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CONTROLLING MESH INSTALLATION BASED ON A MESH DEFORMATION PARAMETER

- (57) Example embodiments generally relate to the field of mesh installation on a rock surface. An apparatus may obtain a surface model of a rock surface; determine, based on the surface model, whether a mesh can be installed on a planned position of the mesh on the rock surface without violating at least one deformation param-
- eter of the mesh; and determine to refrain from installation of the mesh on the planned position of the mesh, in response to determining that the mesh can not be installed on the planned position of the mesh without violating the at least one deformation parameter.

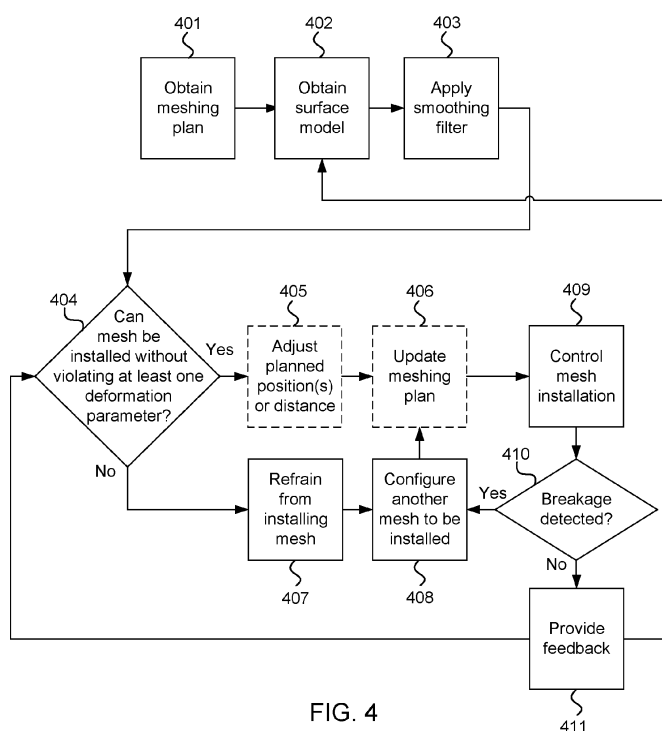


FIG. 4

Description

TECHNICAL FIELD

[0001] Various example embodiments generally relate to the field of mesh installation on a rock surface. Some example embodiments relate to controlling mesh installation to a rock surface based on at least one deformation parameter of a mesh.

BACKGROUND

[0002] In various applications, such as for example underground mining, it may be desired to protect equipment or people from rocks falling from a rock surface. This may be done for example by installing protective meshes on the rock surface. A mesh installation rig may comprise one or more booms with appropriate tools for installing meshes to the rock surface. Positions of the meshes may be determined on-site by a human operator sitting in the cabin of the mesh installation rig. The rock surface may be rough, for example, because it may be hard to exactly control how explosives behave during excavation.

SUMMARY

[0003] This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the detailed description. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter.

[0004] According to a first aspect, an apparatus for controlling mesh installation is disclosed. The apparatus may comprise: at least one processor; and at least one memory including computer program code, the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus at least to: obtain a surface model of a rock surface; determine, based on the surface model, whether a mesh can be installed on a planned position of the mesh on the rock surface without violating at least one deformation parameter of the mesh; and determine to refrain from installation of the mesh on the planned position of the mesh, in response to determining that the mesh can not be installed on the planned position of the mesh without violating the at least one deformation parameter.

[0005] According to a second aspect, a mesh installation rig is disclosed. The mesh installation rig may be configured to: obtain a surface model of a rock surface; determine, based on the surface model, whether a mesh can be installed on a planned position of the mesh on the rock surface without violating at least one deformation parameter of the mesh; and determine to refrain from installation of the mesh on the planned position of the mesh, in response to determining that the mesh can not be installed on the planned position of the mesh without violating the at least one deformation parameter.

[0006] According to a third aspect, a method for controlling mesh installation is disclosed. The method may comprise obtaining a surface model of a rock surface; determining, based on the surface model, whether a mesh can be installed on a planned position of the mesh on the rock surface without violating at least one deformation parameter of the mesh; and determining to refrain from installation of the mesh on the planned position of the mesh, in response to determining that the mesh can not be installed on the planned position of the mesh without violating the at least one deformation parameter

[0007] According to a fourth aspect, an apparatus is disclosed. The apparatus may comprise means for obtaining a surface model of a rock surface; means for determining, based on the surface model, whether a mesh can be installed on a planned position of the mesh on the rock surface without violating at least one deformation parameter of the mesh; and means for determining to refrain from installation of the mesh on the planned position of the mesh, in response to determining that the mesh can not be installed on the planned position of the mesh without violating the at least one deformation parameter.

[0008] According to a fifth aspect, a computer program is disclosed. The computer program may comprise instructions which, when executed by an apparatus, cause the apparatus at least to: obtain a surface model of a rock surface; determine, based on the surface model, whether a mesh can be installed on a planned position of the mesh on the rock surface without violating at least one deformation parameter of the mesh; and determine to refrain from installation of the mesh on the planned position of the mesh, in response to determining that the mesh can not be installed on the planned position of the mesh without violating the at least one deformation parameter.

[0009] Example embodiments of the above aspects are described in the claims, the description, and/or the drawings. According to some aspects, there is provided the subject matter of the independent claims. Some further aspects are defined in the dependent claims. Many of the attendant features will be more readily appreciated as they become better understood by reference to the following description considered in connection with the accompanying drawings.

LIST OF DRAWINGS

[0010] The accompanying drawings, which are included to provide a further understanding of the example embodiments and constitute a part of this specification, illustrate example embodiments and, together with the description, help to explain the example embodiments. In the drawings:

FIG. 1 illustrates an example of a mesh installation rig;

FIG. 2 illustrates an example of a mesh installation rig communicatively coupled to a remote mesh con-

trol device;

FIG. 3 illustrates an example of a data structure of a meshing plan;

FIG. 4 illustrates an example of a flow chart for controlling mesh installation;

FIG. 5 illustrates an example of adjusting mesh position;

FIG. 6 illustrates an example of adjusting fastener position;

FIG. 7 illustrates an example of adjusting fastening distance;

FIG. 8 illustrates an example of an apparatus configured to practise one or more example embodiments; and

FIG. 9 illustrates an example of a method for controlling mesh installation.

[0011] Like references are used to designate like parts in the accompanying drawings.

DESCRIPTION

[0012] Reference will now be made to embodiments, examples of which are illustrated in the accompanying drawings. The description provided below in connection with the appended drawings is intended as a description of the present examples and is not intended to represent the only forms in which the present example may be constructed or utilized. The description sets forth the functions of the example and the sequence of steps for constructing and operating the example. However, the same or equivalent functions and sequences may be accomplished by different examples.

[0013] At present, there are no systematic meshing guidance systems. For example, a certain surface profile of a rock surface (e.g., a tunnel) may be planned, but after blasting the profile may include a combination of different levels of under and over breakage that may require rock support. Meshes may be pressed against the rock surface and bolted to attach them. If a mesh is loose, more shotcrete may be needed to cover the rock surface. Major over and under breakage may cause a mesh to be broken during installation, for example if too heavy force is applied. For example, each mesh may be associated with an acceptable bending that may be dependent on material and diameter of mesh wires.

[0014] Example embodiments of the present disclosure enable considering mesh deformation, when meshing a rock surface. For example, a mesh installation rig may be configured with imaging capability, such as for example three-dimensional (3D) scanning, to identify an actual profile of the rock surface. Based on known physical properties of the mesh, e.g., deformation parameters such as for example allowed pressing force and allowed bending radius, and the actual surface model it is possible to estimate whether the mesh can be installed on the rock surface without breaking it. For example, as the target position and surface shape is known, the bolting strat-

egy may be adjusted to control locations of bolts such that too tight bending is avoided. It is also possible to use less force to press the mesh against the rock surface, for example at particular parts of the mesh, if the rock surface is rough. Such adaptive meshing strategy utilizing the physical properties of the mesh enables to decrease the likelihood of breaking the mesh during installation.

[0015] To further enhance the system, advanced image recognition of mesh grid integrity may be used. For example, the system may be configured to look for breakages in the mesh grid. This may be implemented for example by a computer vision algorithm that may be configured to focus on recognizing a rigid grid from an uneven surface. Performance of the system may be enhanced by using painted mesh to differentiate it from the rock surface more clearly.

[0016] FIG. 1 illustrates an example of a mesh installation rig. Even though mesh installation rig 100 is illustrated as an underground mesh installation rig, example embodiments of the present disclosure may be applied also to other type of mesh installation machines, for example rigs configured for installing meshes on rock cuttings along roads or railways.

[0017] Mesh installation rig 100 may be an automated mesh installation rig, for example an automated mining vehicle equipped with tools configured for mesh installation. An automated mining vehicle, for example an automated mesh installation rig, operating in an automatic mode may be configured to, for example, receive a task to be performed, perceive the environment of the automated mining vehicle, and autonomously perform the task while taking the environment into account. An automated mining vehicle operating in an automatic mode may be configured to operate independently but may be taken under external control at certain operation areas or conditions, such as during states of emergencies. Example embodiments may be however applied also in non-autonomous or semi-autonomous mining vehicles, for example remote-controlled mining vehicles.

[0018] In the example of FIG. 1, axis x represents the forward driving direction of mesh installation rig 100. Axis y represents the other horizontal direction, in this example towards left from mesh installation rig 100. Axis z represents the vertical direction, in this example towards the roof of the tunnel. Mesh installation rig 100 may comprise a movable carrier 110 and at least one boom 120 connected to movable carrier 110. Movable carrier 110 may comprise equipment for moving or stabilising mesh installation rig 100, such as for example a motor, wheels, or stabilizer jacks. Movable carrier 110 may be configured to move autonomously or it may be controlled by a human operator, either remotely or locally at mesh installation rig 100. Even though two booms 120-1, 120-2 have been illustrated in FIG. 1, mesh installation rig 100 may generally comprise one or a plurality (e.g., two, three, four,...) of booms 120. Boom 120-1 may be referred to as a first boom. Boom 120-2 may be referred to as a second boom.

[0019] A gripper 124 may be coupled to a distal end portion of boom 120-1. Gripper 124 may be configured to grab and hold mesh 101, for example to enable boom 120-1 to position mesh 101 at rock surface 140. Rock surface 140 may comprise the roof of the tunnel and/or at least some of the walls of the tunnel. A bolter 126 may be coupled to a distal end portion of boom 120-2. Bolter 126 may be configured to fasten mesh 101 at rock surface 140. Bolting is provided as one example of fastening mesh 101 to rock surface 140, but other means for fastening or mounting, such as for example riveting, may be also used. Bolts and rivets are examples of fasteners suitable for fastening mesh 101 to rock surface 140.

[0020] Mesh installation rig 100 may comprise at least one sensor 112 for scanning environment of mesh installation rig 100, for example, rock surface 140 and/or any meshes already installed thereon. Sensor 112 may include for example one or more of the following: a camera, a radio detection and ranging (radar) sensor, a light detection and ranging (lidar) sensor. Sensor 112 may therefore comprise a group of two or more sensors. Sensor 112 may be configured to scan rock surface 140 to detect geometry of rock surface 140 or to detect the meshes, for example particular features thereof, such as edge(s) or corner(s) of the meshes. Scanning rock surface 140 may comprise scanning with sensor 112 such that its sensing direction is towards rock surface 140. Alternatively, or additionally, mesh installation rig 100 may be configured to scan rock surface 140 with a device configured to physically probe rock surface 140. Such device (e.g., a probe) may be connected to a boom of mesh installation rig 100.

[0021] A camera may be used to extract depth information of objects such as for example rock surface 140 or mesh 101, for example by comparing two images taken at slightly different positions (e.g., by two camera units). Alternatively, sensor 112 may comprise a time-of-flight (ToF) camera, which may be configured to determine a distance between the camera and the object by measuring a round-trip time of an artificial light signal provided by a laser or a light-emitting diode (LED). A lidar sensor may be configured to determine a distance to different points of the object by targeting the object with a laser and measuring the time for the reflected light to return to a receiver of the lidar sensor. A radar sensor may be configured to transmit electromagnetic energy towards the object and to observe the echoes returned from the object to determine distances to different points of the object.

[0022] Based on scanning, mesh installation rig 100 may be configured to obtain point cloud data that represents the scanned environment. The point cloud data may for example comprise three-dimensional (3D) model of rock surface 140 or a detected mesh, or at least certain features such as edge(s) of the mesh. Mesh installation rig 100 may be therefore configured to obtain an actual surface model of rock surface 140. A position of the mesh, or certain points such as corners or edges of the mesh,

may be also determined based on the scanning data. The position of the mesh may be therefore fixed to, or known in relation to, a coordinate system or frame of mesh installation rig 100 (e.g., coordinate frame F_{rig}). The coordinate frame of mesh installation rig 100 may be stationary with respect to mesh installation rig 100. Mesh controller 114 may be configured to map the position(s) of the detected meshes to a coordinate system that is stationary with respect to rock surface 140 (e.g., coordinate frame F_{tunnel}), for example for providing feedback on actual positions of installed meshes on rock surface 140.

[0023] Mesh installation rig 100 may comprise a mesh controller (MC) 114. Mesh controller 114 may be for example provided as a software application residing on a memory and being executable by a processor. An example of an apparatus suitable for implementing mesh controller 114 is provided in FIG. 7. Mesh controller 114 may comprise, or be communicatively coupled to, various functions, blocks, or applications for implementing functionality of mesh controller 114. For example, mesh controller 114 may comprise or be communicatively coupled to a data management server, which may be configured to store information on a digital meshing plan, tunnel lines, point cloud or mesh presentations of tunnel lines or profiles, a mine map point cloud, or the like; or in general a planned surface model of rock surface 140. The planned surface model may comprise an intended profile of a rock surface, for example a tunnel. The planned surface model may be for example generated under supervision of a human operator with a tunnel planning tool. The planned surface model may be provided in a coordinate system that is stationary with respect to rock surface 140 (e.g., F_{tunnel}).

[0024] The digital meshing plan, also referred to as a meshing plan, may comprise planned mesh positions and optionally also planned fastener positions for fastening mesh(es). A mesh position may comprise a position of a mesh on rock surface 140, for example position of a corner, edge, or centre of mass of the mesh. A fastener position may comprise a position of fastener or fastening means (e.g., a bolt or a rivet) by which the mesh is configured to be fastened to rock surface 140. A planned fastener position may comprise a planned position for a fastener at rock surface 140. Mesh controller 114 may be configured to control installation of mesh 101 based on a planned position of mesh 101 and/or planned fastener position(s) of mesh 101. The planned position of mesh 101 and/or the associated fastener position(s) may be provided with respect to the coordinate system stationary with respect to rock surface 140. Mesh controller 114 may be configured to translate the position(s) to the coordinate system of mesh installation rig 100 (F_{rig}) based on a current position of mesh installation rig in the coordinate system stationary with respect to rock surface 140.

[0025] Mesh controller 114 may comprise a navigation application configured to control, or enable a human op-

erator to control, navigation of mesh installation rig 100, for example to move mesh installation rig 100 to a desired position (installation position) for installing a mesh at its planned position on rock surface 140 and/or to determine planned mesh position(s) or planned fastener position(s) of the digital meshing plan relative to a current position of mesh installation rig 100. A position of mesh installation rig 100 may be referred to as a navigation position. An installation position may be therefore a navigation position, which has been planned or determined for mesh installation rig 100 to install a mesh at rock surface 140. Mesh controller 114 may be configured to map positions of the planned surface model to the coordinate system of mesh installation rig 100 (F_{rig}), for example in order to compare the planned surface model of rock surface 140 to the actual surface model obtained based on scanning rock surface 140, for example at the installation position.

[0026] Mesh controller 114 may be configured to determine and/or maintain the digital meshing plan, a 3D model of at least one component of mesh installation rig 100 (e.g., a 3D model of boom(s) 120, gripper 124 or bolter 126), and/or a kinematic model of mesh installation rig 100, or component(s) thereof. A 3D model of a component of mesh installation rig 100 may comprise 3D geometry data of the component, obtained for example from a computer aided design (CAD) model of the respective physical component. The digital meshing plan may be provided as part of a drilling plan. The drilling plan may comprise planned drilling positions at rock surface 140, for example for bolting rock surface 140 (with or without meshing) to strengthen rock surface 140.

[0027] A kinematic model of mesh installation rig 100, or component(s) thereof, may comprise a mathematical description of at least a part of mesh installation rig 100. A kinematic model may describe motion of mesh installation rig 100 or component(s) of mesh installation rig 100 without taking into account the forces that cause the motion. The kinematic model may be used for estimating or simulation of a position of mesh installation rig 100 or component(s) of mesh installation rig 100, for example based on measurement data from one or more sensors associated with mesh installation rig 100 or motion of mesh installation rig 100 caused, or to be caused, by given control inputs. The kinematic model of mesh installation rig 100 may comprise at least dimensions of mesh installation rig 100 and/or reach of mesh installation rig 100 such as a movement range of at least one boom 120 of mesh installation rig 100. The kinematic model may comprise information on dimensions of boom(s) 120, or parts thereof, for example gripper 124 or bolter 126, characteristics of joint(s) 122 (e.g., their degrees of freedom), constraints between moving parts of mesh installation rig 100, or the like. The kinematic model may thus enable modelling movement of the component(s) of mesh installation rig 100, for example to determine possible positions for installing mesh 101 from a particular installation position or to predict/prevent collisions between component(s) of mesh installation rig, mesh 101, and/or rock

surface 140. The kinematic model may for example enable determining a maximum distance reachable by gripper 124 or bolter 126. The 3D model(s) of the component(s) may be provided as point cloud data indicative of the surface of the component(s). Point cloud data may comprise a plurality of data points representing, for example, distances between mesh installation rig 100 and its component(s) or other objects in the environment of mesh installation rig 100, for example at a particular time instance. An individual point included in a point cloud may be presented by, for example, x and y coordinates, or x, y, and z coordinates with respect to a particular coordinate frame (e.g., F_{rig}).

[0028] Mesh installation rig 100 may be controlled by a remote mesh control device 200, which may be external to mesh installation rig 100, as illustrated in FIG. 2. Remote mesh control device 200 may be for example a server located remote from mesh installation rig 100, for example outside the tunnel. Functionality of mesh controller 114 may be provided at mesh installation rig 100, remote mesh control device 200, or distributed between mesh installation rig 100 and remote mesh control device 200. Information may be exchanged between remote mesh control device 200 and mesh installation rig 100 over a communication interface including any suitable wireless or wired connection. Examples of suitable communication interfaces are described with reference to FIG. 8.

[0029] Mesh controller 114 may be configured to determine and/or maintain the digital meshing plan. The 3D and kinematic model(s) of mesh installation rig 100, or the planned surface model, may be stored at mesh controller 114, for example based on pre-configuration of the model(s) at mesh controller 114. Alternatively, mesh controller 114 may be configured to receive one or more of the models from mesh installation rig 100 or the data management server. Example embodiments of the present disclosure may be thus implemented locally at mesh installation rig 100 and/or at remote mesh control device 200.

[0030] FIG. 3 illustrates an example of a data structure of a digital meshing plan. The data structure of a digital meshing plan may comprise a computer-implemented data structure embodied on a computer-readable medium for controlling mesh installation. The data structure may be provided on a memory, such as for example a computer-readable storage medium, examples of which include, but are not limited to, movable storage devices (e.g., universal serial bus stick, compact disc, or the like). Further examples of suitable types of memory for storing the digital meshing plan are described with reference to the at least one memory 804 of FIG. 8.

[0031] A data structure *digital_meshing_plan* may comprise the digital meshing plan. Data structure *digital_meshing_plan* may be associated with one or more other data structures, such as for example data structure *mesh* comprising information associated with one mesh (e.g., a single mesh). A data structure may be also called an

object, a data object, or an information object. Cardinality between data structures or attributes is represented by values "0", "1" or "*". For example, data structure *digital meshing_plan* may be associated with one or a plurality of ("1... *") data structures *mesh*, which may comprise or be associated with one attribute *planned_mesh_position*. Data structure *mesh* may comprise or be associated with zero or more ("0... *") attributes *planned_fasterer_position*.

[0032] Data structure *digital meshing_plan* may comprise or be associated with one or more (sub)data structures *mesh*. Data structure *mesh* may comprise or be associated with one or more attributes that are related to one *mesh*. For example, data structure *mesh* may comprise or be associated with attribute *planned_mesh_position*, which may be configured to indicate a planned position of a mesh on rock surface 140 for installation of the mesh to rock surface 140 by mesh installation rig 100. The planned position of the mesh may be configured to be indicated with respect to a coordinate frame that is stationary with respect to rock surface 140, e.g., with respect to the coordinate frame of the tunnel (F_{tunnel}). The planned position of the mesh may comprise a planned position of least one part (e.g., an edge or corner) of the mesh on rock surface 140. For example, planned positions of two corners of the mesh may be provided to indicate the planned position of the mesh. Alternatively, a planned position of a single point (e.g., a corner) of the mesh may be provided along with a planned orientation of the mesh, in order to indicate the planned position of the mesh. An instance of data structure *mesh* may comprise or be associated with one attribute *planned_mesh_position*. The attribute *planned_mesh_position* may however comprise one or more positions corresponding to different parts of the mesh.

[0033] Data structure *mesh* may comprise or be associated with zero or more ("0... *") attributes *planned_fastener_position*, which may be configured to indicate planned fastener position(s) for installation of the associated mesh to rock surface 140. The planned fastener position(s) may be configured to be indicated with respect to a coordinate frame (e.g., F_{tunnel}) that is stationary with respect to rock surface 140, for example the same coordinate frame used for indicating the planned position of the associated mesh.

[0034] The planned position of the mesh or the planned fastener position(s) may be provided as a three-dimensional (3D) position(s), which may directly indicate the relevant position at the coordinate frame stationary with respect to rock surface 140. Alternatively, the planned position(s) may be indicated as a two-dimensional (2D) position, for example on a 2D projection of rock surface 140 or as 2D position on a reference plane from which the position is projected to rock surface 140.

[0035] An instance of data structure *mesh* may be identified by a mesh identifier, represented in this example by attribute *mesh_id*. One mesh may be associated with

one mesh identifier (1...1). A mesh identifier may comprise for example one or more of the following: a serial number, a type identifier (e.g., type number), or a part number of the mesh. A mesh identifier may therefore identify an individual mesh and/or a type of mesh. The mesh identifier may be associated with a planned position of rock surface 140 (e.g., by means of attribute *planned_mesh_position*). A type identifier may be configured to indicate for example one or more of the following: the shape of mesh eyes (e.g., square or diamond), size of the mesh eyes, a mesh with equal size of mesh eyes, a mesh with different mesh eye size with a particular pattern, material of the mesh (e.g., hot galvanized mesh, stainless mesh, ferritic mesh), size of mesh (e.g., 2270 mm x 2530 mm), or the like.

[0036] Data structure *digital meshing_plan* may comprise or be associated with zero or more (0... *) data structures *slot*, which may represent a slot (e.g., an area of rock surface 140) for installing a mesh at rock surface 140. A slot may be identified by a slot identifier (e.g., by attribute *slot_id*). Data structure *slot* may comprise or be associated with zero or more (0... *). Data structure *slot* may comprise or be associated with other properties, such as for example a position of the slot on rock surface 140, or position(s) of mesh to be installed on the slot. For example, attributes *planned_mesh_position* and/or *planned_mounting_position* may be associated with a slot (e.g., data structure *slot* having a particular *slot_id*). Alternatively, or additionally, attributes of a slot may be configured to indicate an area of rock surface 140 for installing an associated mesh. This may be in addition or alternative to similar attribute(s) being associated with a particular mesh (e.g., data structure *mesh* having a particular *mesh_id*). Therefore, the planned position of a mesh or its fastener position(s) may be indicated by attribute(s) of a slot. Mesh controller 114 may be configured to map a particular mesh to a particular slot. Mesh controller 114 may therefore be configured to create an association between a slot and a mesh, as illustrated by the dashed line.

[0037] Data structure *mesh* may comprise or be associated with one or more (1... *) instances of attribute *deformation_parameter*. A deformation parameter may characterize allowed deformation of the associated mesh, for example when installing the mesh on rock surface 140. Examples of the deformation parameter include allowed elongation of the mesh, or part(s) thereof, for example, a mesh wire, a mesh opening, or an edge of the mesh. The allowed elongation may be provided for example as a percentage or as an absolute length (e.g., in millimetres or centimetres), for example for a particular part of the mesh. The allowed elongation may define a maximum allowed elongation for the associated mesh or part of mesh.

[0038] Another example of a deformation parameter is an allowed bending radius for the mesh, or part(s) thereof. The allowed bending radius may be indicated for example by the smallest allowed (minimum) bending radi-

us, for example in centimetres. The bending radius may be however indicated by any suitable measure that characterises the bended shape of a mesh (part) formed when bending mesh for fitting it to rock surface. The bending radius may comprise a radius or an imaginary circle, where a part of the circle aligned with the bended shape of the mesh.

[0039] Another example of a deformation parameter is allowed pressing force, which may be provided for example in Newtons. For example, in case of a thin chicken wire mesh the allowed pressing force may be in the order of 500 N and in case of a thicker (e.g., 20 mm) welded corrugated bar mesh the allowed pressing force may be in the order of 100 000 N. Suitable values for the allowed pressing force may be therefore selected from the range of 5000 N to 20 000 N, for example 10 000 N. The allowed pressing force may indicate the highest (maximum) allowed force for pressing the associated mesh towards rock surface 140, when installing the mesh. The deformation parameter(s) enable mesh controller 114 to determine whether a particular mesh can be installed on rock surface 140 such that it is not likely to break, as will be further described below.

[0040] Data structure *mesh* may comprise or be associated with attributes *actual_mesh_position* and/or *actual_mounting_position* (not shown). This may be the case for example if data structure *slot* comprises or is associated with attributes *planned_mesh_position* and/or *planned_mounting_position*. Mesh controller 114 may be configured to assign values for *actual_mesh_position* and/or *actual_mounting_position* based on the actual position of the mesh and/or its actual fastener positions, for example subsequent to installation of the mesh on rock surface 140. Even though particular hierarchy of data structures and attributes is illustrated in FIG. 3, it is appreciated that similar functionality and benefits may be provided with other type of structures of the digital meshing plan.

[0041] Attributes of a particular data structure may include attributes relating to characteristics of the object (e.g., digital or real object) represented by that data structure. For example, attributes of a digital meshing plan (e.g., data structure *digital_meshing_plan*) may include attributes relating to characteristics of the digital meshing plan. Attributes of a mesh (e.g., data structure *mesh*) may include attributes relating to characteristics of the mesh. Attributes of a slot (e.g., data structure *slot*) may include attributes relating to characteristics of the slot. Such attributes may be referred to as (digital) meshing plan attributes, mesh attributes, or slot attributes, respectively.

[0042] FIG. 4 illustrates an example of a flow chart for controlling mesh installation. Even though operations of the flow chart are described to be performed by mesh controller 114, they may be generally configured to be performed by an apparatus, such as for example mesh installation rig 100, a control apparatus thereof, or remote mesh control device 200.

[0043] At operation 401, mesh controller 114 may be

configured to obtain a meshing plan, for example as an instance of data structure *digital_meshing_plan*. The meshing plan may be digital, for example represented as binary digits (bits) or other digital values on a computer-readable memory. The meshing plan may be indicative of planned position(s) of mesh(es) on rock surface 140. The position(s) may be configured for installation of mesh(es) to rock surface 140 by mesh installation rig 100. The planned position(s) of the mesh(es) may be configured to be indicated with respect to coordinate frame F_{tunnel} , or in general a coordinate frame that is stationary with respect to rock surface 140. Mesh controller 114 may be configured to obtain information on planned fastener position(s) of the mesh(es), for example as part of the meshing plan. Mesh controller 114 may be configured to obtain information about deformation parameter(s) associated with mesh(es), for example as part of the meshing plan. The meshing plane may comprise information for mesh 101 and other meshes.

[0044] Mesh controller 114 may be configured to obtain the meshing plan by receiving the meshing plan, for example over an internal communication interface of mesh installation rig 100 or from a device external to mesh installation rig 100 (e.g., remote mesh control device 200). Alternatively, mesh controller 114 may be configured to obtain the meshing plan by retrieving it from at least one memory of an apparatus (e.g., a control apparatus) comprising mesh controller 114, or from at least one memory of mesh installation rig 100. This enables remote and/or local configuration of the digital meshing plan, thereby providing a flexible solution for controlling mesh installation.

[0045] Mesh controller 114 may be configured to map the planned position(s) indicated in the meshing plan to a coordinate system of mesh installation rig 100, for example coordinate frame F_{rig} , or in general a coordinate frame that is stationary with respect to mesh installation rig 100. Mesh installation rig 100 may be configured to monitor its location with respect to the coordinate frame (e.g., F_{tunnel}) that is stationary with respect to the rock surface 140, for example during navigation in a tunnel. Mesh controller 114 may be configured to determine the planned position(s) with respect to its own coordinate frame (e.g., F_{rig}) based on the current position of mesh installation rig 100 and the planned position(s) indicated in the meshing plan, both with respect to the coordinate frame stationary with respect to rock surface 140. This mapping may be performed for the planned position(s) of the mesh(es) and/or the planned fastener position(s). Respectively, mesh controller 114 may be configured to map detected actual positions of mesh(es) or fastener(s) from its own coordinate frame to the coordinate frame stationary with respect to rock surface 140, for example for provision of feedback at operation 411.

[0046] At operation 402, mesh controller 114 may be configured to obtain a surface model of rock surface 140. The surface model may comprise an actual surface model of rock surface 140. An example of the surface model

is illustrated in FIGs. 5 to 7 by surface model 142. The actual surface model may correspond to the in situ rock surface 140 observable by mesh installation rig 100, for example in a particular position of mesh installation rig 100 in the tunnel, prior to or during mesh installation. The actual surface model may be based on scanning data of rock surface 140. Mesh installation rig 100, or in general any other scanning device, may be configured to scan rock surface 140, for example as described above, to obtain scanning data indicative of the geometry of rock surface 140. Mesh controller 114 may be configured to cause the scanning, for example by instructing mesh installation rig 100 to perform the scanning. Mesh controller 114 may be configured to receive the scanning data from the scanning device.

[0047] At operation 403, mesh controller 114 may be configured to apply a smoothing filter, e.g., a Gaussian blur filter, on the scanning data. Mesh controller 114 may be configured to apply the smoothing filter on the scanning data. A smoothing filter may be configured to act as a low pass filter that smoothens geometrical variations in the surface model to a desired extent. This enables to simulate how a mesh would be deformed when installing it on rock surface 140. For example, very steep variations in the actual rock surface may be ignored when determining whether the deformation parameter(s) would be violated when installing a mesh on rock surface 140. It is however noted that example embodiments may be alternatively applied on raw scanning data or that a smoothing filter may be applied on the scanning data before mesh controller 114 receives the scanning data, for example at the scanning device such as for example sensor 112.

[0048] At operation 404, mesh controller 114 may be configured to determine whether mesh 101 can be installed on rock surface 140 without violating the deformation parameter(s). For example, mesh controller 114 may be configured to determine, based on the planned mesh position and geometry of surface model 142, an expected elongation or expected bending radius of mesh 101, or part(s) thereof, when installing mesh 101 on its planned position, optionally also considering the planned fastener position(s). This may be done prior to initiating installation of mesh 101. Mesh controller 114 may be configured to determine that mesh 101 can not be installed without violating the deformation parameter(s), if the expected elongation or bending radius violates the respective deformation parameters, for example if the expected elongation is longer than the allowed elongation or the expected bending radius is smaller than the allowed bending radius. Alternatively, or additionally, mesh controller 114 may be configured to monitor the pressing force applied to mesh 101 when fastening it to rock surface 140. Mesh controller 114 may be configured to receive pressure data from a pressure sensor, which may be for example coupled to a fastening tool (e.g., bolter 126) of mesh installation rig 100. Mesh controller 114 may be configured to determine that mesh 101 can

not be installed without violating the deformation parameter(s), if the measured pressing force reaches the allowed pressing force and installation of mesh 101 has not been completed. Mesh controller 114 may be configured to move to execution of operation 409, without the adjustment(s) of operation 405 or the update of operation 406), in response to determining that mesh 101 can be installed on the planned position and/or with the planned fastener position(s) without violating the deformation parameter(s) of mesh 101.

[0049] Mesh controller 114 may be further configured to determine whether mesh 101 can be installed without violating the deformation parameter(s) if the planned mesh position, planned fastener position(s), and/or a distance of mesh 101 from rock surface 140 were adjusted. For example, mesh controller 114 may be configured to preliminarily adjust the planned mesh position, planned fastener position(s) and/or the distance from rock surface 140 and perform the above analysis again with the adjusted mesh position, adjusted fastener position(s), and/or the adjusted distance.

[0050] Adjustment of the mesh position, fastener position(s), and/or the distance may be based on trial and error, for example based on a preconfigured pattern of adjustments, or based on geometry of surface model 142. In the latter case, mesh controller 114 may be configured to adjust the planned mesh position to cause an edge of mesh 101 to coincide with a recess of rock surface 140. An example of this is provided in FIG. 5. If mesh 101 were installed on its originally planned position 501, mesh 101 might break when mounted at a recess of rock surface 140 reflected in surface model 142, as illustrated on the left. As illustrated on the right, planned mesh position 501 may be adjusted to the left such that an edge of mesh 101 substantially coincides with the recess. This provides the benefit of enabling mesh 101 to be installed on rock surface 140 without bending mesh 101 at the bottom of the recess, and thereby to reduce the risk of breakage. Mesh controller 114 may be configured to determine the position of the recess based on geometry of surface model 142. Substantially coinciding may correspond to aligning the edge of mesh 101 with the recess such that bending at the bottom of the recess is avoided, or at least reduces to the extent that breakage of mesh 101 may be avoided.

[0051] Alternatively, or additionally, mesh controller 114 may be configured to adjust the planned fastener position(s) away from the recess of surface model 142, for example to cause the fastener(s) not to coincide with the recess of rock surface 140. An example of this is provided in FIG. 6. As illustrated on the right, planned fastener position (p_{planned}) may be adjusted to the left and/or right (p_{adjusted}) such that mesh 101 is not fastened at the bottom of the recess. This provides the benefit of enabling mesh 101 to be installed on rock surface 140 without causing excessive bending, possibly a breakage, at the position of the recess. For example, this enables mesh 101 to be installed such that it bridges the recess

and is fastened to rock surface 140 at two sides of the recess. Adjusting fastener positions may comprise increasing or reducing the number of fastener positions.

[0052] Mesh controller 114 may be configured with a default value (e.g., zero) for the distance between meshes and rock surface 140. Adjustment of the distance may include increasing the distance. An example of this is illustrated in FIG. 7. As illustrated on the right, the distance of mesh 101 at the planned fastener position (p_{planned}) may be adjusted (increased) such that mesh 101 is not pressed to the bottom of the recess. This provides the benefit of enabling mesh 101 to be installed on rock surface 140 without causing excessive bending, possibly a breakage, at the position of the recess.

[0053] Referring back to FIG. 4, mesh controller 114 may be configured to move from execution of operation 404 to execution of operation 405, in response to determining that mesh 101 can be installed (substantially at the planned position) with adjusted mesh position, adjusted fastener position(s), and/or adjusted distance from rock surface 140 without violating the deformation parameter(s).

[0054] At operation 405, mesh controller 114 may be configured to adjust the planned position of mesh 101, the planned fastener position(s), and/or the distance of mesh 101 from rock surface 140 such that mesh 101 can be installed on rock surface 140 without violating the deformation parameter(s). This may be in response to determining at operation 404 that mesh 101 can be installed without violating at least one deformation parameter of the mesh, if adjusting the planned position of the mesh, the planned position of the fastener(s), and/or the distance of the mesh from rock surface 140. Mesh controller 114 may be configured to select the adjusted position for mesh 101, the adjusted position(s) of the fastener(s), or the adjusted distance, as determined at operation 404. Mesh controller 114 may be therefore configured to determine to refrain from installation of mesh 101 at the planned position. Mesh controller 114 may be however configured to subsequently enable installing mesh 101 at the planned position, for example in response to determining that adjustment of fastener position(s) or the distance from rock surface 140 enables installing mesh 101 at the planned position without violating the deformation parameter(s). Refraining from installing a mesh may therefore comprise temporarily preventing installation of the mesh.

[0055] At operation 406, mesh controller 114 may be configured to update the meshing plan with the adjusted position of mesh 101, adjusted fastener position(s), and/or the distance. For example, mesh controller 114 may be configured to change value(s) of attribute(s) *planned_mesh_position* or *planned_fastener_position* of data structure *mesh* corresponding to mesh 101, or to replace the value of default fastening distance with the adjusted distance value. This provides the benefit of maintaining up-to-date information about the current status of the meshing plan and installation of meshes at their

adjusted positions and/or with the adjusted fastener positions or distances. However, updating the meshing plan may generally comprise any operation configured to record information about the adjusted mesh position(s), fastener position(s), or distance, regardless of whether such update is recorded within the original meshing plan. For example, such update information could also be stored separately from the original data structure *digital_meshing_plan*.

[0056] At operation 407, mesh controller 114 may be configured to refrain from installation of mesh 101 on the planned position. This may be in response to determining that mesh 101 can not be installed on its planned position (even with the adjustment(s)) without violating the deformation parameter(s).

[0057] At operation 408, mesh controller 114 may be configured to configure another mesh to be installed on rock surface 140, e.g., at the planned position of mesh 101. This may be in response to determining that the other mesh can be installed on the planned position of mesh 101 without violating deformation parameter(s) of the other mesh. For example, mesh controller 114 may be configured to determine to replace mesh 101 with another mesh that is associated with deformation parameter(s) that allow installation of the other mesh at the position originally planned for mesh 101, optionally with adjustment of the mesh position, fastener position(s), or distance of the mesh to rock surface 140. Mesh controller 114 may be for example configured to select another a mesh with higher allowed elongation, smaller allowed bending radius, or higher allowed pressing force to replace mesh 101. This provides the benefit of enabling meshing of rock surface 140 also at positions where the originally planned mesh can not be installed due to its excessive deformation. This enables meshing to be cost-effectively planned with relatively weak meshes, which may be then replaced with relatively strong meshes whenever required by the geometry of rock surface 140. The total cost of meshing rock surface 140 may be therefore reduced.

[0058] Mesh controller 114 may be configured to move from execution of operation 408 to execution of operation 406, in order to update the meshing plan with the replacement of the originally planned mesh. For example, mesh controller 114 may be configured to change the identifier of the mesh (*mesh_id*) and optionally also the position of the mesh (e.g., *planned_mesh_position*) and/or the fastener position(s) (e.g., *planned_fastener_position*) in the meshing plan.

[0059] At operation 409, mesh controller 114 may be configured to control mesh installation based on the updated meshing plan. For example, mesh controller 114 may be configured to control installation of mesh 101, or the replacement mesh, to rock surface 140 based on the planned position of the relevant mesh, obtained based on the meshing plan and/or as adjusted by mesh controller 114. Mesh controller 114 may be configured to control fastening of the mesh to rock surface 140 based

on its planned fastener position(s), for example as indicated in the meshing plan and/or as adjusted by mesh controller 114. Mesh controller 114 may be configured to control fastening of the mesh(es) such that the mesh is installed at the default or adjusted distance from rock surface 140.

[0060] Controlling mesh installation may comprise controlling positioning of a mesh for installation at rock surface 140. For example, mesh controller 114 may be configured to control movement at least one boom, for example boom 120-1 comprising gripper 124, to position the mesh for being installed on rock surface 140. Mesh controller 114 may be configured to determine the position of the mesh based on the updated meshing plan, or in general the adjusted mesh position, adjusted fastener position(s), or the adjusted distance from rock surface 140.

[0061] Controlling mesh installation may comprise controlling fastening the mesh to rock surface 140. Controlling the fastening of the mesh may comprise causing mesh installation rig 100 to fasten the mesh at rock surface 140 with fastener(s). Controlling fastening of the mesh may comprise determining an order of fastener positions or a fastening rate (e.g., in bolts/min). Controlling fastening of the mesh may comprise causing mesh installation rig 100 to fasten mesh 101 to rock surface 140 according to the determined order of fastener positions or the fastening rate. Controlling fastening of the mesh may comprise controlling movement of at least one boom, for example boom 120-2 comprising bolter 126, to cause mounting of the mesh to rock surface 140.

[0062] Controlling mesh installation may therefore comprise controlling movement of at least one boom, for example booms 120-1, 120-2 and their respective tools, to cause both placement of the mesh at rock surface 140 and fastening of the mesh at rock surface 140 at this position. Controlling mesh installation may comprise providing control instructions, e.g., to a kinematic controller of mesh installation rig 100, to cause desired movement of the boom(s) and tool(s). Controlling mesh installation may further comprise controlling collision avoidance, for example when moving the mesh with boom 120-1 and gripper 124 or when moving bolter 126 for mounting the mesh. Mesh controller 114, or mesh installation rig 100, may be configured to perform collision avoidance to avoid collisions between component(s) of mesh installation rig 100 (e.g., boom 120-1, boom 120-2, gripper 124, bolter 126, or movable carrier 110), mesh 101, or rock surface 140. Collision avoidance may be based on the kinematic model of mesh installation rig 100. When the procedure of FIG. 4 is performed by mesh installation rig 100, mesh installation rig 100 may perform the mesh installation.

[0063] At operation 409, mesh controller 114 may be configured to detect breakage of a mesh. For example, mesh controller 114 may be configured to detect breakage of mesh 101 based on scanning data received from sensor 112, e.g., by means of a computer vision algorithm configured to be executed on visual data received from

a camera. Mesh controller 114 may be configured to perform breakage detection during or after installation of mesh 101, for example in response to completing installation of mesh 101 (e.g., completing fastening mesh 101 with a planned number of fasteners). If breakage is detected, mesh controller 114 may be configured to move back to execution of operation 408, in order to configure another mesh to be installed substantially at the position of the broken mesh 101. Mesh controller 114 may be configured to update the meshing plan accordingly at operation 406 and control installation of the other (additional) mesh substantially at the position of the broken mesh 101 at operation 409.

[0064] At operation 411, mesh controller 114 may be configured to provide feedback, for example indication(s) of actual position(s) of mesh 101 and/or the other mesh installed on rock surface 140, their fastener position(s), and/or their distances from rock surface 140. Mesh controller 114 may be for example configured to determine the actual position of mesh 101 on rock surface 140 after installation of mesh 101. Mesh controller 114 may be configured to determine the actual position of mesh 101 based on the actual fastener position(s) used for fastening mesh 101 on rock surface 140. Mesh controller 114 may be configured to determine the actual position or actual fastener position(s) of mesh 101 based on the adjusted position(s) determined at operation 405 or based on monitoring location and/or orientation of gripper 124 and/or a mounting tool (e.g., bolter 126) when installing mesh 101 on rock surface 140. Alternatively, or additionally, mesh controller 114 may be configured to control scanning of rock surface 140 by sensor 112, in order to detect mesh 101. Mesh controller 114 may be configured to determine the actual position of mesh 101 based on scanning data of sensor 112. Mesh controller 114 may be configured to store actual position and/or actual mounting position(s) of mesh 101, for example in the meshing plan (e.g., as attributes *actual_mesh_position* and/or *actual_mounting_position* of associated with data structure *mesh*).

[0065] Mesh controller 114 may be configured to transmit an indication of the actual position of mesh(es) installed rock surface 140, for example over an internal communication interface of mesh installation rig 100 or to a device external to the mesh installation rig (e.g., remote mesh control device 200). Mesh controller 114 may be configured to transmit as feedback indication(s) of other parameter(s) associated with installing the meshes included in the digital meshing plan, for example indication(s) of actual fastener position(s). The feedback may be provided as an updated instance of the meshing plan.

[0066] Mesh controller 114 may be configured to move from execution of operation 404 to determine whether a next mesh can be installed without violating its deformation parameter(s), for example if the planned position or slot of the next mesh is included in the surface model obtained at operation 402. If not, mesh controller 114 may be configured to move to execution of operation 402

to obtain a surface model for the planned position or slot of at least the next mesh.

[0067] Even though particular sequence of operations is illustrated in FIG. 4, it is understood that the operations may be executed in any suitable order and that some operations might not be present in all example embodiments. For example, application of the smoothing filter (operation 404), breakage detection (operation 410), and provision of the feedback (operation 411) may be optional. Furthermore, the procedure of FIG. 4 may be iterated for multiple meshes or individual operations may be performed for multiple meshes in one go, e.g., sequentially or in parallel.

[0068] FIG. 8 illustrates an example of an apparatus configured to practise one or more example embodiments. Apparatus 800 may be or comprise a mesh control apparatus, such as for example a server, communicatively coupled to mesh installation rig 100, a mesh control apparatus located at mesh installation rig 100, mesh controller 114, mesh installation rig 100 itself, or in general any device or system configured to implement the functionality described herein. Although apparatus 800 is illustrated as a single device, it is appreciated that, wherever applicable, functions of apparatus 800 may be distributed to a plurality of devices.

[0069] Apparatus 800 may comprise at least one processor 802. The at least one processor 802 may comprise, for example, one or more of various processing devices, such as for example a co-processor, a microprocessor, a controller, a digital signal processor (DSP), a processing circuitry with or without an accompanying DSP, or various other processing devices including integrated circuits such as, for example, an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), a microcontroller unit (MCU), a hardware accelerator, a special-purpose computer chip, or the like.

[0070] Apparatus 800 may further comprise at least one memory 804. The at least one memory 804 may be configured to store, for example, computer program code or the like, for example operating system software and application software. The at least one memory 804 may comprise one or more volatile memory devices, one or more non-volatile memory devices, and/or a combination thereof. For example, the memory may be embodied as magnetic storage devices (such as hard disk drives, etc.), optical magnetic storage devices, or semiconductor memories (such as mask ROM, PROM (programmable ROM), EPROM (erasable PROM), flash ROM, RAM (random access memory), etc.). Memory 804 is provided as an example of a (non-transitory) computer readable medium. The term "non-transitory," as used herein, is a limitation of the medium itself (i.e., tangible, not a signal) as opposed to a limitation on data storage persistency (e.g., RAM vs. ROM). The at least one memory 804 may be also embodied separate from apparatus 800, for example as a computer readable (storage) medium, examples of which include memory sticks, compact discs (CD), or the like.

[0071] When apparatus 800 is configured to implement some functionality, some component and/or components of apparatus 800, such as for example the at least one processor 802 and/or the at least one memory 804, may be configured to implement this functionality. Furthermore, when the at least one processor 802 is configured to implement some functionality, this functionality may be implemented using program code 806 comprised, for example, in the at least one memory 804.

[0072] The functionality described herein may be performed, at least in part, by one or more computer program product components such as software components. According to an example embodiment, apparatus 800 comprises a processor or processor circuitry, such as for example a microcontroller, configured by the program code 806, when executed, to execute the embodiments of the operations and functionality described herein. Program code 806 is provided as an example of instructions which, when executed by the at least one processor 802, cause performance of apparatus 800.

[0073] For example, mesh controller 114 may be at least partially implemented as program code configured to cause apparatus 800 to perform functionality of mesh controller 114. Similarly, transmission or reception of data (e.g. sensor data, kinematic model(s), or the digital meshing plan) over an internal or external communication interface of mesh installation rig 100 may be controlled by software.

[0074] Alternatively, or in addition, the functionality described herein can be performed, at least in part, by one or more hardware logic components. For example, and without limitation, illustrative types of hardware logic components that can be used include field-programmable gate arrays (FPGAs), application-specific integrated circuits (ASICs), application-specific standard products (ASSPs), system-on-a-chip systems (SOCs), complex programmable logic devices (CPLDs), graphics processing units (GPUs), neural processing unit (NPU), tensor processing unit (TPU), or the like.

[0075] Apparatus 800 may comprise a communication interface 808 configured to enable apparatus 800 to transmit and/or receive information. Communication interface 808 may comprise an internal or external communication interface, such as for example a radio interface between mesh installation rig 100 and remote mesh control device 200 or an internal control bus within mesh installation rig. Apparatus 800 may further comprise other components and/or functions such as for example a user interface (not shown) comprising at least one input device and/or at least one output device. The input device may take various forms such as a keyboard, a touch screen, or one or more embedded control buttons. The output device may for example comprise a display, a speaker, or the like. The user interface may enable a human operator to monitor various functions and data, such as for example the digital meshing plan, or the like.

[0076] Apparatus 800 may be configured to perform or cause performance of any aspect of the method(s) de-

scribed herein. Further, a computer program or a computer program product may comprise instructions for causing, when executed by apparatus 800, apparatus 800 to perform any aspect of the method(s) described herein. Further, apparatus 800 may comprise means for performing any aspect of the method(s) described herein. In one example, the means comprises the at least one processor 802, the at least one memory 804 including program code 806 (instructions) configured to, when executed by the at least one processor 802, cause apparatus 800 to perform the method(s). In general, computer program instructions may be executed on means providing generic processing functions. Such means may be embedded for example in a computer, a server, or the like. The method(s) may be thus computer-implemented, for example based algorithm(s) executable by the generic processing functions, an example of which is the at least one processor 802. Apparatus 800 may comprise means for transmitting or receiving information, for example one or more wired or wireless (e.g. radio) transmitters or receivers, which may be coupled or be configured to be coupled to one or more antennas, or transmitter(s) or receiver(s) of a wired communication interface.

[0077] According to a first aspect, an apparatus for controlling mesh installation is disclosed. The apparatus may comprise: at least one processor; and at least one memory including computer program code, the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus at least to: obtain a surface model of a rock surface; determine, based on the surface model, whether a mesh can be installed on a planned position of the mesh on the rock surface without violating at least one deformation parameter of the mesh; and determine to refrain from installation of the mesh on the planned position of the mesh, in response to determining that the mesh can not be installed on the planned position of the mesh without violating the at least one deformation parameter.

[0078] According to an example embodiment of the first aspect, the computer program code is further configured to, with the at least one processor, cause the apparatus to: adjust the planned position of the mesh such that the mesh can be installed on the rock surface without violating the at least one deformation parameter, adjust a planned position of at least one fastener configured to fasten the mesh on the rock surface such that the mesh can be installed on the rock surface without violating the at least one deformation parameter, adjust a distance of the mesh from the rock surface at the planned or adjusted position of the at least one fastener such that the mesh can be installed on the rock surface without violating the at least one deformation parameter, and/or configure another mesh to be installed on the rock surface instead of the mesh, in response to determining that the other mesh can be installed on the planned position of the mesh without violating at least one deformation parameter of the other mesh.

[0079] According to an example embodiment of the

first aspect, the computer program code is further configured to, with the at least one processor, cause the apparatus to: determine at least one of an actual position of the at least one mesh on the rock surface or an actual position of the at least one fastener on the rock surface; and transmit at least one of an indication of the actual position of the at least one mesh or an indication of the actual position of the at least one fastener over an internal communication interface of the apparatus or to a device external to the apparatus.

[0080] According to an example embodiment of the first aspect, the computer program code is further configured to, with the at least one processor, cause the apparatus to: obtain a meshing plan indicative of at least one of the planned position of the mesh or the planned position of at least one fastener; and determine at least one of the planned position of the mesh or the planned position of at least one fastener based on the meshing plan.

[0081] According to an example embodiment of the first aspect, the computer program code is further configured to, with the at least one processor, cause the apparatus to: update the meshing plan based on the adjustment of the planned position of the mesh and/or the planned position of the at least one fastener.

[0082] According to an example embodiment of the first aspect, the computer program code is further configured to, with the at least one processor, cause the apparatus to: control installation of the mesh on the planned or adjusted position of the mesh, in response to determining that the mesh can be installed on the planned position of the mesh without violating the at least one deformation parameter.

[0083] According to an example embodiment of the first aspect, wherein the at least one deformation parameter comprises at least one of the following: an allowed elongation of at least one part of the mesh, an allowed bending radius for the at least one part of the mesh, or an allowed pressing force.

[0084] According to an example embodiment of the first aspect, the computer program code is further configured to, with the at least one processor, cause the apparatus to: detect a breakage of the mesh during or after installation of the mesh on the rock surface; and control installation of another mesh at a position of the breakage of the mesh.

[0085] According to an example embodiment of the first aspect, the surface model is based on scanning data of the rock surface.

[0086] According to an example embodiment of the first aspect, the computer program code is further configured to, with the at least one processor, cause the apparatus to: obtain the scanning data from at least one of the following: a camera, a radio detection and ranging sensor, a light detection and ranging sensor laser, or a device configured to physically probe the rock surface.

[0087] According to an example embodiment of the first aspect, the computer program code is further con-

figured to, with the at least one processor, cause the apparatus to: apply a smoothing filter on the scanning data to obtain the surface model.

[0088] According to a second aspect, a mesh installation rig is disclosed. The mesh installation rig may comprise the apparatus according to any example embodiment of the first aspect.

[0089] FIG. 9 illustrates an example of a method for controlling mesh installation, according to a third aspect of the present disclosure. The method may comprise a computer-implemented method performed by, for example, apparatus 800 such as mesh controller 114.

[0090] At 901, the method may comprise obtaining a surface model of a rock surface.

[0091] At 902, the method may comprise determining, based on the surface model, whether a mesh can be installed on a planned position of the mesh on the rock surface without violating at least one deformation parameter of the mesh.

[0092] At 903, the method may comprise determining to refrain from installation of the mesh on the planned position of the mesh, in response to determining that the mesh can not be installed on the planned position of the mesh without violating the at least one deformation parameter.

[0093] The method may be performed by mesh controller 114, mesh installation rig 100, or remote mesh control device 200, for example based on program code 806, when executed by processor 802. Various examples of the methods are explained above with regard to functionalities of mesh controller 114, mesh installation rig 100, and/or remote mesh control device 200, in addition to the example embodiments listed below. It should be understood that example embodiments described may be combined in different ways unless explicitly disallowed.

[0094] According to an example embodiment of the third aspect, the method may comprise: adjusting the planned position of the mesh such that the mesh can be installed on the rock surface without violating the at least one deformation parameter, adjust a planned position of at least one fastener configured to fasten the mesh on the rock surface such that the mesh can be installed on the rock surface without violating the at least one deformation parameter, adjusting a distance of the mesh from the rock surface at the planned or adjusted position of the at least one fastener such that the mesh can be installed on the rock surface without violating the at least one deformation parameter, and/or configuring another mesh to be installed on the rock surface instead of the mesh, in response to determining that the other mesh can be installed on the planned position of the mesh without violating at least one deformation parameter of the other mesh.

[0095] According to an example embodiment of the third aspect, the method may comprise: determining at least one of an actual position of the at least one mesh on the rock surface or an actual position of the at least

one fastener on the rock surface; and transmitting at least one of an indication of the actual position of the at least one mesh or an indication of the actual position of the at least one fastener over an internal communication interface of the apparatus or to a device external to the apparatus.

[0096] According to an example embodiment of the third aspect, the method may comprise: obtaining a meshing plan indicative of at least one of the planned position of the mesh or the planned position of at least one fastener; and determining at least one of the planned position of the mesh or the planned position of at least one fastener based on the meshing plan.

[0097] According to an example embodiment of the third aspect, the method may comprise: updating the meshing plan based on the adjustment of the planned position of the mesh and/or the planned position of the at least one fastener.

[0098] According to an example embodiment of the third aspect, the method may comprise: controlling installation of the mesh on the planned or adjusted position of the mesh, in response to determining that the mesh can be installed on the planned position of the mesh without violating the at least one deformation parameter.

[0099] According to an example embodiment of the third aspect, wherein the at least one deformation parameter comprises at least one of the following: an allowed elongation of at least one part of the mesh, an allowed bending radius for the at least one part of the mesh, or an allowed pressing force.

[0100] According to an example embodiment of the third aspect, the method may comprise: detecting a breakage of the mesh during or after installation of the mesh on the rock surface; and controlling installation of another mesh at a position of the breakage of the mesh.

[0101] According to an example embodiment of the third aspect, the surface model is based on scanning data of the rock surface.

[0102] According to an example embodiment of the third aspect, the method may comprise: obtaining the scanning data from at least one of the following: a camera, a radio detection and ranging sensor, a light detection and ranging sensor laser, or a device configured to physically probe the rock surface.

[0103] According to an example embodiment of the third aspect, the method may comprise: applying a smoothing filter on the scanning data to obtain the surface model.

[0104] According to a fourth aspect, an apparatus may comprise means for performing the method according to the third aspect, or any example embodiment(s) thereof.

[0105] According to a fifth aspect, a computer program, a computer program product, or a (non-transitory) computer-readable medium may comprise instructions which, when executed by an apparatus, cause the apparatus at least to perform the method according to the third aspect, or any example embodiment(s) thereof.

[0106] Although the subject matter has been described

in language specific to structural features and/or acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as examples of implementing the claims and other equivalent features and acts are intended to be within the scope of the claims.

[0107] It will be understood that the benefits and advantages described above may relate to one embodiment or may relate to several embodiments. The embodiments are not limited to those that solve any or all of the stated problems or those that have any or all of the stated benefits and advantages. It will further be understood that reference to 'an' item may refer to one or more of those items.

[0108] The steps or operations of the methods described herein may be carried out in any suitable order, or simultaneously where appropriate. Additionally, individual blocks may be deleted from any of the methods without departing from the scope of the subject matter described herein. Aspects of any of the example embodiments described above may be combined with aspects of any of the other example embodiments described to form further example embodiments without losing the effect sought.

[0109] The term 'comprising' is used herein to mean including the method, blocks, or elements identified, but that such blocks or elements do not comprise an exclusive list and a method or apparatus may contain additional blocks or elements.

[0110] As used herein, "at least one of the following: <a list of two or more elements>" and "at least one of <a list of two or more elements>" and similar wording, where the list of two or more elements are joined by "and" or "or", mean at least any one of the elements, or at least any two or more of the elements, or at least all the elements. Term "or" may be understood to also cover a case where both of the items separated by "or" are included. Hence, "or" may be understood as an inclusive "or" rather than an exclusive "or".

[0111] Although subjects may be referred to as 'first' or 'second' subjects, this does not necessarily indicate any order or importance of the subjects. Instead, such attributes may be used solely for the purpose of making a difference between subjects.

[0112] It will be understood that the above description is given by way of example only and that various modifications may be made by those skilled in the art. The above specification, examples and data provide a complete description of the structure and use of exemplary embodiments. Although various embodiments have been described above with a certain degree of particularity, or with reference to one or more individual embodiments, those skilled in the art could make numerous alterations to the disclosed embodiments without departing from scope of this specification.

Claims

1. An apparatus for controlling mesh installation, the apparatus comprising:

at least one processor; and
at least one memory including computer program code, the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus at least to:

obtain a surface model of a rock surface;
determine, based on the surface model, whether a mesh can be installed on a planned position of the mesh on the rock surface without violating at least one deformation parameter of the mesh; and
determine to refrain from installation of the mesh on the planned position of the mesh, in response to determining that the mesh can not be installed on the planned position of the mesh without violating the at least one deformation parameter.

2. The apparatus according to claim 1, wherein the computer program code is further configured to, with the at least one processor, cause the apparatus to:

adjust the planned position of the mesh such that the mesh can be installed on the rock surface without violating the at least one deformation parameter,
adjust a planned position of at least one fastener configured to fasten the mesh on the rock surface such that the mesh can be installed on the rock surface without violating the at least one deformation parameter,
adjust a distance of the mesh from the rock surface at the planned or adjusted position of the at least one fastener such that the mesh can be installed on the rock surface without violating the at least one deformation parameter, and/or
configure another mesh to be installed on the rock surface instead of the mesh, in response to determining that the other mesh can be installed on the planned position of the mesh without violating at least one deformation parameter of the other mesh.

3. The apparatus according claim 2, wherein the computer program code is further configured to, with the at least one processor, cause the apparatus to:

determine at least one of an actual position of the at least one mesh on the rock surface or an actual position of the at least one fastener on the rock surface; and

- transmit at least one of an indication of the actual position of the at least one mesh or an indication of the actual position of the at least one fastener over an internal communication interface of the apparatus or to a device external to the apparatus.
4. The apparatus according to claim 2 or 3, wherein the computer program code is further configured to, with the at least one processor, cause the apparatus to:
- obtain a meshing plan indicative of at least one of the planned position of the mesh or the planned position of at least one fastener; and determine at least one of the planned position of the mesh or the planned position of at least one fastener based on the meshing plan.
5. The apparatus according claim 4, wherein the computer program code is further configured to, with the at least one processor, cause the apparatus to: update the meshing plan based on the adjustment of the planned position of the mesh and/or the planned position of the at least one fastener.
6. The apparatus according to any of claims 1 to 5, wherein the computer program code is further configured to, with the at least one processor, cause the apparatus to: control installation of the mesh on the planned or adjusted position of the mesh, in response to determining that the mesh can be installed on the planned position of the mesh without violating the at least one deformation parameter.
7. The apparatus according to any of claims 1 to 6, wherein the at least one deformation parameter comprises at least one of the following:
- an allowed elongation of at least one part of the mesh,
an allowed bending radius for the at least one part of the mesh, or
an allowed pressing force.
8. The apparatus according to any of claims 1 to 7, wherein the computer program code is further configured to, with the at least one processor, cause the apparatus to:
- detect a breakage of the mesh during or after installation of the mesh on the rock surface; and control installation of another mesh at a position of the breakage of the mesh.
9. The apparatus according to any of claims 1 to 8, wherein the surface model is based on scanning data of the rock surface.
10. The apparatus according to claim 9, wherein the computer program code is further configured to, with the at least one processor, cause the apparatus to: obtain the scanning data from at least one of the following: a camera, a radio detection and ranging sensor, a light detection and ranging sensor laser, or a device configured to physically probe the rock surface.
11. The apparatus according to claim 9 or 10, wherein the computer program code is further configured to, with the at least one processor, cause the apparatus to: apply a smoothing filter on the scanning data to obtain the surface model.
12. A mesh installation rig comprising the apparatus according to any of claims 1 to 11.
13. A method, comprising:
- obtaining a surface model of a rock surface; determining, based on the surface model, whether a mesh can be installed on a planned position of the mesh on the rock surface without violating at least one deformation parameter of the mesh; and determining to refrain from installation of the mesh on the planned position of the mesh, in response to determining that the mesh can not be installed on the planned position of the mesh without violating the at least one deformation parameter.
14. The method according to claim 13, wherein the computer program code is further configured to, with the at least one processor, cause the apparatus to:
- adjusting the planned position of the mesh such that the mesh can be installed on the rock surface without violating the at least one deformation parameter,
adjusting a planned position of at least one fastener configured to fasten the mesh on the rock surface such that the mesh can be installed on the rock surface without violating the at least one deformation parameter,
adjusting a distance of the mesh from the rock surface at the planned or adjusted position of the at least one fastener such that the mesh can be installed on the rock surface without violating the at least one deformation parameter, and/or configuring another mesh to be installed on the rock surface instead of the mesh, in response to determining that the other mesh can be installed on the planned position of the mesh without violating at least one deformation parameter of the other mesh.

15. A computer program comprising instructions which, when executed by an apparatus, cause the apparatus at least to:

obtain a surface model of a rock surface; 5
determine, based on the surface model, whether
a mesh can be installed on a planned position
of the mesh on the rock surface without violating
at least one deformation parameter of the mesh;
and 10
determine to refrain from installation of the mesh
on the planned position of the mesh, in response
to determining that the mesh can not be installed
on the planned position of the mesh without vi-
olating the at least one deformation parameter. 15

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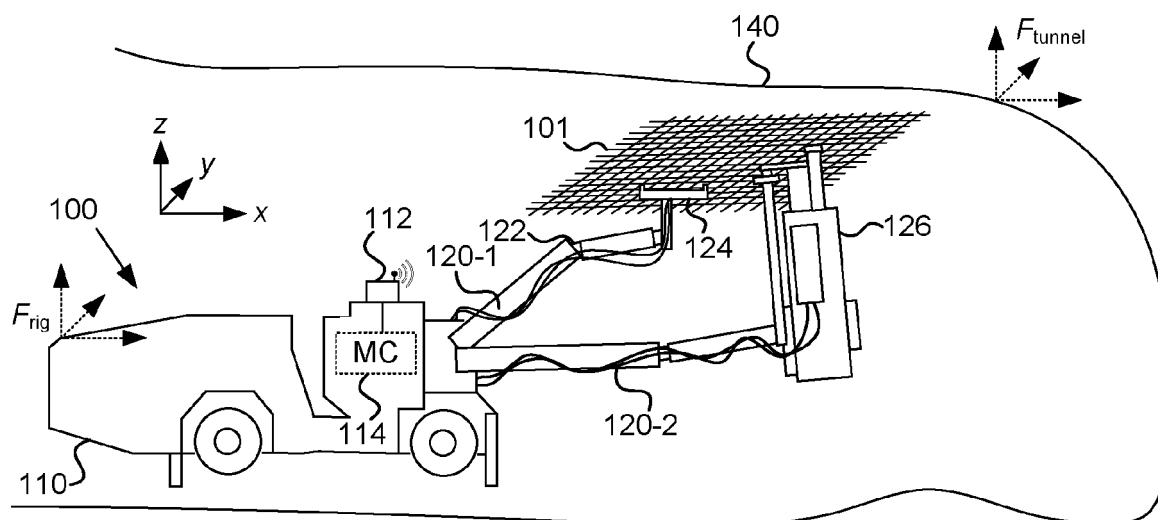


FIG. 1

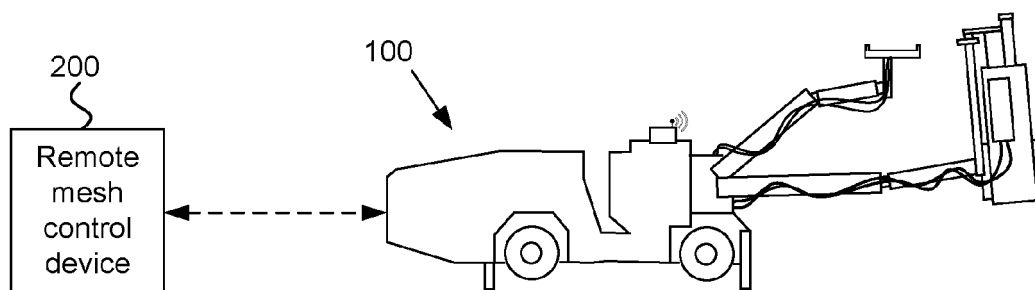


FIG. 2

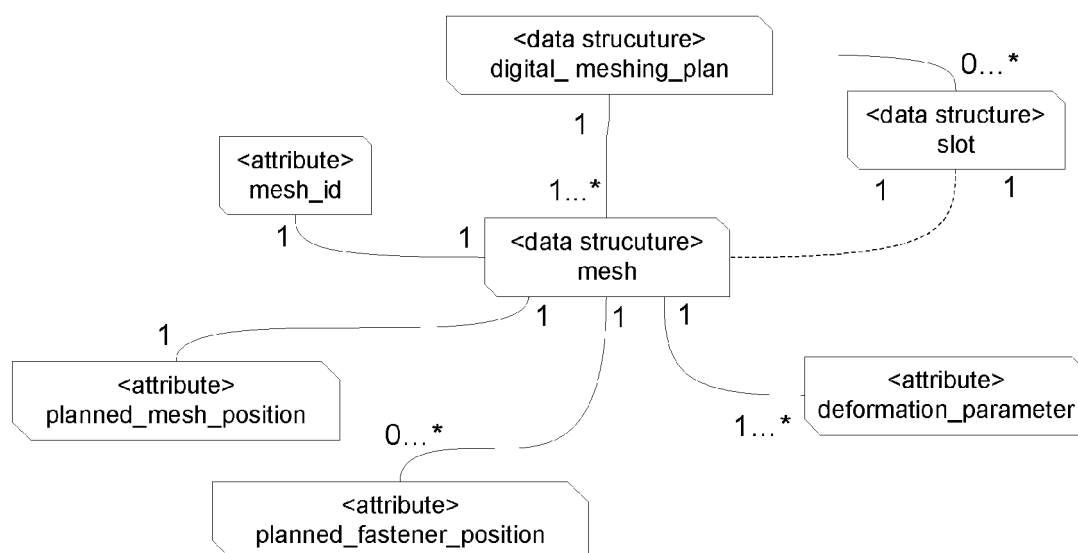


FIG. 3

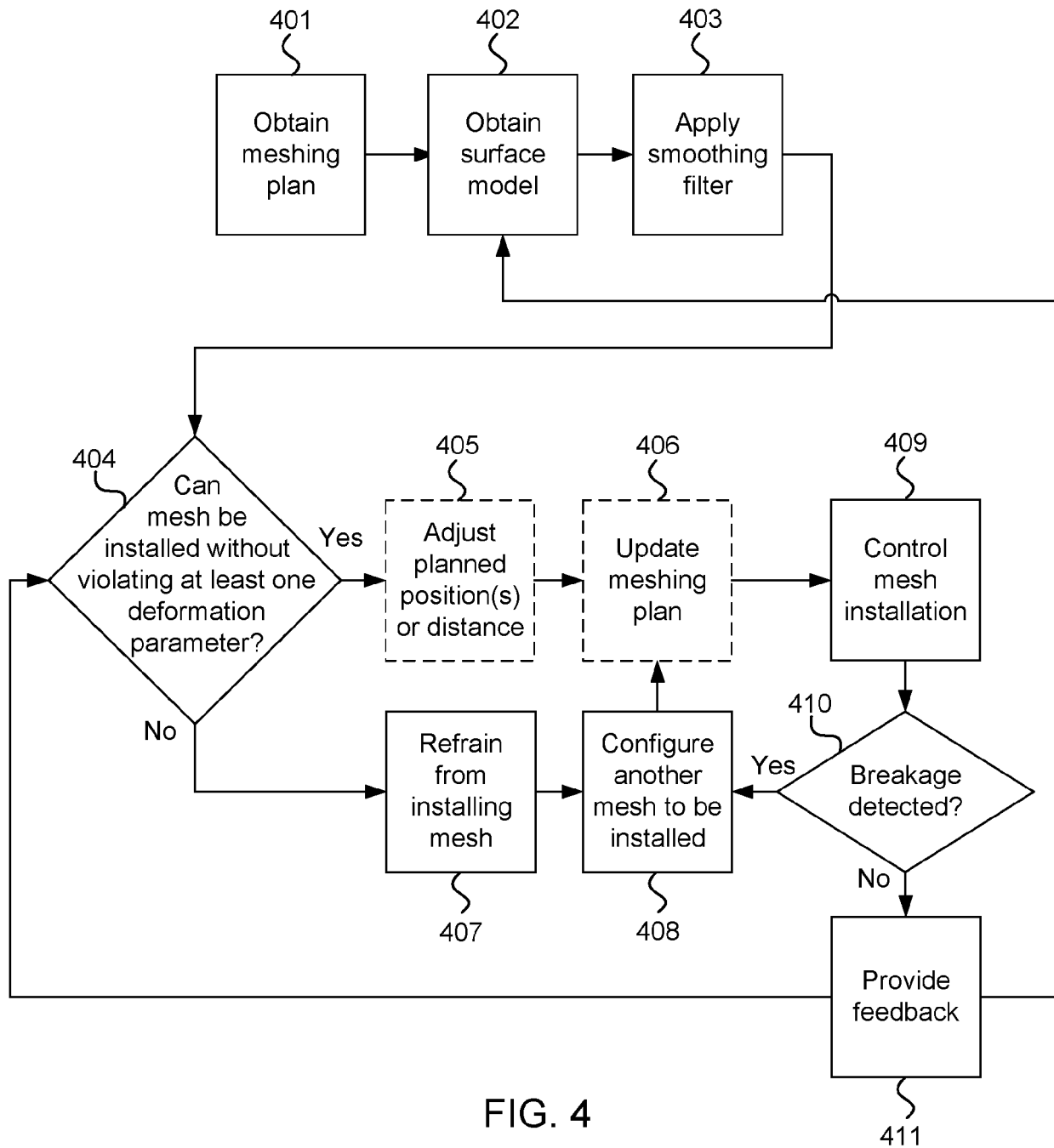


FIG. 4

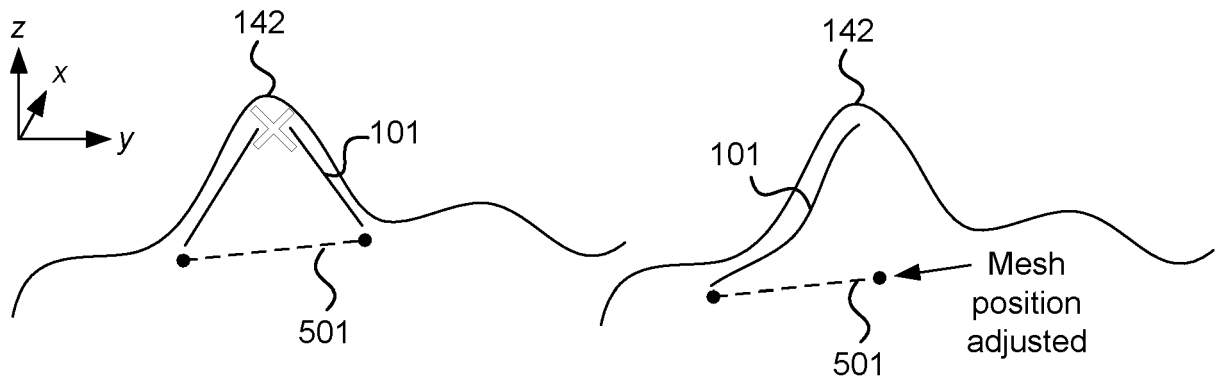


FIG. 5

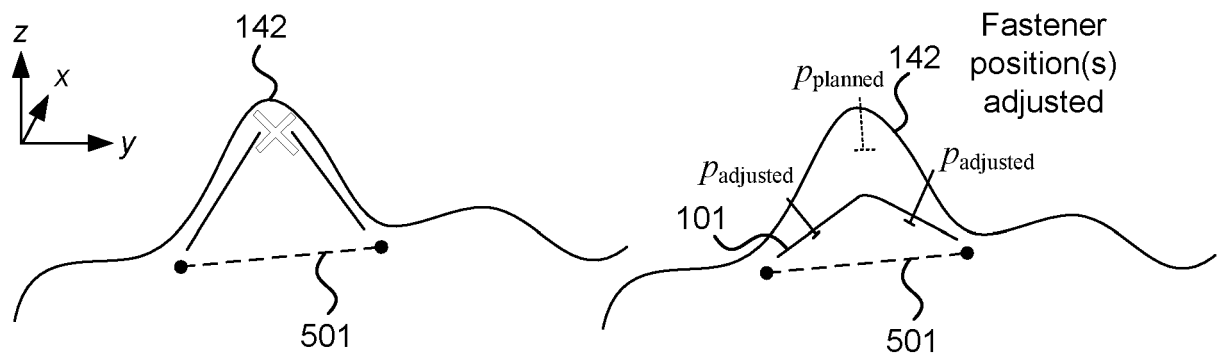


FIG. 6

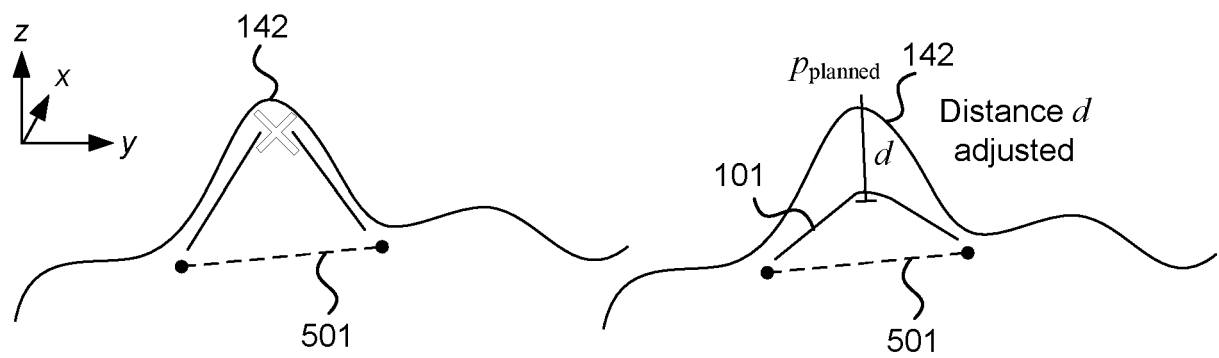


FIG. 7

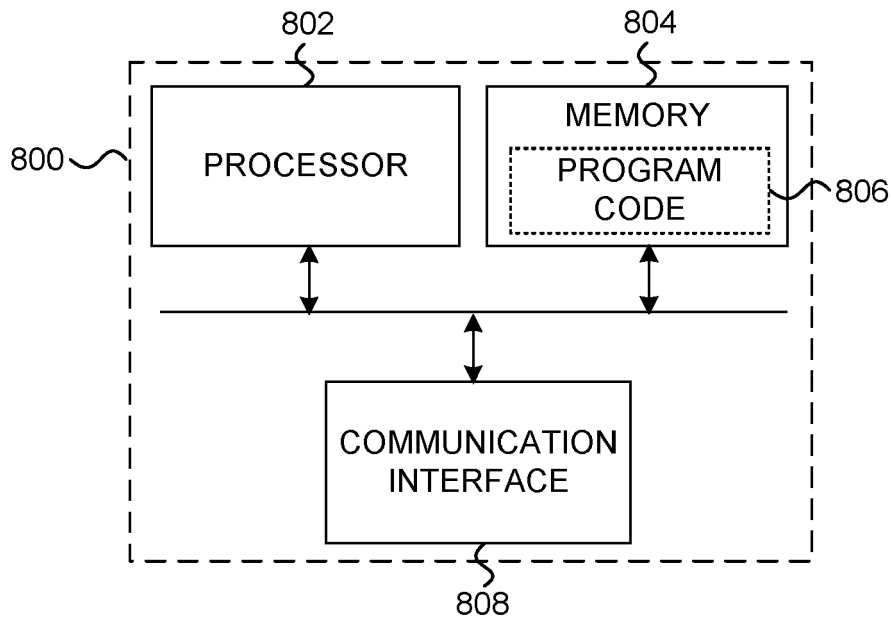


FIG. 8

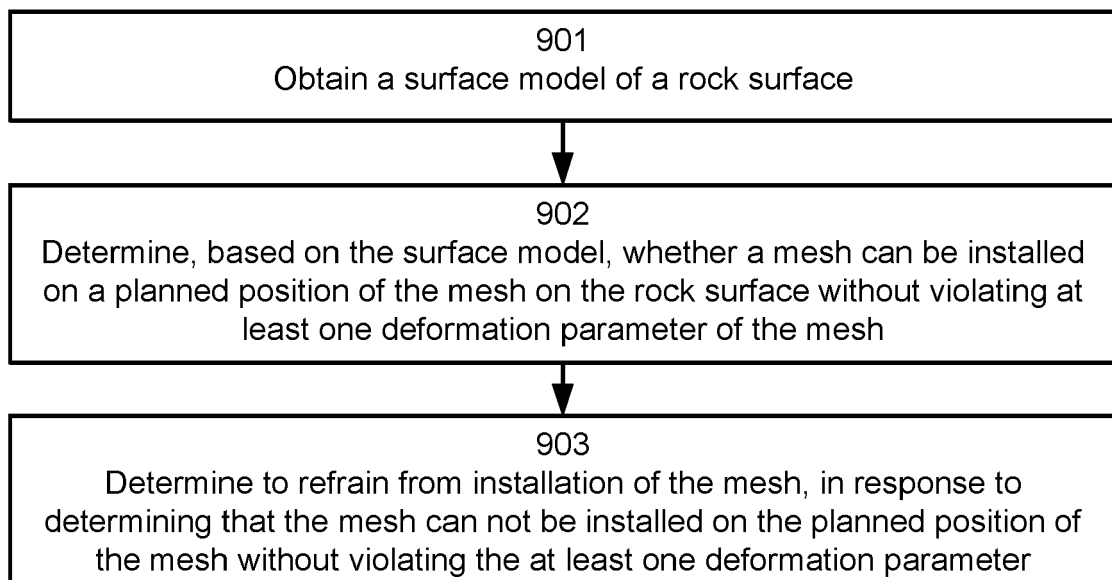


FIG. 9



EUROPEAN SEARCH REPORT

Application Number

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 02/18749 A1 (COMMW SCIENT IND RES ORG [AU]; CUNNINGHAM JOCK BERNARD [AU] ET AL.) 7 March 2002 (2002-03-07)	13, 14	INV. E21D11/00 E21D11/15 E21D19/00
A	* figure 4 * * page 2, lines 21-35 * * page 3, lines 3-15, 26-30 * * page 4, line 22 - page 5, line 3 * * page 5, lines 16-18, 22-25 * * page 6, lines 16-18 * * page 7, lines 12-14 * * page 11, line 21 - page 12, line 25 * -----	1-12, 15	
			TECHNICAL FIELDS SEARCHED (IPC)
			E21D
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 30 September 2023	Examiner Maukonen, Kalle
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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30-09-2023

10	Patent document cited in search report	Publication date	Patent family member(s)	Publication date
	WO 0218749	A1	07-03-2002	NONE
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