

PILE DRIVING ASSEMBLY**TECHNICAL FIELD OF THE INVENTION**

The present invention relates to a pile driving assembly for installing a foundation pile into the ground. More specifically, although not exclusively, this invention relates to a marine vessel comprising the pile driving assembly and to a method for installing, preferably in an offshore location, a foundation pile into ground.

BACKGROUND OF THE INVENTION

Offshore foundation piles, such as monopiles, are generally installed by suspending the pile from the side of a marine vessel, in a vertical configuration. The pile is typically lowered through the water and subsequently driven into the ground using a pile driving device, such as a hydraulic or vibrating hammer provided on top of the foundation pile.

The pile driving assembly can include a measuring system be used to help maintain the pile in a vertical orientation and to monitor the penetration of the pile during its driving into the ground. Known measuring systems typically provide measurements using a point of reference on the pile. However, in offshore applications the penetration of the pile into the ground can only be measured up to a point where the pile is visible or at least the top part of the pile remains above water level. In cases of driving anchor piles, the entire pile will be in a fully submerged position and therefore, penetration monitoring cannot be performed. Furthermore, when the pile is being driven into the soil, by mechanical means, the pile will vibrate resulting in difficulties in focusing on a reference point. This reduces the accuracy of the obtained measurements.

In some known systems, as described in US10451519B2, the measurement is done by having two image elements or points of reference with two image receiving devices being spaced from one another to capture the required information for determining the pile penetration. This increases the cost and difficulty of the measurement operation. In addition, this operation is still subject to inaccuracies introduced with vibratory movements on the pile.

Due to the large size of offshore foundation piles, the visual range of the measuring systems can vary. Known systems use or rely on activation sensors or other visual means that are connected to the pile to be driven into the soil. Still, due to the mechanical impacts or blows imposed on the top part of the pile, these type of sensors can become loose and the measuring systems do not perform as intended.

It would therefore be advantageous to overcome at least some of these limitations.

According to a first aspect of the invention there is provided a pile driving assembly for installing a foundation pile into ground, preferably in an offshore location, wherein the pile driving assembly comprises:

an optical system including:

an image capture device for capturing visual images; and

5 a processing unit configured to receive visual images from the image capture device or the optical system and to process the visual images; and

a pile driving element for driving a foundation pile into the ground,

wherein in an operational configuration the optical system is provided at a distance from the pile driving element, such that the image capture device is configured to capture a visual image of at least one
10 point of reference on the pile driving element,

wherein the processing unit is configured to determine the penetration of a foundation pile into the ground and/or the penetration direction of the foundation pile into the ground from at least two visual images of the at least one point of reference.

15 Advantageously, the pile driving assembly is able to continuously and accurately track the displacement of the pile indirectly by tracking the pile driving element. That is, pile penetration / pile penetration direction is determined from data regarding the pile driving element, which is directly correlated to pile advancement. This minimizes measurement errors and enhances the quality of penetration information. Moreover, it eliminates the necessity for complex and specialized sensors required for direct pile penetration measurement. As a result,
20 the system reduces equipment complexity, maintenance demands, and associated costs, making it a cost-effective choice for offshore construction projects.

Furthermore, the pile driving assembly can provide real-time feedback during pile installation. Operators can access pile driving element data in real time, enabling prompt adjustments to the pile driving process. This
25 adaptability ensures optimal pile installation by preventing over-penetration or under-penetration, leading to improved efficiency and safety.

In addition, the pile driving assembly can operate effectively in harsh conditions as the measurements of the pile driving element are always taken from above water level. As such, the pile driving assembly has continuous
30 visual contact with the pile driving element, which remains at all time at least partially above water level.

In certain embodiments, the optical system includes a frame element, wherein the image capture device is pivotally mounted to the frame element such that during operation of the pile driving element the image capture device can follow the movement of the at least one point of reference. Advantageously, this helps the image
35 capture device to track movement of the pile driving element, and therefore also the pile, during a pile driving

operation. By allowing the image capture device to pivot within the frame element the pile driving assembly can effectively track the at least one point of reference without the necessity for a large field of view.

5 In certain embodiments, the optical system comprises a main body, the main body comprising: the image capture device; a body portion; and an actuation system configured to rotate the image capture device relative to the body portion. Actuation of the actuation system varies the orientation of the image capture device relative to the body portion. This allows the image capture device to maintain a predetermined orientation relative to the pile driving element even if the body portion moves, for example with vessel movement.

10 In certain embodiments, the actuation system is configured to rotate the image capture device about a longitudinal axis of the optical system.

In certain embodiments, the optical system comprises a housing, the body portion being housed within the housing, wherein the main body is movably mounted to the housing via a mounting assembly.

15 In certain embodiments, the mounting assembly comprises at least one bearing element configured to allow the main body to rotate relative to the housing about a longitudinal axis of the optical system.

In certain embodiments, the mounting assembly comprises a gimbal element, wherein the gimbal element is configured to allow the main body to move relative to the housing. Advantageously, the gimbal element helps stabilize the main body where the housing is subject to movement, for example as a result of vessel movement. This helps ensure the image capture device remains stable and balanced, even in harsh conditions. In addition, the gimbal element helps improve the longevity of components within the main body (for example the image capture device, the actuation system) by decoupling the main body from vibrations of the housing.

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25 Advantageously, the use of a gimbal element, particularly a gimbal element with pivot portions, is an effective friction-less way of decoupling motion of the main body from the housing.

In certain embodiments the gimbal element is a collar member, the collar member having at least one pair of pivot portions configured to allow the main body to pivot relative to the housing.

30 In certain embodiments the optical system comprises a damping system for damping movement of the main body relative to the housing. The damping system may be a damping element or damping fluid between the main body and the housing. The damping element or damping fluid may be part of the mounting assembly and/or between the body portion and the housing.

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In certain embodiments, the pile driving assembly comprises a control unit configured to control the actuation system in response to movement of the body portion. Advantageously, by controlling the actuation system in response to movement of the body portion, for example as a result of vessel movement, the control unit can provide active motion compensation to the optical system.

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In certain embodiments, the pile driving assembly comprises one or more sensors configured to measure movement of the body portion.

In certain embodiments, the optical system comprises a GPS antenna to locate the pile driving operation.

10 In certain embodiments, the pile driving assembly further comprises an energy source or power supply to provide electric power to one or more of the optical system and the processing unit.

In certain embodiments, wherein the at least one point of reference comprises a calibration element, wherein the processing unit is configured to calibrate from a visual image of the calibration element at least one of:

- 15 the distance between the image capture device and the calibration element; and
 the relative orientation between the image capture device and the calibration element.

Advantageously, integration of a calibration element into the at least point of reference allows parameters to be calibrated while the optical system and pile driving element are in-situ. As such, implementation of the system is flexible.

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In certain embodiments, the at least one point of reference comprises an indicator element, wherein the processing unit is configured to obtain information regarding the pile driving element from the indicator element. Advantageously, use of an indicator element which provides an operator with information regarding the pile driving element helps assist an operator during the pile driving process. For example, the information provided
25 by the indicator element may assist the operator in their use or control of the pile driving element.

In certain embodiments, the pile driving assembly further comprising a foundation pile, wherein in the operational configuration the pile driving element is provided on the foundation pile.

30 According to a further aspect of the invention there is provided a marine vessel comprising the pile driving assembly of the first aspect of the invention or any embodiments thereof.

According to a further aspect of the invention there is provided a method for installing, preferably in an offshore location, a foundation pile into ground, the method comprising the following steps:

- 35 a) providing a pile driving assembly according to the first aspect of the invention or any embodiments thereof;

- b) positioning the optical system at a distance from the pile driving element;
- c) capturing a visual image of at least one point of reference on the pile driving element;
- d) at least partially installing a foundation pile into ground with the pile driving element;
- e) capturing a further visual image of the at least one point of reference during or after the at least partial installation of the foundation pile;
- f) determining the penetration of the foundation pile into the ground and/or the penetration direction of the foundation pile into the ground from the at least two visual images of the at least one reference point.

10 In certain embodiments, simultaneously and/or after step f) the optical system repeatedly performs steps c) to e) in a looped manner.

In certain embodiments, the method comprising the step of calibrating from the visual image of the at least one point of reference at least one of:

- the distance between the image capture device and the calibration element; and
- the relative orientation between the image capture device and the calibration element.

According to further aspect of the invention there is provided a monitoring assembly for monitoring a pile driving assembly during installation of a foundation pile into ground, preferably in an offshore location, wherein the monitoring assembly comprises:

- an optical system including:
 - an image capture device for capturing visual images of a pile driving element or a foundation pile; and
 - a processing unit configured to receive visual images from the image capture device or the optical system and to process the visual images.

25 In certain embodiments, the image capture device is configured to capture a visual image of at least one point of reference on a pile driving element or a foundation pile.

30 In certain embodiments, the processing unit is configured to determine the penetration of a foundation pile into the ground and/or the penetration direction of the foundation pile into the ground from at least two visual images of the at least one point of reference.

In certain embodiments, the optical system includes a frame element, wherein the image capture device is pivotally mounted to the frame element such that during operation of the pile driving element the image capture device can follow the movement of the at least one point of reference.

In certain embodiments, the optical system comprises a main body, the main body comprising:

the image capture device;

a body portion; and

an actuation system configured to rotate the image capture device relative to the body portion.

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In certain embodiments, the actuation system is configured to rotate the image capture device about a longitudinal axis of the optical system.

10 In certain embodiments, the optical system comprises a housing, the body portion being housed within the housing, wherein the main body is movably mounted to the housing via a mounting assembly.

In certain embodiments, the mounting assembly comprises at least one bearing element configured to allow the main body to rotate relative to the housing about a longitudinal axis of the optical system.

15 In certain embodiments, the mounting assembly comprises a gimbal element, wherein the gimbal element is configured to allow the main body to move relative to the housing.

In certain embodiments, the gimbal element is a collar member, the collar member having at least one pair of pivot portions configured to allow the main body to pivot relative to the housing.

20 In certain embodiments, the optical system comprises a damping system for damping movement of the main body relative to the housing.

In certain embodiments, the monitoring assembly comprises a control unit configured to control the actuation system in response to movement of the body portion.

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In certain embodiments, the monitoring assembly comprises one or more sensors configured to measure movement of the body portion.

In certain embodiments, the optical system comprises a GPS antenna to locate the pile driving operation.

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In certain embodiments, the monitoring assembly further comprises an energy source or power supply to provide electric power to one or more of the optical system and the processing unit.

35 The present disclosure will now be described by way of example only with reference to the accompanying drawings in which:

Figure 1 shows a pile driving assembly;

Figure 2 shows a schematic of the pile driving assembly of Figure 1;

Figure 3 shows an optical system of a pile driving assembly;

Figures 4, 5 and 6 show sectioned views of the optical system of Figure 3;

Figure 7 shows a close-up of a portion of Figure 6; and

- 5 Figure 8 shows a perspective view of components within a damping assembly of the optical system of Figure 3.

DETAILED DESCRIPTION

Turning to Figures 1 and 2, a pile driving assembly for installing a foundation pile 300 into ground is shown.

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The pile driving assembly includes a pile driving element 200 for driving the foundation pile 300 into the ground. The foundation pile 300 may be a monopile or jacket pile, for example. The pile driving element 200 may be any suitable pile driving element 200, for example an impact hammer or a vibratory hammer. In use the pile driving element 200 is provided on the foundation pile 300.

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The pile driving assembly includes an optical system 100. As shown in Figures 3 to 8 the optical system 100 includes an image capture device 102 for capturing visual images. The image capture device 102 may be any image capture device with a resolution suitable for capturing a point of reference on the pile driving element 200 as described below. For example any conventional camera (either specialist or recreational) may be used.

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The pile driving assembly includes a processing unit 400 configured to receive visual images from the image capture device 102 or the optical system 100 and to process the visual images. The processing unit 400 may include any suitable circuitry configured to operably execute computer-readable instructions, for example an image processing algorithm.

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The processing unit 400 may be integral with the optical system 100. Alternatively, as illustrated in Figure 2, the processing unit 400 may be separate to the optical system 100. In use, the processing unit 400 may receive visual images directly from the image capture device 102 or indirectly, for example via a memory unit (not shown). The processing unit 400 may be connected to the image capture device 102 or the optical system 100 with a wired or wireless connection.

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Figures 1 and 2 show the pile driving assembly in an operational configuration. In the operational configuration, the optical system 100 is provided at a distance from the pile driving element 200, such that the optical system 100 is configured to capture a visual image of at least one point of reference 202 on the pile driving element 200.

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In the illustrated example a single point of reference 202 is used, although any suitable number of points of reference may be used. The point of reference 202 may be a point marker on the pile driving element 200. Alternatively, the point of reference 202 may include a more complex marker or pattern, for example an indicator element or calibration element as described below.

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In the operational configuration the processing unit 400 is configured to determine the penetration of the foundation pile 300 into the ground and/or the penetration direction of the foundation pile 300 into the ground from at least two visual images of the at least one point of reference 202.

- 10 An example method of implementing the pile driving assembly may be as follows. Firstly, the image capture device 102 captures a first visual image of the at least one point of reference 202 on the pile driving element 200. The pile driving element 200 then at least partially installs the foundation pile 300 into the ground. For example, where the pile driving element 200 is an impact hammer, the pile driving element 200 may perform one or more impact blows to the foundation pile 300. Alternatively, where the pile driving element 200 is a vibratory hammer, the pile driving element 200 may vibrate for the foundation pile 300 to a driven point or for a pre-determined amount of time. The image capture device 102 captures a second visual image of the at least one point of reference 202 during or after the at least partial installation of the foundation pile 300. The first visual image and the second visual image are each sent to the processing unit 400, which can determine the penetration of the foundation pile 300 that has occurred between the capture of the first visual image and the second visual image. Alternatively, or in addition, the processing unit 400 can determine the penetration direction of the foundation pile 300 into the ground from the first visual image and the second visual image.

- 25 The processing unit 400 can determine the penetration of the foundation pile 300 and/or the penetration direction of the foundation pile 300 by determining the change in position of the at least one point of reference 202 from the first visual image to the second visual image. For example, for a known distance between the image capture device 102 and the pile driving element 200 the change in position of the at least one point of reference 202 in the driving direction (the Z-direction following the coordinate system shown in the Figures) from the first visual image to the second visual image can be used to calculate the change in driving depth of the foundation pile 300 from the first visual image to the second visual image. Similarly, the penetration direction (in particular any deviation of the penetration direction from the driving direction) can be calculated from the change in position of the at least one point of reference 202 from the first visual image to the second visual image.

- 35 In some examples the optical system 100 may be positioned a pre-determined distance from the pile driving element 200. In other examples, the distance between the image capture device 102 and the pile driving element 200 may be calibrated prior to, or during, the capture of at least the first visual image. In some examples

the at least one point of reference 202 includes a calibration element. The processing unit 400 is configured to calibrate the distance between the image capture device 102 and the calibration element from a visual image of the calibration element. For example the calibration element may include an array of markers, for example an ArUco calibration board, a ChArUco calibration board or the like. The use of a ChArUco calibration board is particularly beneficial as these boards provide effective marker or corner detection even in harsh environments. In addition, ChArUco boards have high sub-pixel accuracy. The processing unit 400 may be configured to compare the visual image to a predetermined list of markers provided in a memory unit (not shown) to identify the presence of a marker and extract information related to the markers in a memory unit (not shown). The extracted information may be used to calibrate the distance between the image capture device 102 and the calibration element.

In some examples the processing unit 400 is also configured to calibrate the relative orientation between the image capture device and the calibration element from a visual image of the calibration element. In other examples a separate calibration element (for example the ArUco or ChArUco calibration board) may be used to calibrate the relative orientation between the image capture device 102 and the calibration element. Calibrating the relative orientation between the image capture device 102 and the calibration element helps provide feedback as to whether the foundation pile 300 is being driven in the intended penetration direction.

With this arrangement pile penetration data is determined directly from the pile driving element 200. This helps enhance the quality of penetration information and minimize measurement errors. Notably pile penetration data can still be obtained even when the foundation pile 300 is not visible, for example if the foundation pile 300 is beneath the water level, as measurements are always taken above water level. That is, the optical system 100 has constant visual contact with the pile driving element 200 as this remains at least partially above water level. Therefore the described system is particularly advantageous for applications where the foundations piles are installed in an offshore location. In such applications, the optical system 100 may be positioned on a marine vessel adjacent to the pile driving element 200.

The described system provides real-time monitoring capabilities, with pile penetration being monitored before, during and even after pile-driving operations. This monitoring occurs at a distance from the foundation pile 300, ensuring that operators are provided with safe working conditions and the integrity of the optical system 100 is not compromised. The system is particularly effective at determining pile penetration information since the pile penetration data is determined from the pile driving element 200 rather than the foundation pile 300, minimizing measurement errors and enhancing the quality of penetration information.

The above described method can be repeatedly performed throughout the pile installation process. For example the image capture device 102 can capture an additional visual image of the point of reference 202

after each impact blow during installation. In this manner an operator can monitor the incremental progress of the pile installation.

5 In the example shown in Figure 2, the pile driving assembly includes a display or user interface 500 configured to receive data from the processing unit 400 and present the data to an operator. The display or user interface 500 may be integral with the optical system 100. Alternatively, as illustrated in Figure 2, the display or user interface 500 may be separate to the optical system 100. The display or user interface 500 may include input means for an operator to input controls for the pile driving element 200. For example, the operator may choose to input controls for the pile driving element 200 based on the data displayed to the operator. For example, the
10 operator may increase or decrease the impact energy of subsequent blows of the pile driving element 200 based on the progress of the pile installation.

In examples where the user interface 500 is remote from the optical system 100, the operator can remotely operate and amend the input controls from a remote and/or safe place, not necessarily in the vicinity of the pile
15 driving assembly. The operator can provide input controls based on the data displayed to the operator by means of the processed information.

Figures 3 to 7 show the optical system 100. In this example the optical system 100 includes a frame element 106. The image capture device 102 is pivotally mounted to the frame element 106 such that during operation
20 of the pile driving element 200 the image capture device 102 can follow the movement of the at least one point of reference 202. That is, the image capture device 102 can pivot within the frame element 106 to reposition the field of view 104. The field of view 104 can be moved in accordance with movement of the point of reference 202. For example, the image capture device 102 may pivot to keep the point of reference 202 within the field of view 104, or substantially central within the field of view 104, following each impact from the pile driving
25 element 200.

In this example the image capture device 102 is pivotal around a horizontal axis. That is, using the coordinate system shown in the Figures, the image capture device 102 is pivotal around an axis in the X-Y plane. This allows the image capture device 102 to follow movement of the pile driving element 200 during the installation
30 process. Specifically, using the coordinate system shown in the Figures, the image capture device 102 can track movement of the pile driving element 200 in the Z-direction.

The image capture device 102 may be pivotally mounted to the frame element 106 in any suitable manner. For example, the image capture device 102 may be mounted to the frame element 106 via a roller bearing or a
35 system of roller bearings. It would be understood that the range of pivotal movement of the image capture device 102 within the frame element 106 may depend on a number of factors, for example the size of the field

of view 104, the expected distance between the image capture device 102 and the pile driving element 200 and the expected penetration distance per blow of the pile driving element 200. The change in position of the point of reference 202 in the driving direction may be calculated using one or more of the change in position of the point of reference 202 within the field of view 104 and the change in position of the field of view 104 as a result of pivotal movement of the image capture device 102 within the frame element 106.

The optical system 100 may include an actuator (not shown) configured to pivot the image capture device 102 within the frame element 106. Any suitable actuator may be used, for example a linear actuator or a motor with a chain or drive belt.

In this example the optical system 100 includes a main body, the main body comprising the image capture device 102 and a body portion 108.

In this example the body portion 108 includes an inner housing 126. The body portion 108 further includes any hardware housed within the inner housing 126 or connecting the inner housing 126 to the image capture device 102. The inner housing 126 may house an energy source or power supply configured to provide power to one or more of the optical system 100 and the processing unit 400, for example.

In this example, the image capture device 102 is rotatably coupled to the body portion 108. In this example the image capture device 102 is rotatable around a longitudinal axis of the optical system 100. Using the coordinate system shown in the Figures, the longitudinal axis extends in the Z direction, normal to the X-Y plane.

The main body includes an actuation system configured to rotate the image capture device 102 relative to the body portion 108. The actuation system is configured to rotate the image capture device 102 about the longitudinal axis of the optical system 100. The actuation system allows the image capture device 102 to maintain a predetermined orientation within the X-Y plane relative to the pile driving element 200 even if the body portion 108 moves with vessel movement. In this manner the actuation system provides active motion compensation to the image capture device 102.

In this example the actuation system includes a motor 112, a drive belt 114, a drive wheel 116 and a drive sprocket 118. In use, the motor 112 drives the drive belt 114, which rotates the drive wheel 116 and the drive sprocket 118 mounted thereon. The drive sprocket 118 is engaged with a corresponding sprocket 120. The sprocket 120 is connected to, or integral with, a connection member 122 (shown in Figure 7), which extends from or forms part of the connection between the actuation system and the frame 106. In use, rotation of the drive sprocket 118 rotates the sprocket 120 causing the connection member 122 to rotate. In turn the frame 106 and image capture device 102 also rotate.

It would be understood that any suitable actuation system may be used. That is, any actuation system, which, when actuated, rotates the image capture device 102 relative to the body portion 108 may be used. For example the sprocket 120 may be directly driven by a drive belt 114 or chain member. Advantageously the actuation system allows a full 360 degree (or substantially 360 degree) rotation of the image capture device 102 about the longitudinal axis of the optical system 100.

In this example, the optical system 100 includes a housing 124. The body portion 108 is housed within the housing 124. In use, the optical system 100 is mounted to a surface via the housing 124. For example, the housing 124 may be mounted to the deck of a vessel. In this example, the frame 106 and image capture device 102 extend through an orifice in an upper surface 140 of the housing 124.

In this example, the pile driving assembly comprises a control unit 600. The control unit 600 may include one or more controllers (not shown). The one or more controllers may include an input means and an output means. The input means may comprise an electrical input. The input may be arranged to receive an electrical signal for example an input by an operator or from one or more sensors. The output means may comprise an electrical output of the controller. The output may be arranged to output an electrical signal to one or more actuators or actuation systems within the optical system 100.

The control unit 600 may be integral with the optical system 100. Alternatively, as illustrated in Figure 2, the control unit 600 may be separate to the optical system 100. One or more of the processing unit 400, the display or user interface 500 and a memory unit (for example that which stores the predetermined list of markers) may form part of the control unit 600. In the example of Figure 2 both the processing unit 400 and the user interface 500 form part of the control unit 600.

The control unit 600 may be configured to control the actuator that is configured to pivot the image capture device 102 within the frame element 106. The control unit 600 may be configured to control the actuation system, for example the control unit 600 may be configured to control the motor 112 of the actuation system.

In this example, the control unit 600 is configured to control the actuation system (for example the motor 112), in response to movement of the body portion 108. That is, the control unit 600 is configured to receive information regarding movement of the body portion 108 and control the orientation of the image capture device 102 in the X-Y plane accordingly. For example, the control unit 600 may control the actuation system so as to provide active motion compensation for the image capture device 102 as the body portion 108 moves. The movement of the body portion 108 may be as a result of vessel movement, for example movement of the vessel (for example oscillating motion) with respect to the pile driving element 200. In this manner, the control unit 600

can help ensure that the image capture device 102 remains oriented in the same vertical plane as the pile driving element 200.

In some examples, the active motion compensation for the image capture device 102 may also include adjustments to the orientation of the image capture device 102 with respect to the frame element 106. That is, the control unit 600 may be configured to control the actuator that is configured to pivot the image capture device 102 within the frame element 106 in response to movement of the body portion 108. In this manner the field of view 104 of the image capture device 102 can remain oriented towards the reference point 202 on the pile driving element 200.

For example, for an initial position and initial orientation of the body portion 108 in which the field of view 104 of the image capture device 102 is directed towards the pile driving element 200, the control unit 600 receives information regarding any change in position or orientation of the body portion 108. This information can be used to rotate the image capture device 102 about the horizontal axis (within the frame element 106) and/or the longitudinal axis to ensure that the field of view 104 of the image capture device 102 remains substantially oriented towards the pile driving element 200.

In this example the pile driving assembly includes one or more sensors (not shown) configured to measure movement of the vessel and/or the body portion 108. The one or more sensors may include one or more accelerometers and/or inclinometers. Movement of the body portion 108 may be measured in more than one direction. For example movement of the body portion 108 may be measured in one or more of the X, Y and Z directions and/or the circumferential direction around the longitudinal axis.

The use of active motion compensation helps ensure that accurate data can be determined in offshore applications. That is, the active motion compensation effectively decouples the orientation of the image capture device 102 (at least within the X-Y plane) from the body portion 108. As such, the optical system 100 can still be used in offshore applications, where the foundations piles are installed in an offshore location and the optical system 100 is subject to vessel movement.

The optical system 100 may include means by which the image capture device 102 can locate the reference point 202 in order to capture a visual image thereof. For example, the control unit 600 may be configured to iteratively adjust the position and/or orientation of the image capture device 102 until the reference point 202 has been identified within the field of view 104 of the image capture device 102. The reference point 202 may be identified within the field of view 104 through analysis of visual image data from the image capture device 102 by the processor 400.

In this example, the main body is movably mounted to the housing 124 via a mounting assembly.

In this example the mounting assembly includes at least one bearing element 138 configured to allow the main body to rotate relative to the housing 124 about the longitudinal axis of the optical system 100. In this example
5 the at least one bearing element 138 is an annular roller bearing extending around the connection member 122, allowing the connection member 122 to rotate about the longitudinal axis.

In this example, the mounting assembly includes a gimbal element, the gimbal element being configured to allow the main body to move relative to the housing 124. Advantageously, the gimbal element helps stabilize
10 the main body where the housing 124 is subject to movement, for example as a result of vessel movement. This helps ensure the image capture device 102 remains stable and balanced, even in harsh conditions.

Any suitable gimbal element may be used. In this example the gimbal element is a collar member 132, the main body being mounted to the housing 124 via the collar member 132.
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In this example, as best shown in Figure 7, the main body is mounted to the collar member 132 via a flanged sleeve 129 of the mounting assembly that extends through the orifice in the upper surface 140 of the housing 124. The flange 128 of the flanged sleeve 129 extends laterally and is sized so as to overlie the collar member 132, which surrounds the orifice in the upper surface 140 of the housing 124. The bearing 138 is mounted to,
20 or forms part of a radially inner surface of the flanged sleeve 129, with the connection member 122 extending through the flanged sleeve 129.

An example collar member 132 is shown in isolation in Figure 9. In this example the collar member 132 includes at least one pair of pivot portions configured to allow the main body to pivot relative to the housing 124. In this
25 example the collar member 132 includes two pairs of pivot portions – first pivot portions 134 and second pivot portions 136. Each pair of pivot portions allows the main body to pivot about a separate pivot axis or pivot axes as described in more detail below.

In this example, the pivot portions 134, 136 are raised portions on the upper surface of the collar member 132.
30 In this example, the pivot portions of each pair of pivot portions are positioned on opposing sides of the collar member 132 such that the corresponding pivot axis or pivot axes bisects the collar member 132. In this example, the pairs of pivot portions are offset by 90 degrees, such that the pivot axes 146, 148₁, 148₂ are perpendicular.

35 The flange 128 is primarily mounted to the collar member 132 on the raised pivot portions 134, such that the connection member 122 can pivot about the axis 146 joining the pivot portions 134. In this example the flange

128 is mounted to each pivot portion 134 with a fixing 144 that extends through a corresponding fixing hole 142 in the pivot portions 134. The fixings 144 circumferentially constrain the flange 128 with respect to the collar member 132. That is, relative rotation between the flange 128 and the collar member 132 about the longitudinal axis of the optical system 100 is prevented. The fixings 144 prevent the flange 128 from substantially separating
5 from the collar member 132 but allows the flange 128 to pivot or rock about the pivot axis 146 (and also about pivot axes 148₁, 148₂).

In this example (where there are two pairs of pivot portions), the flange 128 is also mounted to the collar member 132 on the raised pivot portions 136. In this example the flange 128 is mounted to each pivot portion
10 136 with a fixing (not shown) that extends through a corresponding fixing hole 142 in the pivot portions 136. Again the fixings circumferentially constrain the flange 128 with respect to the collar member 132. The fixings allow the flange 128 to move relative to the raised pivot portions 136 so as to pivot about axis 134.

If the flange 128 is pivoted about axis 134 in a first rotational direction towards a first pivot portion 136₁ of the
15 raised pivot portions 136, the flange 128 can then also rock or pivot about a pivot axis 148₁. Alternatively, if the flange 128 is pivoted about axis 134 in a second rotational direction towards a second pivot portion 136₂ of the raised pivot portions 136, the flange 128 can instead rock or pivot about a pivot axis 148₂.

The thickness of the collar member 132 at pivot portions 136 may increase from the radially outer side to the
20 radially inner side. This angles the upper surface of the collar member 132, such that the flange 128 can engage with the raised pivot portions 136 as it pivots about axis 134. As such, the pivot axes 148₁ and 148₂ are angled with respect to each other.

The thickness of the collar member 132 at raised pivot portions 134 may be greater than the thickness of the
25 collar member 132 at raised pivot portions 136₁, 136₂. The thickness of the collar member 132 at raised pivot portions 136₁, 136₂ may be greater than the thickness of the collar member 132 at positions between the raised pivot portions 134 and the raised pivot portions 136₁, 136₂.

The fixings may be received in slotted holes, or the like, in the flange 128 to allow the flange 128 to pivot about
30 each of the pivot axes described above. For example, the slotted holes may extend in a radial direction. As best shown in Figure 8 (with components omitted for clarity), in this example, the flange 128 is movably mounted to the collar member 132 via a pivot portion 134. The flange 128 is configured to pivot about the pivot portion 134 with respect to the housing 124. In use, as the flange 128 pivots or rocks about the pivot portion 134, the damping fluid damps the rocking motion. A pendulum damping effect is created, where movement of
35 the damping fluid from one side of the pivot portion 134 to the other dissipates kinetic energy within the system, substantially reducing unwanted oscillations and vibrations of the image capture device 102.

In this example, the pivot portion 134 is a raised portion on the upper surface of the collar member 132. In this example, there are two pivot portions 134 on opposing sides of the collar member 132, although only one pivot portion 134 is shown in Figure 8. The flange 128 is mounted to the collar member 132 on the raised pivot portion 134, such that the connection member 122 can pivot about the collar member 132 on the axis joining the pivot portions 134. In this example the flange 128 is mounted to the pivot portion 134 with a spherical bearing, although any other coupling or fixing that allows the flange 128 to pivot about the pivot portion 134 may also be used.

In some examples the optical system may include one or more damping systems for damping movement of the main body relative to the housing. The damping system may be a damping element or damping fluid between the main body and the housing. The damping element or damping fluid may be part of the mounting assembly. For example a damping fluid may be present as part of the gimbal element 132, for example between the flange 128 and the collar member 132. Alternatively, a damping fluid may be present between the body portion 108 and the housing 124. For example, a damping fluid may be present in the gap 150 between a lower surface of the body portion 108 and a base of the housing 124. In this manner, oscillations or vibrations in the system may be damped to help stabilize the image capture device 102.

As shown in Figure 6, the lower surface of the body portion 108 and the base of the housing 124 may each define a spherical cap or dome, allowing the body portion 108 to pivot on the gimbal element 132.

Various modifications to the above described embodiments are possible. For example, in some examples the pile driving element 200 includes an indicator element, wherein the processing unit 400 is configured to obtain information regarding the pile driving element 200 from the indicator element. For example, the indicator element may provide information including one or more of the mass of the pile driving element 200, the maximum impact energy or minimum impact energy, the maximum frequency for blows or vibrations, for example. The indicator element may form part of the point of reference 202.

In some examples, one or more of the optical system 100 and the pile driving element 102 may include a GPS antenna to locate the pile driving operation.

A monitoring assembly for monitoring a pile driving assembly during installation of a foundation pile into ground, preferably in an offshore location, may be provided including the optical system and processing unit described above. The monitoring assembly may be suitable for monitoring foundation installation through imaging one or both of a pile driving element and the foundation pile itself.

It will be clear to a person skilled in the art that other constructions of the specific arrangements described above may be possible. For example, the specific components within the mounting assembly may differ from those described above.

- 5 It will be clear to a person skilled in the art that features described in relation to any of the embodiments described above can be applicable interchangeably between the different embodiments. The embodiments described above are examples to illustrate various features of the invention.

CLAIMS

1. A pile driving assembly for installing a foundation pile into ground, preferably in an offshore location, wherein the pile driving assembly comprises:
5 an optical system including:
an image capture device for capturing visual images; and
a processing unit configured to receive visual images from the image capture device or the optical system and to process the visual images; and
a pile driving element for driving a foundation pile into the ground,
10 wherein in an operational configuration the optical system is provided at a distance from the pile driving element, such that the image capture device is configured to capture a visual image of at least one point of reference on the pile driving element,
wherein the processing unit is configured to determine the penetration of a foundation pile into the ground and/or the penetration direction of the foundation pile into the ground from at least two visual
15 images of the at least one point of reference.
2. The pile driving assembly of claim 1, wherein the optical system includes a frame element, wherein the image capture device is pivotally mounted to the frame element such that during operation of the pile
20 driving element the image capture device can follow the movement of the at least one point of reference.
3. The pile driving assembly of any preceding claim, wherein the optical system comprises a main body, the main body comprising:
the image capture device;
25 a body portion; and
an actuation system configured to rotate the image capture device relative to the body portion.
4. The pile driving assembly of claim 3, wherein the actuation system is configured to rotate the image
30 capture device about a longitudinal axis of the optical system.
5. The pile driving assembly of claim 3 or 4, wherein the optical system comprises a housing, the body portion being housed within the housing, wherein the main body is movably mounted to the housing via a mounting assembly.

6. The pile driving measurement of claim 5, wherein the mounting assembly comprises at least one bearing element configured to allow the main body to rotate relative to the housing about a longitudinal axis of the optical system.
- 5 7. The pile driving assembly of claim 5 or 6, wherein the mounting assembly comprises a gimbal element, wherein the gimbal element is configured to allow the main body to move relative to the housing.
8. The pile driving assembly of claim 7, wherein the gimbal element is a collar member, the collar member having at least one pair of pivot portions configured to allow the main body to pivot relative to the housing.
- 10 9. The pile driving assembly of any of claims 5 to 8, wherein the optical system comprises a damping system for damping movement of the main body relative to the housing.
- 15 10. The pile driving assembly of any of claims 3 to 9, wherein the pile driving assembly comprises a control unit configured to control the actuation system in response to movement of the body portion.
11. The pile driving assembly of claim 10, wherein the pile driving assembly comprises one or more sensors configured to measure movement of the body portion.
- 20 12. The pile driving assembly of any preceding claim, wherein the optical system comprises a GPS antenna to locate the pile driving operation.
13. The pile driving assembly of any preceding claim, further comprising an energy source or power supply to provide electric power to one or more of the optical system and the processing unit.
- 25 14. The pile driving assembly of any preceding claim, wherein the at least one point of reference comprises a calibration element, wherein the processing unit is configured to calibrate from a visual image of the calibration element at least one of:
- 30 the distance between the image capture device and the calibration element; and
 the relative orientation between the image capture device and the calibration element.
15. The pile driving assembly of any preceding claim, wherein the at least one point of reference comprises an indicator element, wherein the processing unit is configured to obtain information regarding the pile driving element from the indicator element.
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16. The pile driving assembly of any preceding claim, further comprising a foundation pile, wherein in the operational configuration the pile driving element is provided on the foundation pile.

17. A marine vessel comprising the pile driving assembly of any of the preceding claims.

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18. A method for installing, preferably in an offshore location, a foundation pile into ground, the method comprising the following steps:

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- a) providing a pile driving assembly according to any of the preceding claims;
- b) positioning the optical system at a distance from the pile driving element;
- c) capturing a visual image of at least one point of reference on the pile driving element;
- d) at least partially installing a foundation pile into ground with the pile driving element;
- e) capturing a further visual image of the at least one point of reference during or after the at least partial installation of the foundation pile;
- f) determining the penetration of the foundation pile into the ground and/or the penetration direction of the foundation pile into the ground from the at least two visual images of the at least one reference point.

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19. The method of claim 18, wherein simultaneously and/or after step f) the optical system does repeatedly performs steps c) to e) in a looped manner.

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20. The method of any of claims 18 to 19, comprising the step of calibrating from the visual image of the at least one point of reference at least one of:

- the distance between the image capture device and the calibration element; and
- the relative orientation between the image capture device and the calibration element.