

What is claimed is:

1. A system for operating a remotely operated vehicle (ROV) comprising:

5 a database module of 3D elements operable to represent objects disposed in an operation environment of the ROV;

a virtual video generating module operable to generate a virtual video incorporating the 3D elements;

a video camera mounted to the ROV operable to capture a real video of the operation environment of the ROV;

10 a synchronizing module operable to synchronize an angle and position of a virtual camera with an angle and position of the video camera mounted to the ROV,

wherein the virtual camera defines a field of view for the virtual video; and

15 a position estimation engine operable to align a virtual video element with a real video element to create hybrid 3D imagery and generate a ROV position estimation, the position estimation engine comprising:

a projection module that generates N virtual images;

20 a registration module that maps virtual video elements of the N virtual images with real video elements;

a position estimation module that generates the ROV position estimation based at least in part on the N virtual images; and

25 an efficiency module that improves the efficiency of generating the ROV position estimation.

2. The system according to claim 1, wherein the projection module is operable to project visible 3D structures into a corresponding 2D virtual image with a 2D virtual image field-of-view, and wherein each of the visible 3D structures is projected into its corresponding

30

2D virtual image.

3. The system according to claim 2, wherein the 2D virtual image field-of-view is larger than the field of view for the virtual video.

~~4. The system according to claim 3, wherein the projection module generates N virtual images.~~

10 45. The system according to claim 34, wherein the registration module registers the N virtual images with N real frames from the real video.

15 56. The system according to claim 45, wherein the registration module determines edge maps to register the N virtual images.

20 67. The system according to claim 56, wherein the registration module maps at least one virtual edge point to at least one corresponding real edge point with a similarity transformation matrix.

25 78. The system according to claim 67, wherein the registration module generates the similarity transformation matrix in a closed form using Umeyama's method.

30 89. The system according to claim 78, wherein the registration module applies the similarity transformation matrix in an iterative process until the similarity transformation matrix is close to identity or exceeds a maximum number of iterations.

910. The system according to claim 89, wherein the position estimation module generates the ROV position estimation based at least in part on ~~the N virtual images of the projection module and~~ the similarity transformation matrix of the registration module.

1011. The system according to claim 910, wherein the position estimation module determines a rigid body transformation T_i .

1112. The system according to claim 1011, wherein the position estimation module generates a new ROV position estimation by right multiplying a previous ROV position estimation with T_i .

1213. The system according to claim 1112, wherein the position estimation module renders 3D structures from the new ROV position estimation.

1314. The system according to claim 1213, wherein, before rendering the 3D structures from the new ROV position estimation, the position estimation module removes outlier position estimations to generate a set of remaining position estimations and determines an updated ROV position estimation comprising a mean of the set of remaining position estimations.

1415. The system according to any of claims 1 - 1314, wherein the efficiency module uses a full registration process for a specific structure when (i) a predetermined number of virtual edge points or real edge points are lost,

(ii) after a predetermined number of frames, (iii) or when the specific structure enters the real video for a first time.

5 1516. A method of operating a remotely operated vehicle (ROV) comprising:

obtaining 3D bathymetry data using multibeam sonar;

storing 3D elements in a database module, the 3D elements representing objects disposed in the ROV's
10 operation environment and comprising the 3D elements comprising the 3D bathymetry data;

generating a virtual video of the 3D elements;

synchronizing an angle and position of a virtual camera with an angle and position of a video camera mounted
15 to the ROV, wherein the virtual camera defines a field of view for the virtual video; and

aligning a virtual video element with a real video element to create hybrid 3D imagery, wherein aligning comprises:

20 projecting visible 3D structures into a corresponding 2D virtual image with a 2D virtual image field-of-view;

generating N virtual images;

registering the N virtual images with a real frame
25 from the real video; and generating a ROV position estimate based at least in part on mapping of the corresponding 2D virtual image and the registered N virtual images.

30 1617. The method of claim 1516, further comprising using a full registration process for a specific structure.

1718. The methods of one of claims 15-1616—17,

further comprising:

mapping virtual edge points to corresponding real edge points;

applying an iterative process to the mapping; and

5 generating a ROV position estimation.

| 1819. The method of claim 1718, further comprising rendering 3D structures from the ROV position estimation.

| 10 1920. The method of claim 1819, wherein generating an ROV position estimation further comprises:

removing outlier position estimations;

generating a set of remaining position estimations;

and

15 determining an updated ROV position estimation comprising a mean of the set of remaining position estimations.

| 2021. A computer program product comprising
20 instructions which, when the program is executed by a computer, cause the computer to carry out the steps of the method of any of claims 15-19~~claim 16~~.