

Dredging system and method for dredging

Technical Field

[0001] The present disclosure is concerned with dredging of granular materials
5 and in particular with a dredging system and method for dredging.

Background

[0002] Dredging or excavation of granular material from a granular material mass
that is partially or completely submerged under a fluid may be required in
10 various settings. Regular dredging may, for instance, be required to keep
shipping lanes open, to keep industrial basins free from accumulated granular
material, or to remove accumulated granular materials from behind a dam.
Seafloor mining may require the excavation of granular material to retrieve
desired materials. Reinforcement of vulnerable coastlines, or the construction
15 of artificial islands requires the excavation of large granular material volumes,
usually from locations further offshore. The anchoring of (partially) submerged
equipment may require excavation of holes or trenches in a seafloor
comprising granular material. Finally, dredging of large granular material
volumes may be required to release a stranded vessel in shallow waters.

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[0003] Known dredging equipment may be mounted on vessels, such as barges or
purpose-built dredging ships. The dredging equipment may then be brought to
a dredging location by the vessel. During dredging, the vessel stays in place at
the dredging location or moves along with the ongoing dredging operation. A
25 downside of vessel-mounted dredging is that the vessel may partially or
completely block the dredging location for marine traffic. In a harbor basin or in
a narrow waterway, for instance, decreased accessibility may lead to a
negative economic impact. Some dredging locations may not even be
accessible by vessel-mounted dredging equipment, as the dredging location
30 may be too deep or too shallow.

[0004] A further downside of vessel-mounted dredging are the associated logistics
and costs. A vessel-based dredging system usually requires an operating crew

to man the vessel and / or the dredging equipment. Thereby, dredging may be costly and require complicated logistics, especially for dredging operations that last long or take place in remote locations. In areas where dredging is only intermittently required, the vessel-mounted dredging equipment and its operating crew must be brought into place before a dredging operation commences, thereby further complicating logistics.

[0005] Consequently, there is a clear need for an improved dredging system, that overcomes disadvantages of known systems and can be operated such that the blocking of a dredging location by a vessel is not required, while logistics associated to the dredging operation can be simplified.

Summary of the disclosure

[0006] The present disclosure concerns a dredging system according to claim 1. The present disclosure also concerns the use of a dredging system according to claim 18 and a method for dredging according to claim 19.

Figures

[0007] Figure 1A schematically shows a dredging system according to a first embodiment, comprising a bottom crawler.

[0008] Figure 1B schematically shows an alternative dredging system according to the first embodiment, comprising a submersible drone.

[0009] Figure 2 schematically shows a docking station according to the invention.

[0010] Figure 3A schematically shows a side view of a dredging robot according to the invention.

[0011] Figure 3B schematically shows a front view of dredging robot according to the invention.

[0012] Figure 4A schematically shows one flow configuration according to the invention.

5 [0013] Figure 4B schematically shows another flow configuration according to the invention.

[0014] Figure 5A schematically shows a dredging system according to a second embodiment, comprising an umbilical line.

10 [0015] Figure 5B schematically shows an alternative dredging system according to the second embodiment, comprising an umbilical line including a power line.

[0016] Figure 6 schematically shows a dredging system with multiple docking stations according to the invention.

15 [0017] Figure 7 schematically shows a dredging system with a docking station with several docking couplings according to the invention.

Detailed description

20 [0018] Figures 1A and 1B schematically show a dredging system for removing submerged granular material 1 from a bottom surface, according to a first embodiment of the invention. Same reference signs refer to the same features both in fig. 1A and 1B, and in all other figures. The submerged granular material 1 may be partially submerged, or completely submerged, under a fluid

25 2. The fluid 2 may comprise seawater, fresh water, wastewater, liquid or gaseous hydrocarbons, an industrial fluid, a liquid-gas mixture, a gas, or any combinations thereof. The granular material 1 may comprise clay, silt, sand, gravel, or mixtures thereof. Additionally, or alternatively, the granular material 1 may comprise particles comprising metal, plastics, biomass, wood, food

30 materials, ceramics, concrete, glass, minerals, crystalline materials, composites, or combinations thereof. When the dredging system is utilized in a harbor basin, for instance, the granular material 1 may comprise sand and the

fluid 2 may comprise sea water.

[0019] The dredging system comprises a dredging robot 3, for removing granular material, and a docking station 4, for offloading removed granular material from the dredging robot 3. The removed granular material may comprise a mixture of granular material 1 and fluid 2. The dredging robot 3 may comprise a bottom crawler, see fig. 1A. A bottom crawler is configured to drive over the bottom surface. Alternatively, the dredging robot 3 may comprise a submersible drone, see fig. 1B, such as an ROV. A submersible drone is configured to dive within the fluid 2. Advantageously, by utilizing a dredging robot in combination with a docking station, positioning of vessel-mounted dredging equipment at the dredging location may be avoided, thereby avoiding cumbersome logistics. Further advantageously, in dredging locations with marine traffic, said marine traffic may continue uninterrupted.

[0020] The docking station 4, schematically shown in more detail in fig. 2, is attached to the bottom surface. The docking station 4 may be partially or completely submerged in the fluid 2. The docking station 4 may comprise a base 4b. The base 4b may be partially or completely embedded in the bottom surface (fig. 1A) or may rest on the bottom surface by its own weight. Alternatively, the docking station 4 may comprise an anchor line (striped line in fig. 1B), where the anchor line is attached to the bottom surface. In the latter case, the docking station 4 may be held up-right by a float (fig. 1B). The docking station 4 may be positioned at a distance from the dredging location. This may be advantageous for dredging operations in areas with marine traffic, such as the harbors or shipping lanes. Alternatively, the docking station 4 may be positioned at the dredging location. This may be advantageous for dredging operations requiring continuous removal of granular material or the removal of large volumes of granular material, such as during the construction of an artificial island or during seafloor mining. The docking station 4 may comprise a control valve 4c, for controlling the flow of removed granular material therethrough. The docking station 4 may further comprise one or more filters 4d, for filtering the removed granular material. The docking station comprises a

housing 4e. The housing may comprise a metal material, such as a stainless steel, or a composite material, such as a polymer-metal composite or a glass fiber-polymer composite.

5 [0021] The docking station 4 may comprise at least one sensor 4f and optionally a control unit 4g. The at least one sensor 4f may comprise a pressure sensor, a proximity sensor, a sonar, a temperature sensor, a flow meter, and / or an optical sensor. The pressure sensor may monitor fluid pressure within the docking station or externally to the docking station 4. The proximity sensor may
10 monitor proximity of the dredging robot 3 to the docking station 4. The optical sensor may comprise one or more underwater cameras. The temperature sensor may monitor the temperature within the docking station or externally to the docking station 4. The flow meter may monitor fluid flow velocities within the docking station or externally to the docking station 4. The docking station 4
15 may further comprise one or more floodlights 4h, for improving visibility for the underwater cameras. The control unit 4g comprises a CPU, a communications module, and a memory unit. The control unit 4g may send sensor signals to a remote command center and receive command signals from the remote command center. The control unit 4g may receive sensor signals from the
20 dredging robot 3 and / or send control signals to the dredging robot 3. The control unit 4g may, for instance, obtain sensor signals from the at least one sensor 4f, and send command signals to the dredging robot 3, based on the obtained sensor signals. Furthermore, the control unit may send warning signals to the remote command center, based on sensor signals received from
25 the dredging robot 3 or from the at least one sensor 4f. A remote operator may then be warned of a malfunctioning, a maintenance requirement, and / or an operational issue with the dredging system. The docking station 3 may further comprise an analysis unit 4i, for monitoring physical and / or chemical properties of the removed granular material, of the fluid and / or of the
30 environment surrounding the docking station. The analysis unit 4i may, for instance, determine average particle diameters, particle densities, the presence of contamination, and / or the presence of target materials, such as

minerals.

[0022] The dredging system further comprises a riser pipe 5, for transporting removed granular material from the docking station 4 to a remote location. The remote location may comprise a fixed or mobile basin for granular material, such as a floating basin, a seafloor basin, a vessel-based basin, a vehicle-based basin, or an onshore basin. Advantageously, removed granular material may be transported in the mobile basin to a location for further use, for processing, for filtering, or for disposal. Alternatively, the remote location may comprise a construction location or a deposit location. Advantageously, removed granular material may thereby be brought directly to the location where it is utilized as construction material or to the location where it is temporarily or permanently disposed. The riser pipe 5 may be flexible. The riser pipe 5 may comprise a power line 5a (dash-dotted line in fig. 2), for supplying electrical power to the docking station 4. The riser pipe 5 may further comprise a communications line 5b, for sending and receiving communication and control signals to and from the docking station 4. The communications line 5b may, for instance, comprise an optical fiber cable. The riser pipe 5 may comprise one or more control valves 5c, for regulating the flow of removed granular material therethrough. The dredging system may comprise conveying means 5d for conveying removed granular material through the riser pipe 5, from the docking station 4 to the remote location. The conveying means 5d may be integrated in the submerged docking system 4, may be located onshore or may be mounted on a vessel. The conveying means 5d may comprise a slurry pump. Alternatively, the conveying means 5d may comprise a venturi system comprising an eductor, or a gas-lift system comprising a compressor. Alternatively, or additionally, the conveying means 5d may comprise a booster pump. Advantageously, by additionally utilizing a booster pump, removed granular material can be conveyed through the riser pipe from large fluid depths.

[0023] The dredging robot 3, schematically shown in fig. 3A, comprises propulsion means 3a. The propulsion means 3a may be driven by one or more electrical

motors (not shown), thrust motors, or underwater jet motors. For a dredging robot 3 comprising a bottom crawler, shown in fig. 3A, the propulsion means 3a comprise one or more endless belts, or a plurality of wheels. Advantageously, a bottom crawler may carry a heavy granular material load from the dredging location to the docking station. Further advantageously, a bottom crawler may access both submerged, partially submerged, or non-submerged dredging locations. For a dredging robot comprising a submersible drone (not shown), the propulsion means 3a comprise one or more propellers, screws, thrust motors, and / or underwater jet motors. The submersible drone may further comprise at least one rudder and / or one or more fins and optionally, a ballast system for adjusting the buoyancy of the underwater drone. Advantageously, a submersible drone provides increased maneuverability, allowing the dredging robot to move freely over obstacles on the bottom surface. Further advantageously, a submersible drone may more easily be brought to the surface, for instance for maintenance purposes.

[0024] The dredging robot 3 comprises at least one suction head 3b, for removing granular material by means of suction. The at least one suction head 3b may be mounted on a robotic arm 3d. Advantageously, the suction head can thereby be precisely controlled and / or placed over the granular material that is to be removed. Alternatively, the at least one suction head 3b may be mounted in a fixed manner to the dredging robot 3. The at least one suction head 3b may be positioned on the front side of the dredging robot 3. Advantageously, the at least one suction head then removes granular material before the dredging robot moves over a location. Alternatively, or additionally, the at least one suction head 3b may be positioned on the rear side of the dredging robot 3. Advantageously, granular material may then first be loosened (described below) while the dredging robot moves over the granular material before the granular material is removed by the suction head. Further alternatively, or additionally, the at least one suction head 3b may be positioned on the lateral side/s of the dredging robot 3, and / or on the underside of the dredging robot 3.

[0025] The dredging robot 3 may comprise a control unit 3g, configured for operation of the dredging robot 3 by remote control, semi-autonomously and / or autonomously. The control unit 3g may comprise one or more CPUs. The control unit 3g may further comprise communication means, for communicating with the docking station 4 and / or with a remote command center. The remote command center may be vessel-based or onshore-based. The dredging robot 3 may further comprise an underwater positioning system (not shown). The underwater positioning system is coupled to the control unit 3g. The underwater positioning system may comprise a doppler based system, an ultra-short baseline system, or an underwater GPS. The dredging system may further comprise one or more beacons or navigation nodes for the underwater positioning system. The beacons may be placed at different intervals between the docking station 4 and the dredging location. The dredging robot 3 may further comprise at least one sensor (not shown), such as a pressure sensor, a gyroscope, a temperature sensor, a sonar, a depth sensor, and / or an optical sensor. The optical sensor may preferably comprise one or more underwater cameras. The dredging robot 3 may further comprise one or more floodlights (not shown), for improving visibility for the underwater cameras and / or visibility of the dredging robot 3. The at least one sensor is coupled to the control unit 3g. Advantageously, the control unit, the underwater positioning system and the at least one sensor allow the dredging robot to navigate over the bottom surface and / or within the fluid 2 and optionally to dock at the docking station 4. The control unit 3g may be configured to send warning signals to a remote command center, based on data received from the underwater positioning system and / or the at least one sensor. Thereby, a remote operator may be warned of a malfunctioning, a maintenance requirement, or an operational issue. The dredging robot 3 may further comprise an analysis unit (not shown), configured to monitor physical and / or chemical properties of the granular material 1 and / or the fluid. The analysis unit may, for instance, be configured to determine average particle diameters, particle densities, particle shapes, the presence of contamination, and / or the presence of target materials, such as minerals.

[0026] The dredging robot 3 may comprise one or more shearing elements 3i, for loosening of the granular material 1. Advantageously, loosened granular material may more easily be fluidized and subsequently removed by the at least one suction head. The one or more shearing elements 3i may comprise
5 passive shearing elements, such as teeth, blades, or knives. Alternatively, or additionally, the one or more shearing elements 3i may comprise active shearing elements, such as rotating blades, vibrating elements, spiked rollers, or nozzles for emitting high-pressure fluid jets. The active shearing elements may be configured to be driven in a vibrating, pulsating, or a rotating motion.
10 The active shearing elements may be driven electrically or hydraulically. The one or more shearing elements may be retractable shearing elements, such as retractable blades. Deployment of the retractable blades may be driven electrically or hydraulically. Advantageously, the one or more shearing elements can thereby be deployed when needed and retracted when not
15 needed. The one or more shearing elements 3i may be provided on the suction head and / or on a separate arm, mounted to the dredging robot 3. The arm may be a robotic arm, configured to control the movement of the one or more shearing elements 3i. Alternatively, the arm may be a static arm.

20 [0027] The dredging robot 3 may further comprise one or more fluidizing nozzles, for emitting pressurized fluid into the granular material to thereby fluidize and loosen the granular material. Advantageously, fluidized granular material is more easily removed through the suction head. The one or more fluidizing nozzles may be mounted on the suction head 3b. The one or more fluidizing
25 nozzles may, for instance, be placed within the suction head 3b, on the outside of the suction head 3b, and / or on one or more arms, protruding from the suction head 3b. Alternatively, and / or additionally, the one or more fluidizing nozzles may be placed elsewhere on the dredging robot 3, such as on one or more arms, protruding from the dredging robot 3. Advantageously, fluidization
30 of the granular material may thereby be controlled as required, achieving a more efficient removal of granular material. The one or more fluidizing nozzles may be connected to a fluid inlet and a pump (described below), for providing and pressurizing the fluid emitted from the fluidizing nozzles. The fluid inlet

may be coupled to an external fluid source. Alternatively, the fluid inlet may be configured to take in fluid from the surrounding fluid 2. For a dredging system in an industrial wastewater basin, for instance, the pressurized fluid emitted by the fluidizing nozzles may comprise wastewater contained in the basin.

5 [0028] The dredging robot 3 may further comprise a release system 3j, for releasing the dredging robot 3 when it becomes immobilized. For instance, the dredging robot may become immobilized due to partially sinking into a fluidized granular material mass, or due to an obstacle. The release system may include
10 an inflatable bag, an inflatable floatation device, a hydraulic release element, or one or more nozzles for emitting a high-pressure jet. The inflatable bag may be located on the underside of the dredging robot 3. The inflatable bag is configured to push the dredging robot 3 away from the bottom surface during inflation, thereby releasing the dredging robot 3 from the bottom surface. The
15 inflatable floatation device may be located at the sides or top of the dredging robot 3. The inflatable floatation device, when inflated, is configured to provide lift to the dredging robot 3, to thereby release the dredging robot 3 from the bottom surface. The dredging system may comprise a source of compressed gas to inflate the inflatable bag or inflatable floatation device. The source of
20 compressed gas may comprise a compressed gas holder, incorporated in the dredging robot 3. The hydraulic release element may comprise one or more hydraulically operated arms, located at the sides and / or the underside of the dredging robot 3. The hydraulically operated arms are configured to push the dredging robot 3 away from the bottom surface, when deployed, to thereby
25 release the dredging robot 3 from the bottom surface.

[0029] The dredging robot 3 may comprise multiple suction heads 3b, as schematically shown in fig. 3B. The multiple suction heads 3b may be positioned on the same side of the dredging robot 3 or on different sides. For
30 instance, one or more suction heads may be positioned on the front side and one or more suction heads 3b may be positioned on each lateral side of the dredging robot 3, see fig. 3. Advantageously, a broad area can thereby be covered at once, allowing a large volume of granular material to be removed. Alternatively, one or more suction heads 3b may be positioned on the front side

and one or more suction heads 3b may be positioned on the rear side of the dredging robot 3. Advantageously, double suction can thereby be applied to the same location over which the dredging robot moves. Additionally, or alternatively, the multiple suction heads may be positioned on one or both lateral sides of the dredging robot 3 and / or at the underside of the dredging robot 3.

[0030] According to the first embodiment, shown in fig. 1A and 1B, the dredging robot 3 may be configured to shuttle between a dredging location, for removing granular material, and the docking station 4, for offloading the removed granular material. Advantageously, the dredging robot thereby has a large operational reach and may easily navigate around obstacles on the bottom surface or in the fluid 2. In this embodiment, the dredging robot 3 comprises means for applying suction to the suction head 3b, such as an internal pump 3c. The internal pump 3c preferably comprises a slurry pump. A slurry pump is configured to pump a mixture of a fluid and solid particles. The dredging robot 3 further comprises a tank 3e, connected to the at least one suction head 3b, for the temporary storage of removed granular material. A flow line (not shown) connects the suction head 3b with the pump 3c and the tank 3e. In this embodiment, the dredging robot 3 further comprises coupling 3k. The coupling 3k is configured to connect to the docking coupling 4a provided on the docking station 4, when the dredging robot 3 is docked at the docking station 4. The docking station 4 is configured to offload removed granular material from the tank 3e through the docking coupling 4a. Advantageously, by temporarily storing the removed granular material, operational flexibility is achieved. This is especially advantageous when the dredging robot must navigate around submerged obstacles or when the dredging location is far removed from the docking station. In such circumstances, a permanent connection between the dredging robot and the docking station may hinder motion of the dredging robot.

[0031] The dredging robot 3 may further comprise an overflow outlet 3f, see fig. 3A. The overflow outlet 3f may comprise a filter, for filtering out particles from

the fluid flowing through the overflow duct. Advantageously, fluid may flow out of the tank, while granular material is restrained in the tank. Thereby, granular material may be compacted, and the volume of granular material stored in the tank may be increased. Further advantageously, by allowing fluid to flow out of the tank, over-filling of the tank may be prevented. The overflow outlet 3f may comprise an overflow control valve 3f' for closing and opening the overflow outlet 3f. The dredging robot 3 may further comprise a battery 3h, for providing power to the dredging robot 3. In this case, the docking coupling 4a comprises an electrical outlet 4a, for charging the battery 3h when the dredging robot 3 is docked at the docking station 4. Advantageously, greater operational freedom is thereby achieved. Alternatively, or additionally, the dredging system may comprise a power line (not shown), connected to the dredging robot 3, for providing power thereto. The power line may be coupled to the docking station 4. Alternatively, the power line may be coupled directly to an external power source, such as an on-shore power source or a vessel-based power source. Optionally, the power line may include floating elements to compensate for the weight of the power line in the fluid. Advantageously, by utilizing a power line, the dredging robot may be provided with power continuously. Optionally, the power line may comprise a communications line, such as an optical fiber cable, for sending and receiving data and control signals to and from the dredging robot 3. Further optionally, the docking coupling 4a comprises a communication port, for communication with the control unit 3g of the dredging robot 3, when the dredging robot 3 is docked at the docking station 4. Dredging instructions may, for instance, be uploaded to the control unit 3g during docking. Furthermore, sensor data from the dredging robot 3 may be downloaded to the docking station 4 and / or a remote command center during docking.

[0032] With reference to the flow configuration schematically shown in fig. 4A, a granular material control valve 3c' is provided between the suction head 3b and the tank 3e, for controlling the flow of removed granular material, comprising granular material 1 and fluid 2, to the tank 3e. The tank is provided with an offloading line 3q, for offloading granular material, from the tank 3e to the

docking station 4. The offloading line 3q comprises an offloading control valve 3q', for controlling flow of granular material from the tank 3e. A fluid inlet 3m may be provided, coupled to a pump 3n. The fluid inlet 3m may comprise a filter (not shown) for filtering out particles or other contamination. The fluid inlet 3m is connected to at least one nozzle 3r, extending into the tank 3e. Preferably two or more nozzles 3r are provided. A fluid control valve 3n' is provided for controlling the flow from the fluid inlet 3m to the at least one nozzle 3r in the tank 3e. The fluid inlet 3m may further be connected to the one or more fluidizing or jetting nozzles. A further fluid control valve 3n'' is provided for controlling the flow from the fluid inlet 3m to the one or more fluidizing or jetting nozzles.

[0033] In operation, granular material removal commences and the granular material control valve 3c' is opened. Suction is then applied by the internal pump 3c, allowing granular material to be sucked-up by the suction head 3b and deposited in the tank 3e. Optionally, the fluid control valve 3n'' is opened and pressurized fluid is pumped by the pump 3n from the fluid inlet 3m to the fluidizing or jetting nozzles to fluidize the granular material in the vicinity of the suction head. Advantageously, removal of granular material through the suction head is thereby improved. During granular material removal, offloading control valve 3q' is closed to avoid accidental offloading from the tank through the offloading line 3q. The overflow control valve 3f' is opened during granular material removal, to allow fluid 2, deposited in the tank 3e together with removed granular material, to escape from the tank 3e. Advantageously, granular material in the tank is thereby compacted, allowing a larger volume of granular material to be stored in the tank. Once the tank 3e is filled, granular material removal is stopped and the granular material control valve 3c', the fluid control valve 3n', and the overflow control valve 3f' are closed. The dredging robot 3 then moves from the dredging location to the docking station 4. Upon docking at the docking station 4, offloading commences. The offloading control valve 3q' is opened and granular material, is offloaded through the offloading line 3q to the docking station 4. Optionally, fluid control valve 3n' is opened and fluid is pumped from the fluid inlet 3m to the at least

one nozzle 3r, by the pump 3n, to fluidize granular material collected in the tank 3e. Advantageously, fluidized granular material can more easily be offloaded from the tank. During offloading, the granular material control valve 3c' and the overflow control valve 3f' remain closed, to avoid undesired discharge of granular material through the suction head 3b or the overflow outlet 3f.

[0034] Offloading may be driven by an external pump (not shown), applying suction to the offloading line 3q. Alternatively, or additionally, offloading may be driven by pressurized fluid emitted from the at least one nozzle 3r and driven by the pump 3n. The pressurized fluid creates overpressure in the tank 3e, thereby driving fluidized granular material through the offloading line 3q. Further alternatively, offloading may be driven by pressurized gas, provided to the tank 3e by a compressor (not shown). The pressurized gas creates overpressure in the tank 3e, thereby driving fluidized granular material through the offloading line 3q.

[0035] With reference to fig. 4B, in an alternative flow configuration of the first embodiment, offloading is driven by the internal pump 3c. The offloading line 3q is connected to the internal pump 3c. The offloading line 3q comprises a further offloading control valve 3q''. The offloading control valve 3q' and the further offloading control valve 3q'' are respectively placed upstream and downstream of the internal pump 3c. Furthermore, a further granular material control valve 3c'' is provided. The granular material control valve 3c' and the further granular material control valve 3c'' are respectively placed upstream and downstream of the internal pump 3c. Other elements of the flow configuration are the same as for the configuration shown in fig. 4B and described herein above, with reference to fig. 4A.

[0036] In operation, the granular material control valve 3c' and the further granular material control valve 3c'', and optionally the further fluid control valve 3n'', are opened during granular material removal. The offloading control valve 3q' and the further offloading control valve 3q'' are closed during granular material

removal. The internal pump 3c then pumps the removed granular material from the suction head 3b into the tank 3e, through the flow line comprising the granular material control valve 3c' and the further granular material control valve 3c''. During offloading, the granular material control valve 3c', the further granular material control valve 3c'' and the further fluid control valve 3n'', are closed. The offloading control valve 3q' is opened during offloading. Furthermore, the fluid control valve 3n' may be opened, such that pressurized fluid, driven by the pump 3n, fluidizes the granular material in the tank 3e. Consequently, fluidized granular material is offloaded from the tank 3e, driven by the suction applied by internal pump 3c. Additionally, or alternatively, the overflow control valve 3f' may be closed during offloading. By keeping the overflow control valve 3f' closed, overpressure may arise in the tank 3e, driven by the pressurized fluid. The over pressure further drives the offloading of fluidized granular material.

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[0037] According to a second embodiment of the invention, schematically shown in fig. 5A, the dredging system comprises an umbilical line 6, connecting the dredging robot 3 to the docking station 4. The umbilical line 6 comprises a flexible tube for offloading removed granular material from the dredging robot 3 to the docking station 4. Advantageously, by utilizing an umbilical line, the dredging robot may operate continuously, and large granular material volumes may be removed without interruption. granular material.

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[0038] The umbilical line 6 may comprise a power line, as shown in fig. 5B, for supplying electrical power from the docking station 4 to the dredging robot 3. Advantageously, by utilizing a power line, a battery pack can be omitted such that the weight of the dredging robot can be reduced. The umbilical line 6 may further comprise a communications line, such as an optical fiber cable, for sending and receiving data and control signals to and from the docking station 4 to the dredging robot 3. The umbilical line 6 may further comprise one or more hydraulic lines, for driving hydraulic operation of the robotic arm 3d, for hydraulic deployment of the retractable shearing element 3i, and / or hydraulic operation of one or more control valves of the dredging robot 3, such as the

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granular material control valve 3c', the overflow control valve 3f', the fluid control valve 3n' and / or the offloading control valve 3q'. The umbilical line 6 may further comprise a compressed-gas line, for providing compressed gas to the release system 3j. The umbilical line 6 may further comprise a lubrication line, for providing a lubricant to the dredging robot 3. The lubricant may be supplied to one or more moving elements of the dredging robot 3, such as pumps, control valves or robotic arms. In this embodiment, the riser pipe 5 may comprise corresponding one or more hydraulic lines, a compressed-gas line, and / or a lubrication line.

[0039] In the second embodiment, the conveying means 5d may additionally comprise at least one booster pump, for continuous offloading of removed granular material from the suction head 3b through the riser pipe 5. The booster pump may be included in the docking station 4, may be located onshore or may be mounted on a vessel. Advantageously, by utilizing an additional booster pump, removed granular material can be offloaded from greater fluid depths.

[0040] In the second embodiment, the dredging system may comprise a reel 6a for coiling and uncoiling of the umbilical line 6. The reel 6a may be mounted on the dredging robot 3 (shown in fig. 5A), on a separate frame (shown in fig. 5B), or on the docking station 4. When the dredging robot 3 comprises a submersible drone, the reel 6a is preferably mounted on the docking station 4. The separate frame may be anchored to the bottom surface. Alternatively, the umbilical line 6 may be placed uncoiled on the bottom surface. Finally, the umbilical line 6 may comprise a coupling 6b for coupling to the docking station 4. The coupling provides a fluid-proof connection between the umbilical line 6 and the docking station 4. The coupling 6b may comprise connecting elements for the flexible tube. Additionally, the coupling 6b may comprise connecting elements for the power line, the communications line, the one or more hydraulic lines, the compressed-gas line, and / or the lubricant line. The coupling may be provided with a failure indicator, signaling a connection failure to a remote operator. The coupling may comprise a control valve, for controlling the flow of removed

granular material to the docking station 4.

[0041] According to the first and second embodiments, the dredging system may comprise one or more dredging robots 3. In operation, the one or more
5 dredging robots may shuttle between one or more dredging locations. Advantageously, the dredging system may thereby efficiently cover a large area and a high granular material removal rate may be achieved. This configuration may be especially advantageous for areas requiring frequent granular material removal such as harbors or channels for marine traffic.
10 Additionally, or alternatively, the dredging system may comprise multiple docking stations 4 and one or more dredging robots 3, as schematically shown in fig. 6. The multiple docking stations 4 may be connected to a single riser pipe 5. A connecting pipe 7 may connect the multiple docking stations 4. Offloaded granular material is transported from the docking stations 4 through
15 the connecting pipe, to the riser pipe 5. The connecting pipe 7 comprises a power line, for supplying electrical power from the riser pipe 5 to the docking stations 4. The connecting pipe 7 may further comprise a communications line, one or more hydraulic lines, a compressed-gas line, and / or a lubricant line.

20 [0042] Alternatively, several riser pipes 5 may be provided, with one or more docking stations 4 connected to each riser pipe 5, by means of a connecting pipe 7. The one or more dredging robots 3 may be configured to dock at a specific docking station or at any docking station. A central control system may be provided, to control the movements and granular material removal of each
25 dredging robot 3. Advantageously, a configuration with multiple docking stations may efficiently cover a large dredging area, such as a large harbor, an extended length of a channel for marine traffic or a large seafloor mining operation. Further advantageously, by connecting several docking stations, fewer granular material extraction points at the surface may be required,
30 resulting in a more efficient system.

[0043] The dredging system according to the invention may be used for seafloor mining, coastal reinforcement or the construction of artificial peninsulas or

islands, the anchoring of submerged or partially submerged equipment, the excavation of trenches for the laying of off-shore cables, the dredging of granular material around a stranded vessel, the removal of accumulated granular material from behind a dam or from an artificial basin, or the removal
5 of granular material from a waterway, such as a channel, a river, a lake, a harbor, or a shipping lane.

[0044] A method for removing granular material comprises providing at least one dredging system according to the disclosure, comprising a dredging robot 3, a
10 docking station 4 and a riser pipe 5, removing granular material 1 with the dredging robot 3, offloading removed granular material from the dredging robot 3 to the docking station 4; and transporting removed granular material from the docking station 4 to a remote location through the riser pipe 5. The method may further comprise instructing the at least one dredging system to execute a
15 dredging operation. Instructing the at least one dredging system may comprise instructing the control unit 3g of the dredging robot 3 to execute the dredging operation by remote control, semi-autonomously or autonomously.

[0045] When executing a dredging operation by remote control, an onshore-based
20 or vessel-based operator may control the operation of the dredging robot remotely. The underwater positioning system and / or the at least one sensor may provide the operator with information required for operating the dredging robot remotely. Executing a dredging operation by remote control may be advantageous for complex operations, such as dredging around a stranded
25 vessel. When executing a dredging operation semi-autonomously or autonomously, instructions may be uploaded to the control unit 3g, through the communications line. Preferably, the dredging robot 3 comprises machine intelligence, configured to semi-autonomously or autonomously perform the dredging operation. Thereby, the dredging robot 3 may navigate over the
30 bottom surface to the dredging location, remove granular material at the dredging location and return to the docking station to offload granular material while requiring minimal, or no, operator input. Data from the underwater positioning system and / or the at least one sensor may be used by the control

unit 3g to verify operation and / or may be downloaded to a remote station for later usage. The remote station may be onshore-based or vessel-based.

[0046] Executing the dredging operation may comprise executing the dredging operation for a limited time interval, continuously, or at regular time intervals. The dredging operation may further cover predefined dredging areas and / or operator-controlled areas. According to one method one or more dredging robots 3 may shuttle between multiple docking stations 4, at regular intervals or continuously. The docking stations 4 may be placed at some distance from one another. Such a method may be advantageous in a harbor, a channel, or a shipping lane. Each basin in the harbor may be provided with a docking station 4. In a channel, a docking station 4 may be provided at fixed intervals. The one or more dredging robots 3 may autonomously or semi-autonomously move from one docking station 4 to the next, removing accumulated granular material in the areas at or between the docking stations 4. Thereby a regular, or continuous, removal of accumulated granular material over a large area is achieved, without hindering marine traffic. According to an alternative method, one or more dredging robots 3 may shuttle between a dredging location and a docking station 4. Such a method may be advantageous for seafloor mining operations, for coastal reinforcement, or for the creation of artificial islands or peninsulas, where large volumes of granular material must be removed from a limited area.

[0047] Fig. 7 shows an embodiment as described above but where each docking station 4 connected to a single riser pipe 5 may include several docking couplings 4a to allow several dredging robots 3 to be connected to one docking station 4. The solution of fig. 7 allows several dredging robots 3 to offload granular material and /or charge simultaneously from one docking station. Clearly may also several docking stations as shown in fig. 6 include several docking couplings 4a. A system may also include a combination of docking stations with 4 with a single docking coupling 4a and docking stations with several docking couplings 4a.

- [0048] The claim claims that the docking station (4) for offloading removed granular material from the dredging robot (3) is attached to a bottom surface or attached and fixed in relation to the bottom surface. Bottom surfaces also include the bottom of artificial ducts and channels, and the term bottom surface may include a surface that could be called wall, step, ledge, shelf, bank, riverbank, hill, seabed, jetty, port, column, foundation, etc. A bottom surface as expressed above thus provides a fixed and permanent location that is unaffected by elements such as waves, water current, motion, and tide.
- [0049] Figures 8A-8F show various structures, either natural or artificial, that may serve as locations for locating a docking station. Fig. 8a shows a seabed 8, fig. 8b shows a shelf or ledge 9, fig. 8c shows a bracket on a side structure 10, Fig. 8E shows a wall 11 of a jetty or channel and fig. 8F shows an attachment 12 above the water surface at a side structure. The specification "is attached to the bottom surface" is intended to cover all these scenarios.

List of references

[0050]

- 1 granular material
- 2 fluid
- 3 dredging robot
- 3a propulsion means
- 3b suction head
- 3c internal pump
- 3c' granular material control valve
- 3c'' further granular material control valve
- 3d robotic arm
- 3e tank
- 3f overflow outlet
- 3f' overflow control valve
- 3g control unit
- 3h battery

- 3i shearing element
- 3j release system
- 3k coupling
- 3m fluid inlet
- 3n pump
- 3n' fluid control valve
- 3n'' fluid control valve
- 3q offloading line
- 3q' offloading control valve
- 3q'' further offloading control valve
- 3r nozzle
- 4 docking station
- 4a docking coupling
- 4b base
- 4c control valve
- 4d filter
- 4e housing
- 4f sensor
- 4g control unit
- 4h floodlight
- 4i analysis unit
- 5 riser pipe
- 5a power line
- 5b communications line
- 5c valve
- 5d conveying means
- 6 umbilical line
- 6a reel
- 6b coupling
- 7 connecting pipe
- 8 seabed
- 9 shelf or ledge
- 10 bracket on a side structure

- 11 wall of a jetty or channel
- 12 above the water surface at a side
structure

CLAIMS

1. A dredging system for removing submerged granular material (1) from a bottom surface, the dredging system comprising:
 - 5 - a dredging robot (3) for removing granular material (1);
 - a docking station (4) for offloading removed granular material from the dredging robot (3), wherein the docking station (4) is attached in relation to the bottom surface; and
 - a riser pipe (5) for transporting removed granular material from the
10 docking station (4) to a remote location.
2. The dredging system of claim 1, wherein the dredging robot (3) is a bottom crawler or a submersible drone.
- 15 3. The dredging system of any of claims 1 - 2, wherein the dredging robot (3) comprises at least one suction head (3b) for removing granular material (1).
4. The dredging system of claim 3, wherein the suction head (3b)
20 comprises one or more fluidizing nozzles.
5. The dredging system of any of claims 1 - 4, wherein the dredging robot (3) comprises one or more shearing elements (3i), for loosening of the submerged granular material (1), and wherein the one or more shearing
25 elements (3i) comprise teeth, blades, knives, rotating blades, spiked rollers and /or nozzles for emitting high-pressure fluid jets.
6. The dredging system of any of claims 1 - 5, wherein the dredging robot (3) comprises a tank (3e) for temporary storage of removed granular
30 material.

7. The dredging system of claim 6, wherein the dredging robot (3) comprises a battery (3h) for providing power to the dredging robot (3).
- 5 8. The dredging system of claim 6 or 7, further comprising a power line connected to the dredging robot (3), for providing power to the dredging robot (3).
- 10 9. The dredging system of any of claims 1 - 5, further comprising an umbilical line (5) for offloading removed granular material from the dredging robot (3), wherein the umbilical line (5) connects the dredging robot (3) with the docking station (4).
- 15 10. The dredging system of claim 9, wherein the umbilical line (5) comprises a power line for providing power to the dredging robot (3), and optionally one or more of an integrated communications line, a compressed-gas line, at least one hydraulic line and / or a lubrication line.
- 20 11. The dredging system of any of claims 1 - 10, wherein the dredging robot (3) comprises a control unit (3g) configured to operate the dredging robot (3) by remote control, semi-autonomously and / or autonomously.
12. The dredging system of any of claims 1 - 11, wherein the dredging robot (3) comprises an underwater positioning system.
- 25 13. The dredging system of any of claims 1 - 12, further comprising conveying means (5d) for conveying removed granular material through the riser pipe (5).
- 30 14. The dredging system of claim 13, wherein the conveying means (5d) comprises a slurry pump, an eductor, or a compressor, and wherein the conveying means (5d) optionally further comprises a booster pump.

15. The dredging system of any of claims 1 - 14, comprising multiple docking stations (4), wherein two or more docking stations (4) are connected with a connecting pipe (7) to a riser pipe (5).

5 16. The dredging system of any of claims 1 - 15, comprising multiple dredging robots (3).

17. The dredging system of any of claims 1 - 16, comprising at least one docking station (4) with several docking couplings (4a) for simultaneous docking
10 of one or more dredging robots (3).

18. Use of a dredging system of any of claims 1 - 17, for a mining operation, a coastal reinforcement operation, the construction of an artificial peninsula or artificial island, the anchoring of equipment or the laying of cables or
15 pipes, a salvage operation for releasing a stranded or sunk vessel, the removing of granular material from behind an artificial dam or from a mine or tunnel, the removing of granular material from a vessel, a container or a basin, and / or the dredging of a waterway, such as a channel, a river, a lake, a harbor, or a marine navigation channel.

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19. Method for dredging of submerged granular material (1), comprising:
- providing a dredging system according to any of claims 1 - 16;
- removing granular material (1) with the dredging robot (3);
- offloading removed granular material from the dredging robot (3) to the
25 docking station (4); and
- transporting removed granular material from the docking station (4) to a remote location through the riser pipe (5).

20. Method according to claim 19, further comprising instructing the at least
30 one dredging system to remove granular material (1) at one or more dredging locations during one or more time-intervals.