

Claims

1. A method for detecting condition of a bolt on a bolted structure, the method comprising:
inputting an image comprising a bolt for detection;
5 detecting that the bolt is a circular or hexagonal bolt;
performing perspective distortion correction of the bolt in the image to eliminate error arising from angle of capture of the image;
in case that the bolt is detected to be a circular bolt, performing wirelock detection to detect presence of wirelock between more than one detected bolts in the image; and
10 in case that the bolt is detected to be a hexagonal bolt, performing crimp detection to detect whether each bolt edge of the bolt is crimped by a crimping plate or is missing the crimping plate.
2. The method as claimed in claim 1, wherein the method further comprises:
15 using pre-trained classifiers of an Artificial Intelligence (A.I.) system for the wirelock detection and/or the crimp detection.
3. The method as claimed in claim 1, wherein the method further comprises:
detecting whether the bolt is a circular bolt by applying circular hough transform on the image.
- 20 4. The method as claimed in claim 3, wherein the method further comprises:
when circular bolt is detected, fitting boundary of the bolt to an elliptical outline, parameterised by centre of the bolt, orientation of the bolt, major and minor axes of the bolt;
determining an affine transform to represent a transform of a circular outline to the fitted elliptical outline;
25 normalising the affine transform, and cropping around the boundary of the bolt to generate sub-images of the bolt; and
comparing the generated sub-images of the bolt to a database of labelled images of bolts to classify status of the bolt to be wirelocked or otherwise.
- 30 5. The method as claimed in claim 4, wherein classification of status of the detected circular bolt is based on rotation invariant feature extraction that involves providing training images of circular bolt captured at different angles for Artificial Intelligence (A.I.) training.
- 35 6. The method as claimed in claim 1, wherein the method further comprises:
applying collinearity measure and using a line detector to detect status of wirelock or wirelocks between detected bolts to be straight or otherwise.
7. The method as claimed in claim 1, wherein the method further comprises:
40 detecting whether the bolt is a hexagonal bolt by:
applying a line segment detector, which locate lines in the image that are candidates of bolt edges;
filtering the located candidates of bolt edges according to angles between each pair of located lines; and
estimating candidate hexagon or hexagons from the candidates of bolt edges, wherein a
45 perfect hexagon is created by estimating most probable parameters of the bolt's centre, rotation angle, and radius,
wherein success in locating lines in the image that are candidates of bolt edges, filtering of located candidates of bolt edges according to the angles, and estimation of candidate hexagon or hexagons leads to detection of the hexagonal bolt.
- 50 8. The method as claimed in claim 7, wherein the method further comprises:
when hexagonal bolt is detected, calculating affine transform between the estimated perfect hexagon and the candidates of bolt edges;
finding line correspondences from the calculated affine transform to detect the bolt in the image;
55 and

- estimating perspective transformation from the found line correspondences to correct perspective distortion of the detected bolt in the image due to angle of capture of the image;
 extracting a number of sub-images of the detected bolt from the image by cropping regions outside of bolt edges of the detected bolt;
 5 normalising the extracted sub-images of the detected bolt;
 comparing the extracted sub-images of the detected bolt to a database of labelled images of bolts to classify a status of each bolt edge of the detected bolt to be crimped, uncrimped or is missing the crimping plate; and
 10 combining statuses of the bolt edges of the detected bolt to form a joint pattern to provide a final status of the hexagonal bolt.
9. The method as claimed in claim 2, wherein the method further comprises:
 using a line segment based registration algorithm to align images captured when the A.I. system is online to pre-collected images to obtain a spatial transformation representative of highest degree of alignment between images captured when the A.I. system is online and the pre-collected images, wherein the pre-collected images refer to images pre-collected for A.I. training in bolt edge and/or straight wirelock estimation and prediction; constructing a 3D model from the pre-collected images;
 15 estimating a geometric transform between two pre-collected images comprising bolts to detect; and
 20 transferring locations of features of the pre-collected images on the constructed 3D model to an image captured when the A.I. system is online based on the estimated geometric transform; and
 using the spatial transformation and the estimated geometric transform to determine exact 3D location of features in an image captured when the A.I. system is online to facilitate the wirelock detection and/or the crimp detection.
- 25 10. An apparatus for detecting condition of a bolt on a bolted structure, wherein the apparatus comprises:
 a processor configured to execute instructions to control the apparatus to:
 input an image comprising a bolt for detection;
 30 detect that the bolt is a circular or hexagonal bolt;
 perform perspective distortion correction of the bolt in the image to eliminate error arising from angle of capture of the image;
 in case that the bolt is detected to be a circular bolt, perform wirelock detection to detect presence of wirelock between more than one detected bolts in the image; and
 35 in case that the bolt is detected to be a hexagonal bolt, perform crimp detection to detect whether each bolt edge of the bolt is crimped by a crimping plate or is missing the crimping plate.
11. The apparatus as claimed in claim 10, wherein the apparatus is controllable to:
 40 use pre-trained classifiers of an Artificial Intelligence (A.I.) system for the wirelock detection and/or the crimp detection.
12. The apparatus as claimed in claim 10, wherein the apparatus is controllable to:
 detect whether the bolt is a circular bolt by applying circular hough transform on the image.
- 45 13. The apparatus as claimed in claim 12, wherein the apparatus is controllable to:
 when circular bolt is detected, fit boundary of the bolt to an elliptical outline, parameterised by centre of the bolt, orientation of the bolt, major and minor axes of the bolt;
 determine an affine transform to represent the transform of a circular outline to the fitted elliptical outline;
 50 normalise the affine transform, and crop around the boundary of the bolt to generate sub-images of the bolt; and
 compare the generated sub-images of the bolt to a database of labelled images of bolts to classify status of the bolt to be wirelocked or otherwise.

14. The apparatus as claimed in claim 13, wherein classification of status of the detected circular bolt is based on rotation invariant feature extraction that involves providing training images of circular bolt captured at different angles for Artificial Intelligence (A.I.) training.

5 15. The apparatus as claimed in claim 10, wherein the apparatus is controllable to:
 apply collinearity measure and use a line detector to detect status of wirelock or wirelocks between detected bolts to be straight or otherwise.

10 16. The apparatus as claimed in claim 10, wherein the apparatus is controllable to:
 detect whether the bolt is a hexagonal bolt by:
 applying a line segment detector, which locate lines in the image that are candidates of bolt edges;
 filtering the located candidates of bolt edges according to angles between each pair of located lines; and
15 estimating candidate hexagon or hexagons from the candidates of bolt edges, wherein a perfect hexagon is created by estimating most probable parameters of the bolt's centre, rotation angle, and radius,
 wherein success in locating lines in the image that are candidates of bolt edges, filtering of located candidates of bolt edges according to the angles, and/or estimation of candidate hexagon or hexagons leads to detection of the hexagonal bolt.
20

 17. The apparatus as claimed in claim 16, wherein apparatus is controllable to:
 when hexagonal bolt is detected, calculate affine transform between the estimated perfect hexagon and the candidates of bolt edges;
25 find line correspondences from the calculated affine transform to detect the bolt in the image; and estimate perspective transformation from the found line correspondences to correct perspective distortion of the detected bolt in the image due to angle of capture of the image;
 extract a number of sub-images of the detected bolt from the image by cropping regions outside of bolt edges of the detected bolt;
30 normalise the extracted sub-images of the detected bolt;
 compare the extracted sub-images of the detected bolt to a database of labelled images of bolts to classify a status of each bolt edge of the detected bolt to be crimped, uncrimped or is missing the crimping plate; and
 combine statuses of the bolt edges of the detected bolt to form a joint pattern to provide a final
35 status of the hexagonal bolt.

 18. The apparatus as claimed in claim 11, wherein the apparatus is controllable to:
 use a line segment based registration algorithm to align images captured when the A.I. system is online to pre-collected images to obtain a spatial transformation representative of highest degree of alignment between images captured when the A.I. system is online and the pre-collected images,
40 wherein the pre-collected images refer to images pre-collected for A.I. training in bolt edge and/or straight wirelock estimation and prediction;
 construct a 3D model from the pre-collected images;
 estimate a geometric transform between two pre-collected images comprising bolts to detect; and
45 transfer locations of features of the pre-collected images on the constructed 3D model to an image captured when the A.I. system is online based on the estimated geometric transform; and
 use the spatial transformation and the estimated geometric transform to determine exact 3D location of features in an image captured when the A.I. system is online to facilitate the wirelock detection and/or the crimp detection.
50