determined from ambient magnetic fields measured at the location using a method as claimed in any one of claims 32 to 37;

determining, based on the collected rotation-invariant ambient magnetic field vectors, an ambient magnetic field fingerprint for each location; and

for more than one of the plurality of locations, selecting the respective ambient magnetic field fingerprints and associating each of the respective ambient magnetic field fingerprints with the corresponding coordinates.

39. A method for localizing a mobile device, the method comprising:

performing coarse localization, based on ambient magnetic fields, to infer candidate initial poses of the mobile device from candidate locations in a magnetic map,

wherein the ambient magnetic fields are measured over a period of time by a plurality of magnetic field sensors releasably coupled with the mobile device, the plurality of magnetic field sensors being provided by a sensor array,

wherein the magnetic map comprises coordinates established for each of a plurality of locations in an environment; and a rotation-invariant ambient magnetic field fingerprint at each location,

wherein the rotation-invariant ambient magnetic field fingerprint is to be determined based on rotation-invariant ambient magnetic field vectors at that location, each rotation-invariant ambient magnetic field vector to be determined by:

representing the ambient magnetic field measured by one or each of the plurality of magnetic field sensors at a position within the environment or within a working distance of the one or each of the plurality of magnetic field sensors from an edge boundary of the environment as an ambient magnetic field vector in a local coordinate system;

inferring, based on the ambient magnetic field vector, an orientation of the one or each of the plurality of magnetic field sensors; and

aligning, based on the inferred orientation, the ambient magnetic field vector in the local coordinate system to a global coordinate system to generate the rotation-invariant ambient magnetic field vector, the rotation-invariant ambient magnetic field vector comprising two orthogonal components and an integrated intensity of the measured ambient magnetic field;

performing fine localization, based on the candidate initial poses and variations in the measured ambient magnetic fields over the period of time, to infer a fine pose of the mobile device; and

evaluating a joint probabilistic distribution based on a probability distribution of the candidate initial poses and a probability distribution of the fine pose to estimate a specific pose of the mobile device.

40. The method as claimed in claim 39, further comprising applying an assistant localization method to the step of performing coarse localization to expedite the inference of the candidate initial poses of the mobile device from the candidate locations in the magnetic map.

41. The method as claimed in claim 40, wherein the assistant localization method comprises a laser-based localization method, a vision-based localization method, or a GNSS/GPS-based localization method.

42. The method as claimed in any one of claims 39 to 41, further comprising performing substantially continuous tracking of poses of the mobile device by recursively inferring subsequent poses based on candidate subsequent locations, wherein one candidate subsequent location is identified by

calculating an estimated pose of the mobile device at timestep t+1 based on the specific pose at timestep t and data provided by a motion model for fine localization during the timestep t to the timestep t+1;

selecting an area in the magnetic map based on the estimated pose; and

matching, in terms of substantially similar patterns and amplitudes, a first time-series ambient magnetic field sequences corresponding to locations within the selected area and a second time-series ambient magnetic field sequences associated with the rotation-invariant ambient magnetic field vectors determined from the measured ambient magnetic fields to identify the candidate subsequent location.

43. A computer readable storage medium comprising computer readable instructions operable when executed by a computer to perform at least one of the following:

determine a rotation-invariant ambient magnetic field vector to build a magnetic map of an environment, the computer readable instructions configured to perform a method as claimed in any one of claims 32 to 37;

build a magnetic map representative of an environment, the computer readable instructions configured to perform a method as claimed in claim 38; or

localize a mobile device, the computer readable instructions configured to perform a method as claimed in any one of claims 39 to 42.