

SEMI-AUTOMATED BLASTING SYSTEM AND METHOD

Field of Invention

The invention relates to surface blasting systems and methods, and more particularly to an adaptive modular blasting system for efficiently automating a
5 blasting process in shipyards, e.g. a cleaning process on a substantially vertical flat or slightly curved ship hull surface.

Background

Surface blasting is an important operation for regular ship maintenance in shipyards, e.g. it has become an essential step in surface maintenance of a ship
10 hull. This operation can be used to remove rust or contaminants from the ship hull surface and prepare the surface for application of coating/paint by projecting high-pressure jet consisting of grits or water onto the ship hull surface. With this operation, the integrity of the ship hull, which is essential to navigation safety and economical fuel consumption, can be maintained.

15 Surface blasting is currently carried out manually in open air by workers with hand-held blasting guns and standing on a boom lift basket elevated to dozens of meters high. Such operation is not only hazardous for workers, but also relies on workers' experience to identify the surface condition/quality.

Metallic grit blasting is widely used for rust cleaning on ship hull surface
20 as it can provide good paint adhesion and extend the duration of the coating/paint on the surface. However, a great deal of paint/rust dust would be

generated by this process, which will cause high environmental pollution, e.g. air pollution, water pollution. Some European countries have outrightly banned open air grit blasting process in shipyards due to its negative effects on the environment.

5 In recent years, various automated robotized devices for blasting were proposed by researchers and companies. There has been a series of research on designing automated devices for ship hull cleaning. From 2007 to 2013, Francisco et al. developed an EFTCoR family of systems using a huge vertical tower as a global positioning system, climbing vehicles, control units and sensor
10 systems for blasting systems. However, the proposed robotic systems for blasting lack adaptability to various types of operations and greatly rely on the platform which is specially designed for the shipyard. As such, when working environment is changed, both usability and efficiency of the blasting system need to be re-evaluated. In addition, the maintenance of such large system is
15 costly and might influence or delay work schedule of shipyards.

 There have been also some works on exploring climbing robots with magnetically wheels to conduct surface blasting. However, the ship hull surface condition, such as heavy rust or wetness, may have impact on the robots' ability to carry payloads, and no validation about the robot performance in actual rusty
20 ship hull surface has been conducted. Some papers disclose blasting robots with sensor systems for clearly identifying rust on the work surface, but they do not suggest any solution for improving blasting efficiency based on the identification of rust.

Other blasting systems and methods are described in CN 201510626312, CN 201611262136, CN201520556856, CN201610491776 and CN 201710191666. However, the adaptability and efficiency of these proposed systems and methods are still unsatisfactory.

5 **Summary of Invention**

An objective of this invention is to provide a more efficient and adaptable modular blasting system with simple structure which can be used in shipyards for various cleaning demands. Further, another objective of the invention is to provide a blasting system which can provide a safer working environment for
10 workers of blasting operations and reduce environmental pollution caused by the blasting processes.

According to a first aspect of the invention, embodiments of the invention propose a cost-effective semi-automated blasting system. The blasting system includes a blast projection module, an image acquisition module/vision module
15 and a blasting control module. The blast projection module includes at least one blasting gun configured to perform blasting operation on a work surface, and is configured to be removably mounted to a movable platform, wherein the movable platform is configured to dispose the blast projection module at a specified position in relation to the work surface. The image acquisition module
20 is configured to acquire an image of the work surface. The blasting control module, which is communicably coupled to the blast projection module and the image acquisition module, is configured to remotely control the at least one

blasting gun to perform blasting operation on the work surface based on the image acquired by the image acquisition module.

In some embodiments of the invention, the blasting control module may be configured to detect a defect area to be blasted on the work surface based on the image acquired by the image acquisition module and remotely control the at least one blasting gun to perform blasting operation on the defect area. The defect area may be rusted area on the work surface. The work surface may be a ship hull surface or any substantially vertical surface which is substantially flat or slightly curved. The blasting control module may be a computer system which is remotely connected, wirelessly or by wired means, to other components of the blasting system. The computer system may be a portable computer system, e.g. a portable display tablet or laptop.

In some embodiments of the invention, the blasting control module may be further configured to control movement of the movable platform such that the blast projection module mounted thereto can be disposed at a specified position in relation to the work surface. For example, the blasting control module may be configured to control movement of the movable platform to dispose the blast projection mode at a predetermined distance from the work surface, and/or raise or lower the blast projection module to a specified area on the work surface. It should be noted that in some embodiments, the blasting control module may include two different control devices which are configured to control movement of the at least one blasting gun and movement of the movable platform respectively. That is to say, the function of controlling movement of the at least

one blasting gun and the function of controlling movement of the movable platform may be realized by a single device or two separate devices.

5 In some embodiments of the invention, the blasting system may further include an adaptor which is configured to be used to mount/couple/install the blast projection module on/to the movable platform. The movable platform may be a boom lift, scissors lift, fork lift or a winch for conveniently performing various blasting/cleaning demands in shipyards. The adaptor may be integrally formed as a part of the blast projection module, or a separate component which can be removably attached to the blast projection module.

10 In some embodiments of the invention, the blast projection module may further include a guide frame and a blasting gun holder, wherein the at least one blasting gun is fixedly mounted to the blasting gun holder and the blasting gun holder is configured to be movably mounted to the guide frame to move along a rail provided by the guide frame. In some examples, the guide frame may include
15 a XY table to which the blasting gun holder is movably mounted, and the blasting gun holder is configured to move along a vertical rail and/or a horizontal rail provided by the XY table.

In some embodiments of the invention, the blast projection module may further include an enclosure or a chamber configured to form an at least partially
20 enclosed space for the blasting system to prevent grit and dust generated during the blasting process from scattering into the ambient environment. In some examples, the enclosure may include a plurality of parts removably coupled to

each other, e.g. a front part having an open end and a back part having a closed end, which are removably coupled to each other, for compact storage and shipment, and convenient assembly.

5 In some embodiments of the invention, the blast projection module may further include an isolating sheet or partition or separator arranged between the guide frame and the work surface, e.g. between the guide frame and the open end of the front part, to prevent grit from rebounding to the motors and rails of the guide frame. The isolating sheet may be a sheet of canvas coupled to the front part of the enclosure.

10 In some embodiments of the invention, the blast projection module may further include a grit collection passage coupled to the enclosure to collect grit and dust generated during the blasting process. In some examples, the grit collection passage may be coupled to an opening at the bottom of the enclosure to collect grit and dust, which are generated during the blasting process, and
15 configured to channel the collected grit and dust, through a hose, to a collection container, e.g. a car, for reuse.

In some embodiments of the invention, the blasting system may further include a positioning device configured to detect position of the blast projection module, and the blasting control module is further configured to control
20 movement of the movable platform based on the detected position of the blast projection module.

In some embodiments, the positioning device may include at least one sensor and/or at least one laser pointer. In one example, the positioning device may include at least one distance sensor, which is configured to detect/track position of the blast projection module, e.g. detect a distance from the blast projection module to the ship hull. The results detected by the at least one sensor may be displayed on the blasting control module, and the blasting control module may be further configured to control movement of the movable platform based on the results detected by the at least one sensor. In one example, the positioning device may include at least one laser pointer disposed in the enclosure of the blast projection module, e.g. at a top edge of the enclosure, to more precisely detect position of the blast projection module by projecting laser spot(s) on the ship hull surface.

In some embodiments of the invention, the image acquisition module may include a camera, e.g. a digital camera, which is attached to the enclosure, e.g. to the upper internal surface of the enclosure such that the camera can acquire an image of the work surface.

In some embodiments of the invention, the image acquisition module may further include a housing configured to enclose the camera therein, wherein the housing includes a transparent part, e.g. a transparent plate, disposed in front of the camera lens to acquire an image of the work surface. In some examples, the housing may be made of plastic or other material. The transparent plate may be further covered with a shield. The shield may be a metal film, e.g. steel film, to prevent the camera lens from being scratched by grits. The shield may be driven

by a motor disposed in the upper part of the enclosure to cover/uncover the transparent plate. Both the transparent plate and the shield are easily replaced. The housing may be 3D printed using durable material.

In some embodiments of the invention, the image acquisition module may
5 further include a lighting device configured to provide stable lighting condition for the camera.

In some embodiments of the invention, the blasting control module may be further configured to determine a movement path for the at least one blasting gun based on the image acquired by the image acquisition module. For example,
10 the blasting control module is configured to determine a shortest movement path to pass through all of the areas to be blasted on the work surface.

In some embodiments of the invention, the blasting control module may be further configured to ascertain a movement path for the at least one blasting gun based on a working mode selected according to the image acquired by the
15 image acquisition module.

Specifically, the blasting control module may be further configured to receive the image of the work surface, which is acquired by the image acquisition module; use a colour thresholding method to distinguish rusted area from clean area in the image of the work surface; ascertain a movement path for
20 the at least one blasting gun based on a working mode selected for the blast projection module according to the distinguished rusted area; and control

movement of the at least one blasting gun based on the ascertained movement path.

In some embodiments, the blasting control module is further configured to if a spot repair working mode is selected, split the image of the work surface into
5 a plurality of cells; label each cell with a predetermined value according to rust condition therein; and ascertain a movement path for the at least blasting gun by Travelling Salesman Problem (TSP) path planning.

In some embodiments, the blasting control module is further configured to if a full blasting working mode is selected, identify an area to be blasted by
10 scanning the image of the work surface; calculate dimensions of the identified area; and ascertain a movement path for the at least one blasting gun by a zigzag path planning.

In some embodiments, the working mode may be selected, e.g. by a user of the system through the blasting control module, according to the distinguished
15 rusted area, e.g. according to quantity, size and/or distribution of the rusted areas on the work surface. For example, if the work surface is considered full of heavy rust, and/or a substantially complete cleaning of the work surface is required, a full blasting working mode may be selected; otherwise, if the rust only appears on the work surface as spots or small areas, a spot repair working mode
20 may be selected. In some examples, a full blasting working mode may be selected if a first predetermined rust condition is satisfied, e.g. the size of a continuous rusted area on the work surface is greater than a first predetermined threshold value. In some other examples, a spot repair working mode may be selected if a second predetermined rust condition is satisfied, e.g. if the size of
25 each continuous rusted area is smaller than a second predetermined threshold

value, and the number of the continuous rusted area is less than a third predetermined threshold value.

In some embodiments of the invention, the blasting control module is further configured to conduct a calibration test to determine a movement speed
5 and a projection width of the blasting gun before putting the blasting system in use under a new scenario, e.g. a new workpiece or new work area.

According to a second aspect of the invention, embodiments of the invention provide a blasting method suitable for cleaning a substantially vertical surface of a structure, e.g. ship hull. The blasting method comprises:

10 moving a movable platform to which a blast projection module is mounted, to dispose the blast projection module at a specified position in relation to a work surface;

acquiring, by an image acquisition module, an image of the work surface;
and

15 remotely controlling, by a blasting control module, movement of the at least one blasting gun to perform the blasting process based on the image acquired by the image acquisition module.

In some embodiments, the method further comprises: mounting the blast projection module to the movable platform. In some examples, the blast
20 projection module may be mounted to the movable platform using an adaptor.

The modular blasting system provided in embodiments of this invention may be installed on different platforms through specially designed adaptor to satisfy various cleaning/blasting demands.

5 The blasting gun(s) is controlled by the blasting control module based on the image of the work surface such that the blasting process is performed according to the condition of the work surface. As such, the efficiency of the blasting process can be significantly increased, especially when a plurality of blasting guns are used in the blasting process. To further improve the quality and efficiency of the blasting operation, the movement path of the blasting gun(s)
10 may be optimized according to the condition of the work surface, e.g. a rust level of the work surface, which is indicated by the image acquired by the image acquisition module.

Further, the blasting system may be adapted to perform grit blasting or water jetting by replacing the blasting gun holder.

15 In addition, with the blasting system and method provided in embodiments of the invention, the environmental pollution and potential risks/hazards for operators' health and safety may be effectively prevented by forming an enclosed space for the blast projection module using the enclosure and by providing a grit collection passage to collect the grit and dust generated during
20 the blasting process.

Brief Description of the Drawings

The invention will be described in detail with reference to the accompanying drawings, in which:

Figure 1 shows a schematic diagram of a blasting system according to one embodiment of the invention;

5 Figure 2 (a) shows a schematic diagram of a blasting system according to one embodiment of the invention;

Figure 2 (b) shows a perspective view of the blasting system in Figure 2 (a) according to one embodiment of the invention;

Figure 3(a) is a perspective view of the blast projection module of the
10 blasting system in Figure 2 (a) according to one embodiment of the invention;

Figure 3(b) is a perspective view of the XY table in the blast projection module shown in Figure 3(a);

Figure 4 (a) is a front view of the blast projection module which includes a digital camera disposed on a top surface inside the enclosure according to one
15 embodiment of the invention;

Figure 4 (b) is a perspective view of the blast projection module which includes a digital camera disposed on an internal surface of a side wall of the enclosure according to another embodiment of the invention;

Figure 5 (a) shows a control panel held by a user according to one embodiment of the invention; Figure 5 (b) shows an example of a user interface of the control panel;

Figure 6 is a flow chart illustrating a blasting method according to one
5 embodiment of the invention;

Figure 7 shows the results of a series of experiments designed for a calibration test to determine projection width and speed of a blasting gun according to one embodiment of the invention;

Figure 8 is a flow chart illustrating a method for conducting movement
10 path planning for the blasting gun according to one embodiment of the invention;

Figure 9 (a) to (d) show the process of spot repair working mode according to one example of the invention; (a) shows the image of the work surface is split into 9X9 cells; (b) shows the labelling of the 9X9 cells; (c) shows the movement path of the blasting gun ascertained by Traveling Salesman
15 Problem (TSP) path planning in Matlab; (d) shows the simulation of the blasting result;

Figure 10 (a) to (d) show the process of full blasting working mode according to one example of the invention; (a) shows an image of the rusted work surface; (b) shows the binary image of the work surface; (c) shows the
20 rectangular area R to be blasted; (d) shows the simulation of the blasting results of the blasting gun with a zigzag-shaped movement path from S1 till S2;

Figure 11 (a) shows a perspective view of a blast projection mode with four blasting guns according to one embodiment of the invention;

Figure 11 (b) shows the rectangular area to be blasted and the zigzag movement path ascertained for each of the four blasting guns according to one
5 example of the invention.

Detailed Description of Embodiments of the Invention

In the following description, numerous specific details are set forth in order to provide a thorough understanding of various illustrative embodiments of the invention. It will be understood, however, to one skilled in the art, that
10 embodiments of the invention may be practiced without some or all of these specific details. It is understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to limit the scope of the invention.

Embodiments described in the context of one of the methods or devices
15 are analogously valid for the other methods or devices. Similarly, embodiments described in the context of a method are analogously valid for a device, and vice versa.

Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other
20 embodiments. Features that are described in the context of an embodiment may correspondingly be applicable to the other embodiments, even if not explicitly described in these other embodiments. Furthermore, additions and/or combinations and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in
25 the other embodiments.

As used herein, the articles “a”, “an” and “the” as used with regard to a feature or element include a reference to one or more of the features or elements.

As used herein, the term “and/or” includes any and all combinations of
5 one or more of the associated listed items.

As used herein, the terms “first,” “second,” and “third,” etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.

As used herein, the term “configured to” is interchangeable with
10 “operative” or “adapted to”.

As used therein, the term “coupled” and related terms are used in an operational sense and are not necessarily limited to a direct physical connection or coupling. Thus, for example, two devices may be coupled directly, or via one or more intermediary devices.

15 Embodiments of the invention provide a semi-automated modular blasting system for various cleaning operations on a substantially vertical ship hull surface which may be substantially flat or slightly curved.

In one embodiment of the invention, as shown in Figure 1, the blasting system 100 comprises a blast projection module 101, an image acquisition
20 module or vision module 102 and a blasting control module 103. The blasting control module 103 may be a portable computer system, e.g. a laptop or tablet. The blast projection module 101 is provided with at least one blasting gun 1010 for performing a blasting process.

The vision module 102 is attached to the blast projection module 101 and
25 configured to acquire an image of the work surface to be processed. The blasting control module 103 is configured to remotely control the at least one

blasting gun 1010 to perform blasting operation along a work surface based on the image acquired by the vision module 102. For example, the blasting control module 103 may be configured to detect a defect area to be blasted on the work surface based on the image acquired by the vision module 102 and remotely
5 control the at least one blasting gun to perform blasting operation on the defect area. The blasting control module 103 may be configured to control the at least one blasting gun 1010 through controlling motion mechanism of the blast projection module 101. If the blast projection module 101 includes a plurality of blasting guns, the blasting control module 103 may be further configured to
10 remotely control the plurality of blasting guns to move together to perform the blasting operation.

Figure 2(a) shows a schematic diagram of a blasting system 200 according to one embodiment of the invention; Figure 2(b) shows a perspective view of the blasting system 200. As shown in Figure 2(a) and 2(b), the blasting
15 system 200 is mounted to a boom lift 210 or hydraulic crane which is configured to dispose the blast projection module 201 at a specified position near the ship hull surface to be processed. In other embodiments, the blasting system 200 may be installed on a different platform, e.g. a forklift or a winch, to satisfy requirements of different blasting operations. Specially designed adaptors may
20 be used to couple the blasting system to different platforms.

Referring to Figure 2(a), the blasting system 200 includes a blast projection module 201, a vision module 202 and a blasting control module 203.

The blast projection module 201 includes at least one blasting gun for performing the blasting process. The vision module 202 includes a camera which
25 is attached to the blast projection module 201 and configured to acquire an image of the work surface to be processed. The blasting control module 203 includes a control panel 2031 which is configured to remotely control movement of the at least one blasting gun through a manipulator 206 of the blast projection module 201, e.g. a blasting gun holder, based on the image acquired by the

vision module 202. In some embodiments, the control panel 2031 may be held by a user.

To control movement of the boom lift 210, the blasting control module 203 further includes a control unit 2032 which is configured to control movement of the boom lift 210 to dispose the blast projection module 201 at a specified position in relation to the work surface, e.g. dispose the blast projection module 201 at a predetermined distance from the work surface and/or raise or lower the blast projection module 201 mounted thereto to an area of the work surface. When a different platform is used to carry the blast projection module 201 in other embodiments, the control unit 2032 will be configured to control movement of that platform accordingly. It is to be appreciated by a skilled person that in some embodiments, the control unit 2032 may be a separate control device or integrally formed as one single device with the control panel 2031.

In this embodiment, the blasting system 200 may further include a distance sensor 207 configured to detect a distance between the blast projection module 201 to the work surface to be processed. The detected information may be displayed on the control panel 2031.

As shown in Figure 2 (a) and 2 (b), the blasting system 200 is configured to co-operate with a grit collection car 209 which is configured to collect grit and dust generated during the blasting process through a telescopic hose 208. As such, the collected grit can be reused in subsequent blasting process and also the dust can be prevented from scattering into the environment around the blasting system 200.

Blast projection module

Figure 3(a) shows a perspective view of the blast projection module 201 according to one embodiment of the invention. The blast projection module 201 includes two blasting guns 2010, a blasting gun holder 2011, an XY table 2012,

an enclosure 2013 and a grit collection passage 2014. Figure 3 (b) shows a perspective view of the XY table 2012.

As shown in Figures 3(a) and 3(b), the two blasting guns 2010 are movably mounted to the XY table 2012 using blasting gun holder(s) 2011.

5 Specifically, the two blasting guns 2010 are fixedly mounted to the blasting gun holder 2011 and the blasting gun holder 2011 is movably mounted to the XY table 2012 such that the blasting guns 2010 can move together with the blasting gun holder 2011 along the linear rails provided by the XY table 2012. When the blasting system 200 is in use, the blasting guns 2010 may be controlled to move
10 on a plane substantially parallel to the work surface to perform the blasting operation. Referring to Figure 3(b), two linear motors 2015 are mounted to the vertical and horizontal frames of the XY table 2012 to control the movement of the blasting gun holder 2011. In some examples, the frames of the XY table 2012 may be made of stainless steel. When the blasting system 200 is in use,
15 the two blasting guns 2010 are connected to hoses for delivering high-pressure blasting media jets such that the blasting media, e.g. grits, is projected strongly on the work surface to be blasted.

It is to be appreciated by a skilled person that the use of XY table 2012 as a guide frame is only for illustration purpose, and does not to limit the scope of
20 the invention. In other embodiments, a guide frame of different structure may be used to provide rails for the blasting guns and blasting gun holder. Additionally, in other embodiments of the invention, the number of the blasting guns may vary depending on the capacity of the blasting gun holders, the load capacity of the motors.

25 The enclosure 2013 is provided to reduce/prevent grit and dust, which are generated during the blasting process, from scattering into the air. In this embodiment, the enclosure 2013 of generally rectangular cross-section includes a front part having an open end and a back part having a closed end for convenient assembly, compact storage and transportation. The front part is

positioned closer to the work surface when the blasting system 200 is in use. The XY table 2012 is installed in the back part of the enclosure 2013 and an isolating sheet may be provided between the XY table 2013 and the open end of the front part to prevent grit from rebounding back to the motors and linear guide rails. The isolating sheet may be coupled to the front part of the enclosure 2013 and may be made of canvas. It is to be appreciated by a skilled person that the shape of the enclosure 2013 may be different in other embodiments as long as a substantially enclosed space can be formed to reduce/prevent grit and dust generated during the blasting process from scattering into the air.

The grit collection passage 2014 in this embodiment has a funnel-shape structure and is coupled to an opening at the bottom of the enclosure 2013, e.g. at the bottom of the front part of the enclosure 2013. As such, the grit and dust generated during the blasting process can flow through the grit collection passage 2014 and the hose 208, by action of gravity, into a container, e.g. the collection car 209 on the ground. It should be noted that the structure of the grit collection passage in this embodiment is for illustrative purpose only and not as limitation of the invention. In other embodiments, it may have a different structure.

Image Acquisition Module/Vision Module

In this embodiment, the image acquisition module/vision module 202 includes a digital camera 205 which is attached to the blast projection module 201, e.g. the enclosure of the blast projection module 201, and configured to acquire an image of the work surface. Figure 4(a) is a front view of the blast projection module 201 according to one embodiment of the invention. As shown in Figure 4(a), the digital camera 205 may be attached to a top surface inside the enclosure 2013 to acquire an image of the work surface. Figure 4(b) is a perspective view of the blast projection module 201 according to another embodiment of the invention. In this embodiment, the digital camera 205 is disposed on an internal surface of a side wall of the enclosure 2013. As the

optical axis of the camera 205 may not be perpendicular to the blasting surface, distortion correction may be needed after acquisition of an image of the work surface. This distortion correction process may be implemented through the control panel 2031. Further, to ensure the inside of the enclosure 2013 is under
5 stable lighting condition such that the quality of the acquired image is stable and has sufficient clarity, a lighting device, e.g. a LED light, may be provided inside the enclosure 2013.

In some embodiments, the digital camera 205 may be enclosed in a plastic box with a transparent plate disposed in front of the lens of the camera
10 205. The transparent plate may be further covered with a steel film to prevent the lens of the camera 205 from being scratched by grits. Both the transparent plate and the steel film are easily replaced.

Control panel and sensor

An example of the control panel 2031 is shown in Figure 5 (a) and an
15 example of the user interface 2030 of the control panel 2031 is shown in Figure 5(b). The control panel 2031 held by a user standing on the ground is configured to control movement of the two blasting guns 2010 on the XY table 2013. The blasting system 200 is moved to a designated position by the platform to which it is mounted.

20 The distance sensor 207 may be placed on the enclosure 2013 to detect the position of the blast projection module 201. The detected information may be displayed on the control panel 2031 so that the user is aware of the expected position of the blast projection module 201 when moving the platform. The distance sensor 207 may be further configured to detect a distance between the
25 enclosure 2013 to the ship hull, e.g. the work surface, in case they are too close or too far.

Embodiments of the invention also provide a blasting method suitable for cleaning a substantially vertical surface of a ship hull. Figure 6 is a flow chart illustrating the blasting method for cleaning a work surface, e.g. a substantially vertical surface of a ship full, according to one embodiment of the invention by
5 using the blasting system 200 shown in Figure 2(a).

In **Block 601**, a movable platform is moved to dispose a blast projection module 201 of the blasting system 200 which is mounted to the movable platform, at a specified position in relation to the work surface.

As shown in Figure 2(a), the blasting system 200 includes a blast
10 projection module 201 which includes at least one blasting gun, a vision module 202 attached to the blast projection module 201 and a blasting control module/control panel 2031, wherein the blast projection module 201 is mounted to the movable platform. In this embodiment, the movable platform may be the boom lift 210. The blast projection module 201 is disposed at the specified
15 position so that the at least one blasting gun can perform blasting operation on the work surface.

In this embodiment, the boom lift 210 may be controlled by a control unit 2032 to dispose the blast projection module 201 at the specified position in relation to the work surface. The process of disposing the blast projection
20 module 201 at the specified position may include: the control unit 2032 controls the boom lift 210 to dispose the blast projection module 201 at a predetermined

distance from the work surface, and/or raise or lower the blast projection module 201 to approach a predetermined area on the work surface.

In **Block 602**, the vision module 202 acquires an image of the work surface. The vision module 202 may include a camera or other image acquisition
5 device configured to acquire/capture an image of the work surface.

In **Block 603**, the control panel 2031 is configured to control the at least one blasting gun to perform a blasting process based on the image acquired by the vision module 202.

In some embodiments, the vision module 202 includes a digital camera
10 which is attached to a top surface inside the enclosure of the blast projection module 201. Once the blast projection module 201 is moved to the designated area to be processed, the vision module 201 is configured to acquire an image of the work surface. The acquired image of the work surface may be used to determine the condition of the work surface, e.g. the rust level of the work
15 surface, such that the control panel 2031 can control movement of the at least one blasting gun based on the condition of the work surface.

Calibration Test

Before the blasting gun(s) 2010 starts to perform the blasting operation, a calibration test may be conducted to determine the projection width and
20 movement speed of the blasting gun(s) 2010 to further improve the quality and efficiency of the blasting system 200.

The projection width of a blasting gun 2010 is influenced by several parameters, such as distance from the blasting gun 2010 to the blasting surface, the movement speed of the blasting gun 2010, intake air pressure, blasting gun
25 size, grit type and so on. It has been found that the projecting width is not influenced due to change of the size of the front part of the enclosure 2013.

To investigate the correlation between the movement speed and the projection width of the blasting gun 2010, experiments have been designed and carried out. The projection width w can be described as a function of movement speed of gun v , as shown in Equation (1). The function includes the parameters such as intake air pressure, blasting gun size, grit type and so on. The efficiency of blasting p indicates the blasted area per hour, which is a product of the projection width w and movement speed of the blasting gun v , as shown in Equation (2). However, p is possible to increase or decrease with change of movement speed of the blasting gun. Therefore, a calibration test is conducted to find out the trend of efficiency of blasting with the change of the movement speed of the blasting gun.

$$w = f(v) \quad (1)$$

$$p = w \times v = f(v) \times v \quad (2)$$

Table 1 shows the results of a calibration test obtained in a reference shipyard. The segments 1-6 shown in Figure 7 are the blasting results obtained by different blasting operations, Projections #1 to #6, which are respectively performed with different movement speeds of the blasting gun 2010, which range from 10 to 60 mm/s while keeping other parameters relevant to the projection width constant, e.g. air pressure, gun size and grit type. The efficiency of blasting is calculated using Equation (2).

Table 1 Correlation between the movement speed and projection width of the blasting gun

Projection	Movement speed of gun (mm/s)	Projection width (mm)	Efficiency (m ² /hr)	SA level after blasting
#1	10	100.0	3.60	3.0
#2	20	82.0	5.89	3.0
#3	30	73.0	7.85	2.5
#4	40	67.0	9.60	2.5

#5	50	60.0	10.80	2.5
#6	60	53.0	11.23	2.0

SA level is Swedish standard representing the surface preparation quality, i.e. quality of cleaning operation of a blasting system/process. SA 2.5 indicates a near white blast metal surface, where all dirt, rust, paint or other foreign matter have been completely removed except for very light shadows. Typically, the requirement for cleaning a surface through blasting process should achieve SA $\geq$ 2.5 after blasting. According to the results shown in Table 1, projection #6 fails to satisfy the quality requirement, and among other five projections #1 to #5, the projection #5 achieves the highest cleaning efficiency with satisfactory SA level. As such, in the subsequent blasting process, the movement speed of the blasting gun 2010 can be set at 50 mm/s and the movement path planning of the blasting gun(s) 2010 can be determined based on the projection width of the projection #5, i.e. 60mm.

As the movement speed of the blasting gun corresponding to the highest cleaning efficiency would change if the various relevant parameters, e.g. intake air pressure, grit size, are different, the calibration test is recommended to be conducted before using the blasting system under a new scenario.

Movement path planning of blasting gun(s)

As mentioned above, the control panel 2031 is configured to control movement of the blasting gun(s) to perform the blasting process based on an image of the work surface acquired by the vision module 202. Below, a detailed description about how the control panel 2031 controls the movement of the blasting gun(s) according to some embodiments of the invention will be explained with reference to the Figures 8-11.

If it is assumed that the blasting gun(s) is moving at a constant speed, a shortest path passing all of the rusted areas or the whole rusted area on the work surface would be the most effective way to clean the work surface. To

further improve efficiency of the blasting operations, e.g. cleaning operation, some embodiments of the invention provide a method of planning movement path of the blasting gun(s) such that the blasting operation can be adjusted based on the condition of the work surface, e.g. the rust level of the work surface.

As shown in Figure 8, in one embodiment of the invention, a method of planning movement path for a blasting gun includes:

In **Block 801**, the control panel 2031 receives an image of the work surface to be processed, which is acquired by the vision module 202.

10 In **Block 802**, the control panel 2031 uses colour thresholding method to distinguish the rusted area from the clean area in the image.

It should be noted that there may be more than one rusted area on the work surface. Accordingly, the control panel 2031 may be further configured to distinguish all of the rusted areas from the clean areas in the image by using the colour thresholding method.

Thresholding method is a method of image segmentation with binary images. As one of the most obvious differences between rusted area and clean area is the colour, the thresholding method can be applied to distinguish the rusted area from the clean area in the image. A HSV (hue, saturation, value) module may be used to define the rusted area. The threshold values are manually set. As the lighting condition is stable inside the enclosure, the values are suitable for the whole surface with same background colour. With additional limitation on the range of saturation and brightness, the image can be converted into binary image with rusted area masked by white as shown in Figure 9 (a).

20 With this colour thresholding method, almost all of the rusted area can be successfully recognized. Furthermore, the threshold values used in the colour thresholding method may be adjusted according to the colour of the ship hull surface and the colour of the rust.

In **Block 803**, a working mode to be performed by the blast projection module 201 is selected according to the distinguished rusted area on the work surface.

In some embodiments, a working mode may be selected, e.g. by a user of the system through the blasting control module, according to the distinguished rusted area, e.g. according to quantity, size and/or distribution of the rusted areas on the work surface. For example, if the work surface is considered full of heavy rust, and/or a substantially complete cleaning of the work surface is required, a full blasting working mode may be selected; otherwise, if the rust only appears on the work surface as spots or small areas, a spot repair working mode may be selected. In some examples, a full blasting working mode may be selected if a first predetermined rust condition is satisfied, e.g. the size of a continuous rusted area on the work surface is greater than a first predetermined threshold value. In some other examples, a spot repair working mode may be selected if a second predetermined rust condition is satisfied, e.g. if the size of each continuous rusted area is smaller than a second predetermined threshold value, and the number of the continuous rusted area is less than a third predetermined threshold value.

In some embodiments of the invention, the control panel 2031 may be further configured to ascertain blasting intensities to be adopted for blasting process based on rust condition of the work surface. For example, as shown in Figure 10 (a), the rust in right bottom region of the work surface obviously needs more powerful blasting than those in other regions.

In **Block 804**, if the spot repair working mode is selected, the control panel 2031 splits the image of the work surface into cells, e.g. square cells with a

length same as the projection width of the blasting gun. As such, when the jet from the blasting gun passes the centre of the square cell, it is capable of cleaning the whole cell.

It should be noted that the square cells shape in this embodiment is only for illustration purpose, and does not limit the scope of the invention. The cells may take the form of other shapes and/or sizes in other embodiments.

In **Block 805**, the control panel 2031 labels each of the cells with a predetermined value, e.g. 0 or 1, according to the condition of the cell, e.g. rust level of the cell, and a predetermined threshold value.

As shown in Figure 9 (a) and (b), in one example, the image is split into 9X9 square cells. Each of the cells is labelled with 0 or 1 according to the rust condition therein i.e. a percentage of rusted area detected in each cell. For example, if the predetermined threshold value is set as 0.01 and the percentage of rust in one cell is larger than 0.01, the cell is to be labelled with “1”; otherwise if the percentage of rust therein is less than or equal to 0.01, the cell is to be labelled with “0”. It is to be appreciated by a skilled person that the predetermined threshold value for labelling each cell may be adjusted according to requirements of the blasting operation, e.g. the cleaning requirements of the shipyard.

In one example, if the image comprises 9X9 square cells with a length of 60mm each, the total size of the image is 540X540 mm, which is nearly the maximum area covered by the blasting module.

In **Block 806**, the control panel 2031 ascertains a movement path for the blasting gun by Travelling Salesman Problem (TSP) path planning.

In the blasting process, the blasting gun is to be controlled to move along a trace passing all of the pixels with label “1”, i.e. passing all of the rusted areas. This problem is formulated as an integer program and implemented in Matlab

with genetic algorithm. Figure 9 (c) shows the movement path determined for the blasting gun by TSP path planning according to one example of the invention. The movement path between point A and point B is indicated using dotted lines. Figure 9 (d) shows the simulation of the blasting results based on the
5 ascertained movement path. In this simulation, the blasting gun is controlled to move along the determined movement path from the point A to point B thereof.

In **Block 807**, the control panel 2031 controls the blasting gun to move along the ascertained movement path to perform the blasting process.

For example, the control panel 2031 may be configured to generate a
10 sequence of gun positions based on the ascertained movement path, and control the blasting gun to move along the generated sequence of gun positions to perform the blasting operation.

In **Block 808**, if the full blasting working mode is selected, to reduce grit and time waste, the control panel 2031 determines the area to be blasted by
15 scanning the image of the work surface to avoid repeatedly carrying out the blasting operation on the same area.

By scanning the image of the work surface, if the whole surface is rusted, then the whole surface needs to be blasted; however, if part of the work surface might have been blasted previously due to imprecision position control as shown
20 in Figure 10(a), to reduce grit and time waste, the control panel 2031 may be further configured to recognize the blasted area and determine the area to be blasted on the work surface accordingly. Figure 10 (b) illustrates a binary image of the work surface in Figure 10 (a) according to one example of the invention. As shown in Figure 10 (b), the top part of the work surface has been blasted.
25 Figure 10 (c) shows the determined area to be blasted on the work surface, i.e. the rectangular area R having four edges R1, R2, R3 and R4.

In **Block 809**, the control panel 2031 calculates the height H and width W of the rectangular area R on the work surface.

In **Block 810**, the control panel 2031 ascertains a movement path for the blasting gun to completely blast the area R by a zigzag path planning.

In one example of the invention, a zigzag-shaped path is ascertained within the area R based on the projection width of the blasting gun and the height H of the area R. The ascertained zigzag-shaped path must make sure every part of the area R can be blasted. Figure 10 (d) illustrates the ascertained zigzag movement path and part of the simulation of blasting results according to one example of the invention. As shown in Figure 10 (d), the zigzag movement path includes n loops of movement between edge R1 and edge R2 of the area R such that the whole area R from edge R3 to R4 can be blasted completely.

In the blasting process, the blasting gun is to be controlled to move along the zigzag-shaped path to perform the blasting operation. As shown in Figure 10 (d), in this example, the blasting gun is controlled to move from S1 to E1, then E1 to E2, next E2 to S2, and so on, until En to Sn (or Sn to En). The simulation of blasting results from S1 till E2 is shown in Figure 10 (d). It should be noted that the number of movements between two edges of the rectangular area R is determined based on the projection width of the blasting gun and the height of the area R, and there might be overlap between the last two projection lines made by the blasting gun as the height value of the area R may not be divisible by the projection width of the blasting gun.

It should be noted that in this blasting process, the speed and projection width of the blasting gun are determined based on the highest efficiency in the calibration test.

In **Block 811**, the control panel 2031 controls the blasting gun to move along the ascertained movement path to perform the blasting process.

Specifically, the control panel 2031 may generate a sequence of gun positions based on the ascertained movement path, and the blasting gun is

controlled to move along the generated sequence of gun positions to perform the blasting operation.

In this embodiment, the blasted area is only recognized on top of the work surface, however in other embodiments, blasted area(s) may also be recognized at the regions near the left, right and/or bottom edge of the work surface as these regions may also be blasted previously due to imprecision position control. The control panel 2031 is then configured to determine the area which needs to be blasted accordingly and ascertain a movement path for the blasting gun by a zigzag path planning for the determined area which needs to be blasted.

In the embodiment shown in Figure 8 to 10, only one blasting gun is used for the blasting operation. However, in other embodiments, more than one blasting gun may be used for the blasting operation, e.g. if the work surface is obviously heavy rusted and the full blasting mode is selected as the working mode, a plurality of blasting guns, e.g. 2 or 4 blasting guns, may be used to perform the blasting operation together.

Figure 11(a) shows a perspective view of the blast projection module 301 which includes four blasting guns 3010 according to one embodiment of the invention. In this embodiment, the control panel 2031 may be further configured to ascertain a movement path for each of the blasting guns 3010. In one example, the determined area R to be blasted is divided into four equal parts r1 to r4, as shown in Figure 11 (b), and the zigzag movement path for each blasting gun 3010 in the corresponding part of the area R is ascertained based on the projection width of the blasting guns 3010 and the height of each part, i.e. h as shown in Figure 11 (b). In the blasting process, the four blasting guns 3010 are to be controlled to move together and respectively along the ascertained movement path within each part of the area R. With four blasting guns working together, the efficiency of the blasting system will become 4 times of the blasting system with only one blasting gun.

As will be appreciated from the above, embodiments of the invention provide a blasting system for shipyard industry to automate much of the blasting or water jetting process for various cleaning demands. Such an adaptive system can improve the worker safety and reduce work force required. Specifically, the
5 blasting system and method proposed by embodiments of the invention at least have the following advantages:

1. The modular design of the system allows the blasting system to be mounted to different platforms for various blasting operations.
2. The efficiency of the blasting operation can be significantly increased
10 since the movement of the blasting gun may be controlled based on the condition of the work surface to be processed and more than one blasting gun may be used in the blasting operation.
3. The environmental pollution caused by the blasting process can be greatly reduced as an enclosed space is formed by the enclosure of
15 the blast projection module to prevent grit and dust from entering into the environment around, also the grits and dust can be collected to a container through the grit collection passage. Thus, a more health and safer working environment can be provided.
4. The manufacturing and maintenance costs of the blasting system may
20 be reduced due to the grit recycling and platform diversity.

5. Further, automatic rust detection combined with movement path planning of blasting guns may be applied to further improve the efficiency of the blasting process.

It is to be understood that the embodiments and features described above
5 should be considered exemplary and not restrictive. Many other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the invention. The scope of the invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. Furthermore, certain terminology
10 has been used for the purposes of descriptive clarity, and not to limit the disclosed embodiments of the invention.

CLAIMS

1. A blasting system comprising: a blast projection module, an image acquisition module, and a blasting control module,

wherein the blast projection module includes at least one blasting gun
5 configured to perform blasting operation on a work surface, and is configured to be removably mounted to a movable platform, wherein the movable platform is configured to dispose the blast projection module at a specified position in relation to the work surface;

the image acquisition module is configured to acquire an image of the
10 work surface; and

the blasting control module, which is communicably coupled to the blast projection module and the image acquisition module, is configured to remotely control the at least one blasting gun to perform blasting operation on the work surface based on the image acquired by the image acquisition module.

15 2. The system according to claim 1, further comprising:

an adaptor configured to be used to mount the blast projection module to the movable platform.

3. The system according to claim 1 or claim 2, wherein the blasting control module is further configured to control movement of the movable platform to
20 dispose the blast projection module at the specified position.

4. The system according to any preceding claim, wherein the blast projection module comprises a guide frame and a blasting gun holder, wherein the at least one blasting gun is fixedly mounted to the blasting gun holder and the blasting gun holder is configured to be movably mounted to the guide frame
5 to move along a rail provided by the guide frame.

5. The system according to claim 4, wherein the guide frame includes a XY table to which the blasting gun holder is movably mounted, and the blasting gun holder is configured to move along a vertical rail and/or a horizontal rail provided by the XY table.

10 6. The system according to claim 4 or claim 5, wherein the blast projection module further includes an isolating sheet disposed between the guide frame and the work surface to prevent grit from rebounding back to the guide frame.

7. The system according to any preceding claim, wherein the blast projection module further includes an enclosure which is configured to form at
15 least partially enclosed space for the blasting system to prevent or reduce grit and dust, which are generated during the blasting process, from scattering into the ambient environment.

8. The system according to claim 7, wherein the enclosure includes at least two parts removably coupled to each other.

20 9. The system according to claim 7 or claim 8, wherein the blast projection module further includes a grit collection passage coupled to the enclosure to collect grit and dust generated during the blasting process.

10. The system according to any preceding claim, further comprising a positioning device configured to detect position of the blast projection module, and the blasting control module is further configured to control movement of the movable platform based on the detected position of the blast projection module.

5 11. The system according to claim 10, wherein the positioning device includes at least one sensor, and/or at least one laser pointer disposed on the enclosure.

12. The system according to any preceding claim, wherein the image acquisition module includes a digital camera which is disposed on an internal
10 surface of the enclosure.

13. The system according to any preceding claim, wherein the blasting control module is further configured to

receive the image of the work surface, which is acquired by the image acquisition module;

15 use a colour thresholding method to distinguish rusted area from clean area in the image of the work surface;

ascertain a movement path for the at least one blasting gun based on a working mode selected for the blast projection module according to the distinguished rusted area; and control movement of the at least one blasting gun
20 based on the ascertained movement path.

14. The system according to claim 13, wherein the blasting control module is further configured to if a spot repair working mode is selected,

split the image of the work surface into a plurality of cells;

label each cell with a predetermined value according to rust condition
5 therein; and

ascertain a movement path for the at least blasting gun by Travelling Salesman Problem (TSP) path planning.

15. The system according to claim 13, wherein the blasting control module is further configured to if a full blasting working mode is selected,

10 identify an area to be blasted by scanning the image of the work surface;

calculate dimensions of the identified area; and

ascertain a movement path for the at least one blasting gun by a zigzag path planning.

16. The system according to any preceding claim, wherein the blasting
15 control system is further configured to conduct a calibration test to determine a movement speed and a projection width of the blasting gun before putting the blasting system in use.

17. A blasting method, comprising:

moving a movable platform to which a blast projection module is mounted, to dispose the blast projection module at a specified position in relation to a work surface;

acquiring, by an image acquisition module, an image of the work surface;

5 and

remotely controlling, by a blasting control module, movement of the at least one blasting gun to perform the blasting process based on the image acquired by the image acquisition module.

18. The method according to claim 17, further comprising: mounting the
10 blast projection module to the movable platform.

19. The method according to claim 17 or claim 18, wherein the step of moving the movable platform comprises:

controlling, by the blasting control module, movement of the movable platform to dispose the movable platform at the specified position.

15 20. The method according to any one of claim 17 to claim 19, wherein the step of controlling movement of the at least one blasting gun to perform the blasting process comprises:

controlling, by the blasting control module, movement of a blasting gun holder, to which the at least one blasting gun is fixedly mounted, along a rail
20 provided by a guide frame.

21. The method according to claim 20, wherein the guide frame includes a XY table, and the step of controlling movement of the blasting gun holder comprises:

controlling, by the blasting control module, movement of the blasting gun
5 holder along a vertical rail and/or a horizontal rail provided by the XY table.

22. The method according to any one of claim 17 to claim 21, wherein the blast projection module further includes an enclosure and a grit collection passage coupled to the enclosure,

wherein the method further comprises: collecting grit and dust, which are
10 generated during the blasting process, using a grit collection passage which is coupled to the enclosure.

23. The method according to any one of claim 17 to claim 22, further comprising: detecting a position of the blast projection module using a positioning device, and controlling the movement of the movable platform based
15 on the detected position of the blast projection module.

24. The method according to any one of claim 17 to claim 23, wherein the step of remotely controlling movement of the at least one blasting gun further comprises:

receiving, by the blasting control module, an image of the work surface to
20 be processed, which is acquired by the image acquisition module;

using, by the blasting control module, a colour thresholding method to distinguish rusted area from clean area in the image of the work surface;

ascertaining, by the blasting control module, a movement path for the at least one blasting gun based on a working mode selected for the blast projection
5 module according to the distinguished rusted area; and

controlling, by the blasting control module, movement of the at least one blasting gun based on the ascertained movement path.

25. The method according to claim 24,

wherein if a spot repair working mode is selected, the step of ascertaining
10 a movement path for the at least one blasting gun comprises:

splitting, by the blasting control module, the image of the work surface into a plurality of cells;

labelling, by the blasting control module, each cell with a predetermined value according to rust condition therein; and

15 ascertaining, by the blasting control module, a movement path for the at least blasting gun by Travelling Salesman Problem (TSP) path planning.

26. The method according to claim 24, wherein if a full blasting working mode is selected, the step of ascertaining a movement path for the at least one blasting gun based on the selected working mode comprises:

identifying, by the blasting control module, an area to be blasted by scanning the image of the work surface;

calculating, by the blasting control module, dimensions of the identified area; and

5 ascertaining, by the blasting control module, a movement path for the at least one blasting gun by a zigzag path planning.

27. The method according to any one of claim 17 to claim 26, further comprising:

 determining, by the blasting control module, projection width and
10 movement speed of the at least one blasting gun by a calibration test.