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An Image-based Algorithm for Automatic Detection of Loosened Bolts

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Contents

Research background

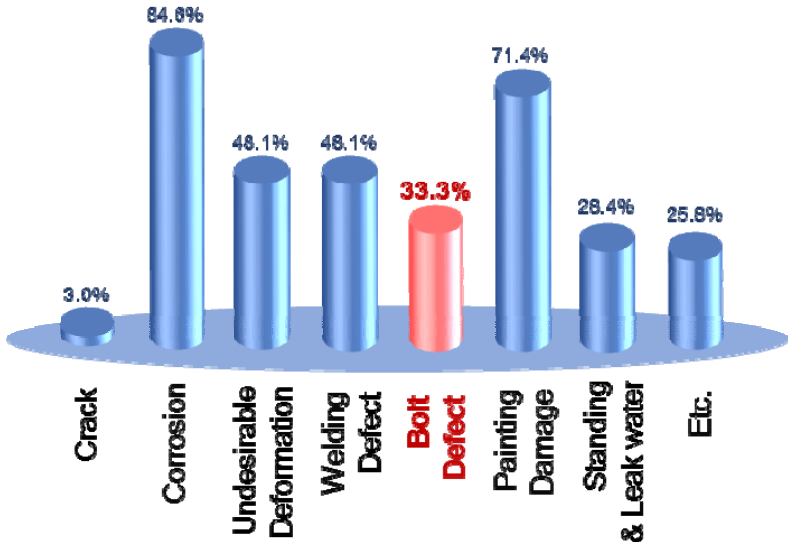
Bolt Defects

- ***Bolts*** are ***important elements*** to connect main members of steel structures, and insufficient preload leads to joint failure and reducing load carrying capacity.
- Korea Expressway Corporation investigated defects occurred in their own operating steel bridges:

  Bolt defects were occurred in ***33.3% of*** bridges.
- **Bolt-loosening detection is very important** to maintain the structural performance of the steel bridges.

Defect Occurrence Rate in Steel Bridges in Korea

$$\frac{\text{No. of Bridges with defects}}{\text{No. of Total Bridges}} \times 100\ (\%)$$



Source: http://sstl.cee.illinois.edu/papers/aeseancrisst15/219_Park_Image-Based.pdf

Traditional Inspection by Human

Advantages

- The simplest ways to detect bolt-loosening
- The most widely used methods for real steel bridges

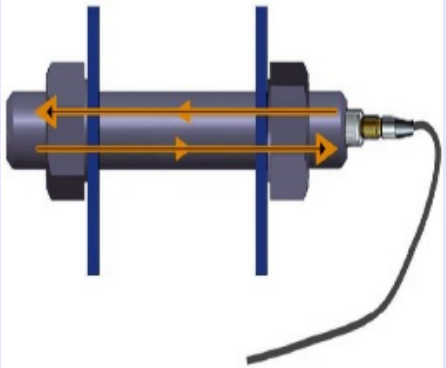
Disadvantage

- Cannot detect until bolts are completely loosened
- ***Depends on the inspector***'s experience and sense
- ***Time consuming and dangerous,*** especially the torque wrench method

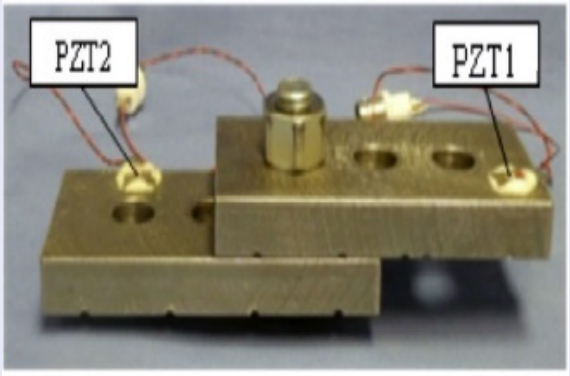
Image Source: https://qualitechirm.com/services/api-derrick-and-bolt-inspection-api-4g/

Inspection based on Smart Sensors

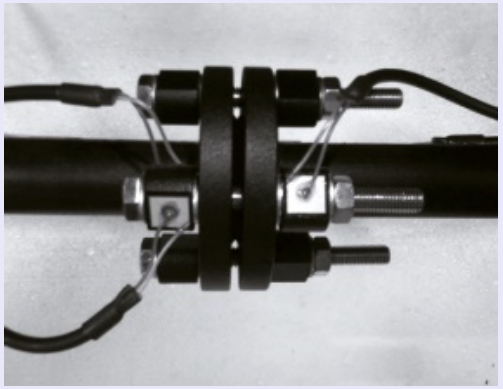
Acoustoelastic



Guided Wave



EM Impedance



Advantages

- Sensitive to small incipient damage
- Promising methods with high accuracy

Disadvantage

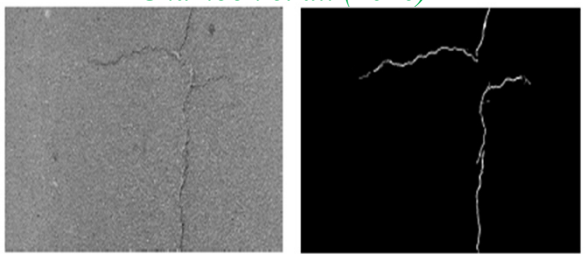
- Need many fixed sensors to cover all bolt joints
- Need ***high cost*** instruments to measure signals
- Need to consider ***ambient uncertainties*** such as noise, temperature, bonding condition, etc..

Image Source: https://doi.org/10.1590/1679-78254231

Image Processing Approach

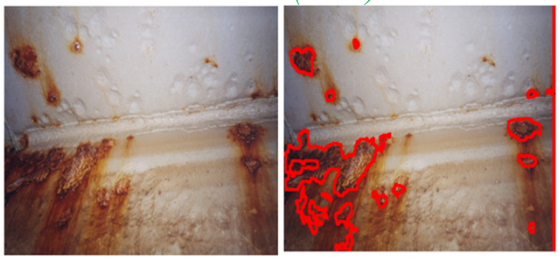
Crack Detection

Chambon et al. (2010)



Corrosion Detection

Ortiz et al. (2016)



Displacement Measurement

Lee et al. (2016)

Vision-based Bolt-loosening Detection

Hough Transform and SVM *(Cha et al. 2016)*

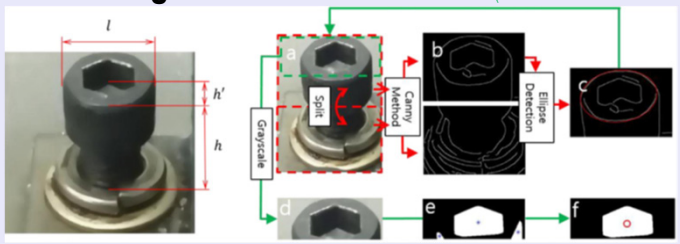
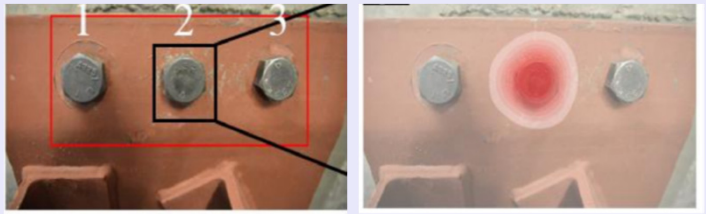


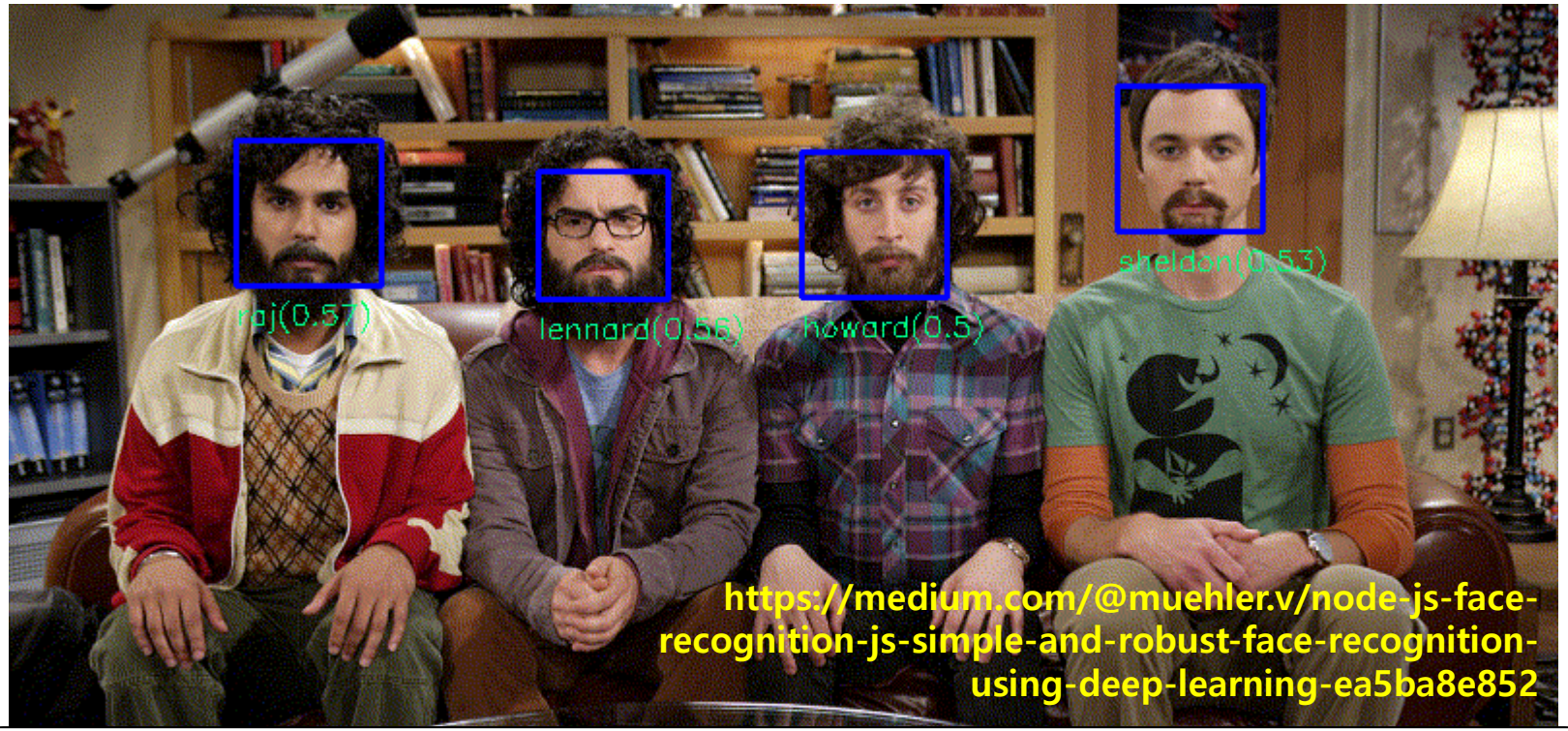
Image Registration *(Kong et al. 2018)*



Features

- Provide intuitive and scientific information
- Use low-cost and non-contact sensing
- Not affected by ambient uncertainty

Deep Learning-based Object Recognition



DeepFace Architecture (*Taigman et al. 2014*)

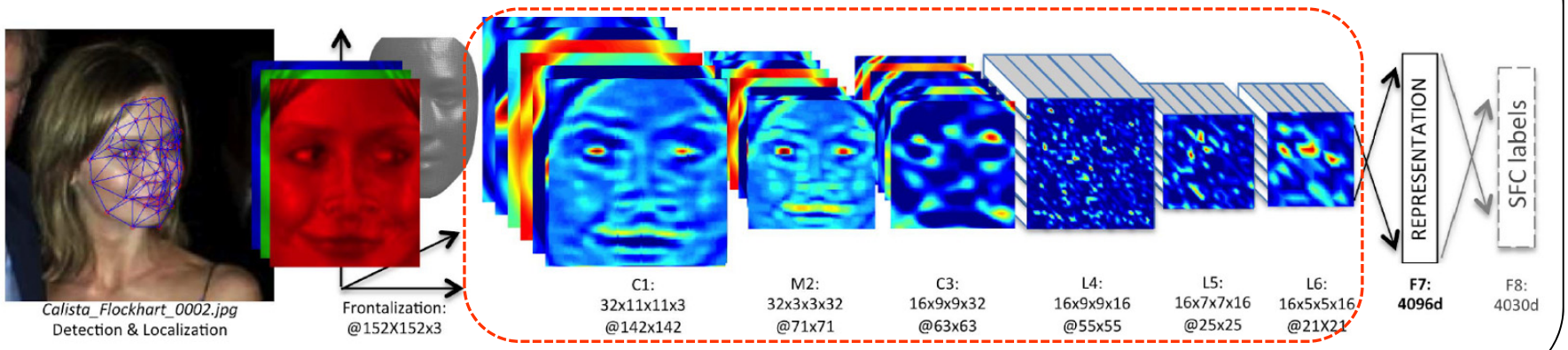
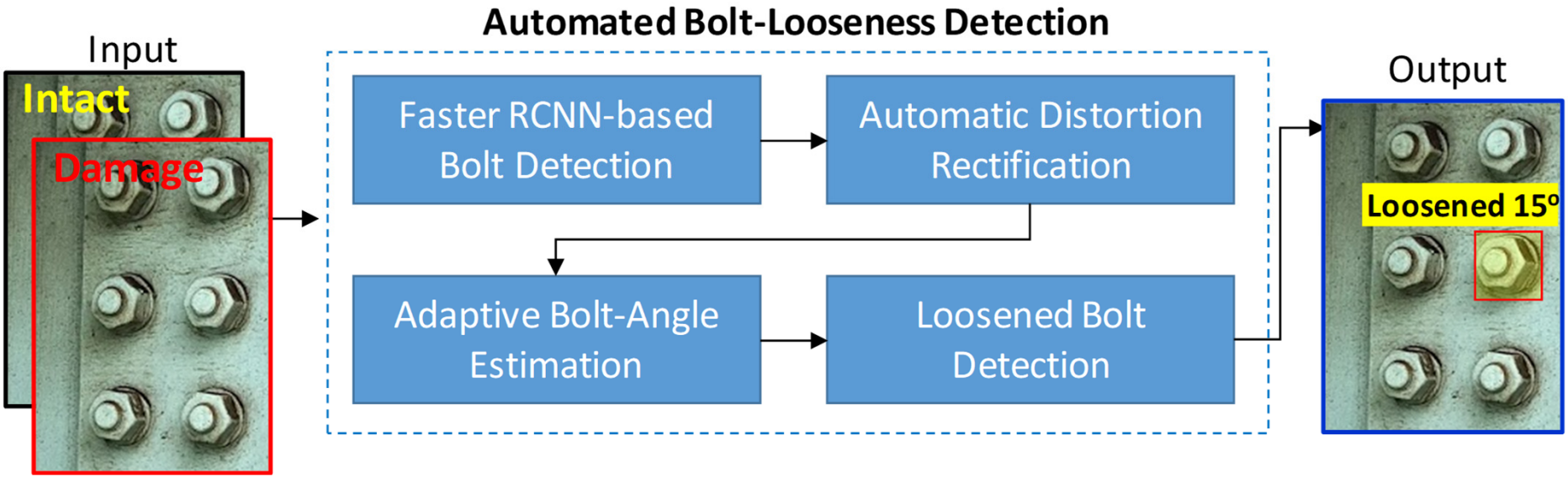


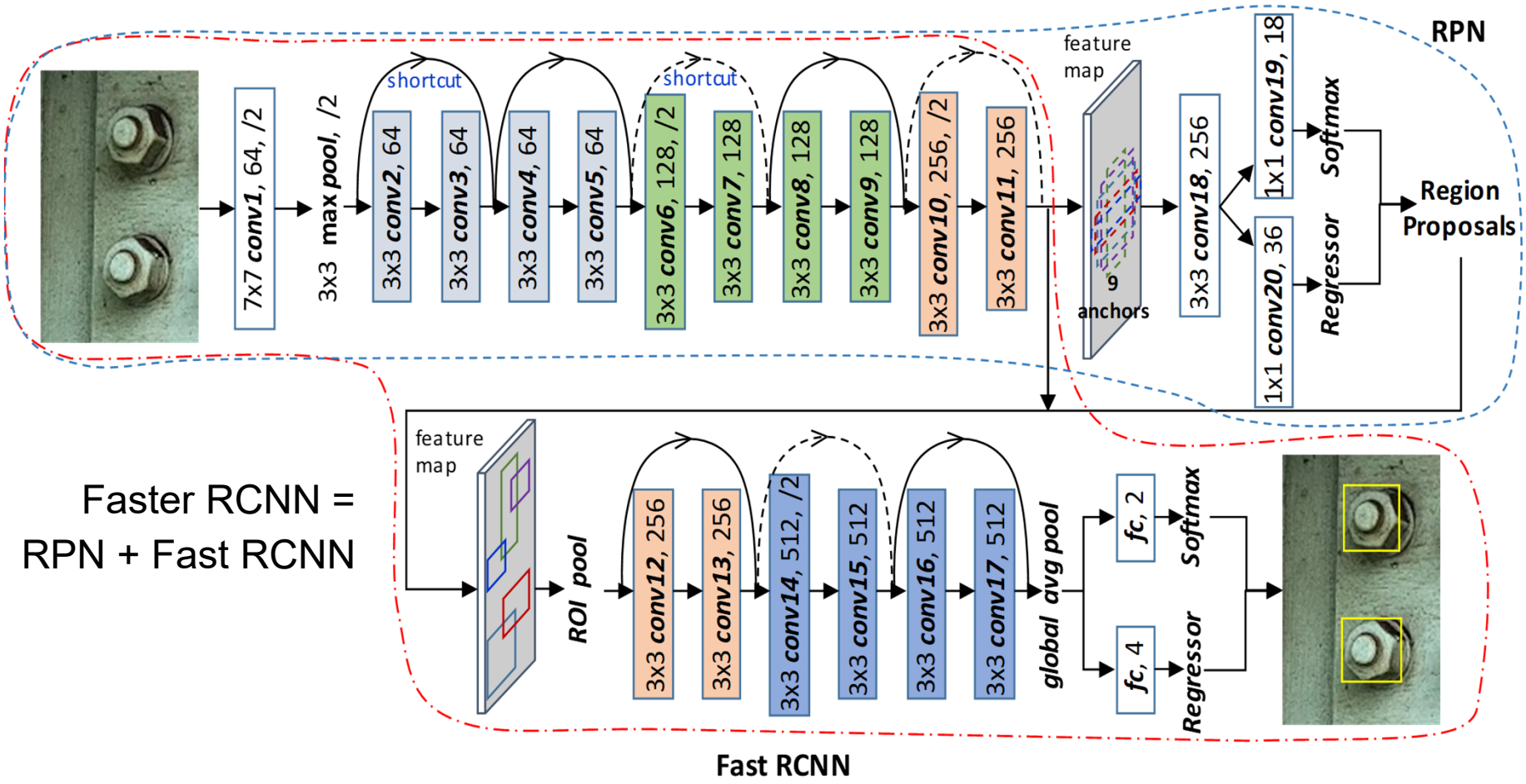
Image-based Bolt-looseness Detection Algorithm

The overall procedure of the automated image-based bolt-looseness monitoring method



The inputs are the digital images of a bolted connection captured before and after a loosening event and the outputs are the localization of loosened bolts in the images and bolt-looseness degrees. The method is composed of four modules: '*Faster RCNN-based bolt detection*', '*Automatic distortion rectification*', '*Adaptive bolt-angle estimation*', '*Loosened bolt detection*'.

The architecture of the ‘Faster RCNN-based bolt detection’ module



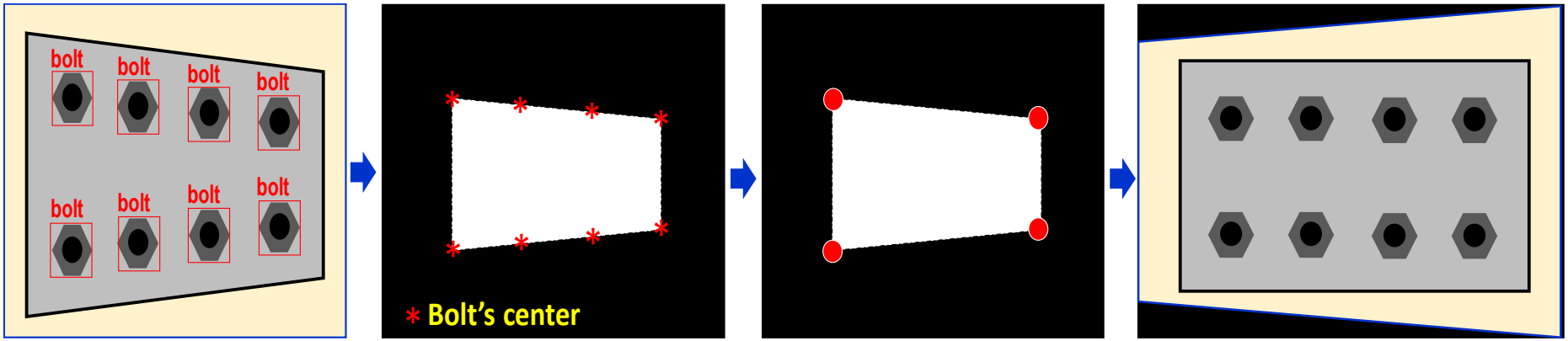
Faster RCNN =
RPN + Fast RCNN

RPN (regional proposal network) for generating object proposals

Fast RCNN for object classification

ResNet18 is modified for Faster RCNN

The procedure of the ‘Automatic distortion rectification’ module



Detecting bolts | Forming a boundary of bolts’ center | Detecting corners of the boundary | Correcting perspective distortion

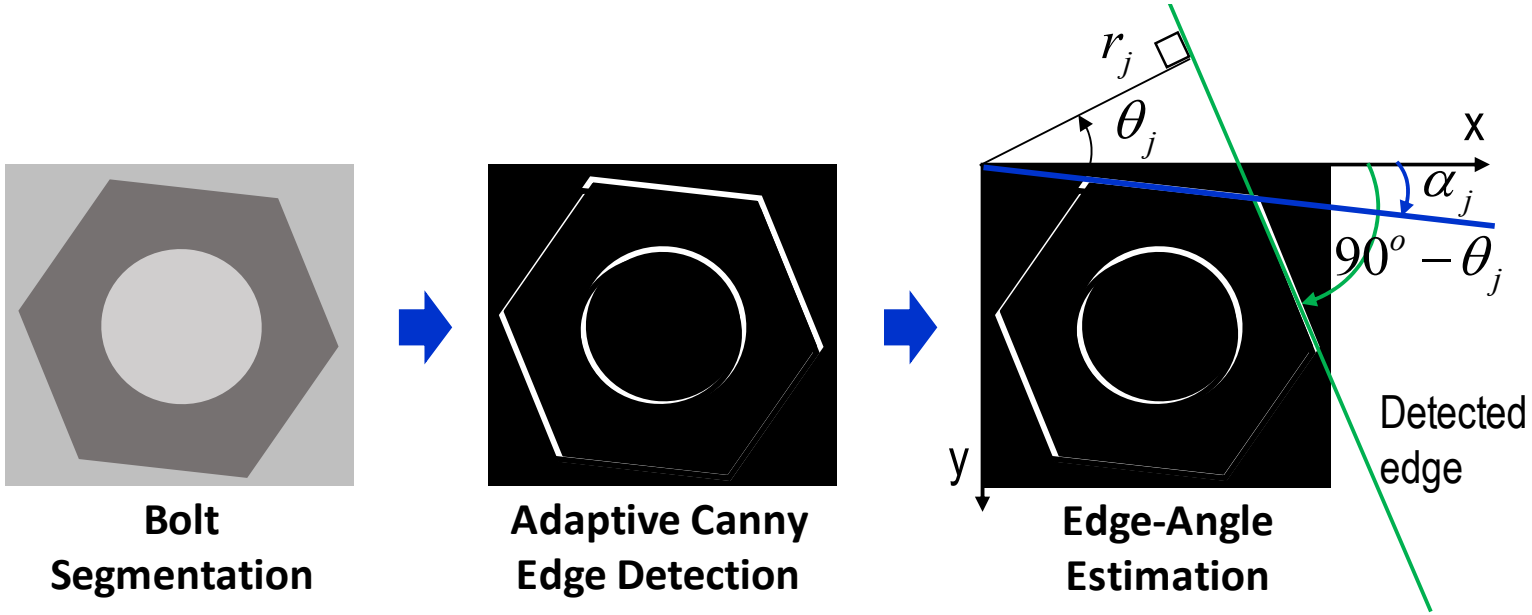
The module is composed of three steps:

(1) a boundary of the bolts’ center is formed using the alpha-shape algorithm;

(2) the four corner points of the formed boundary are detected using the Harris–Stephens corner detection algorithm;

(3) the connection image is corrected using the homography algorithm with the homography matrix computed using the four detected corner points

The procedure of the ‘Adaptive bolt-angle estimation’ module



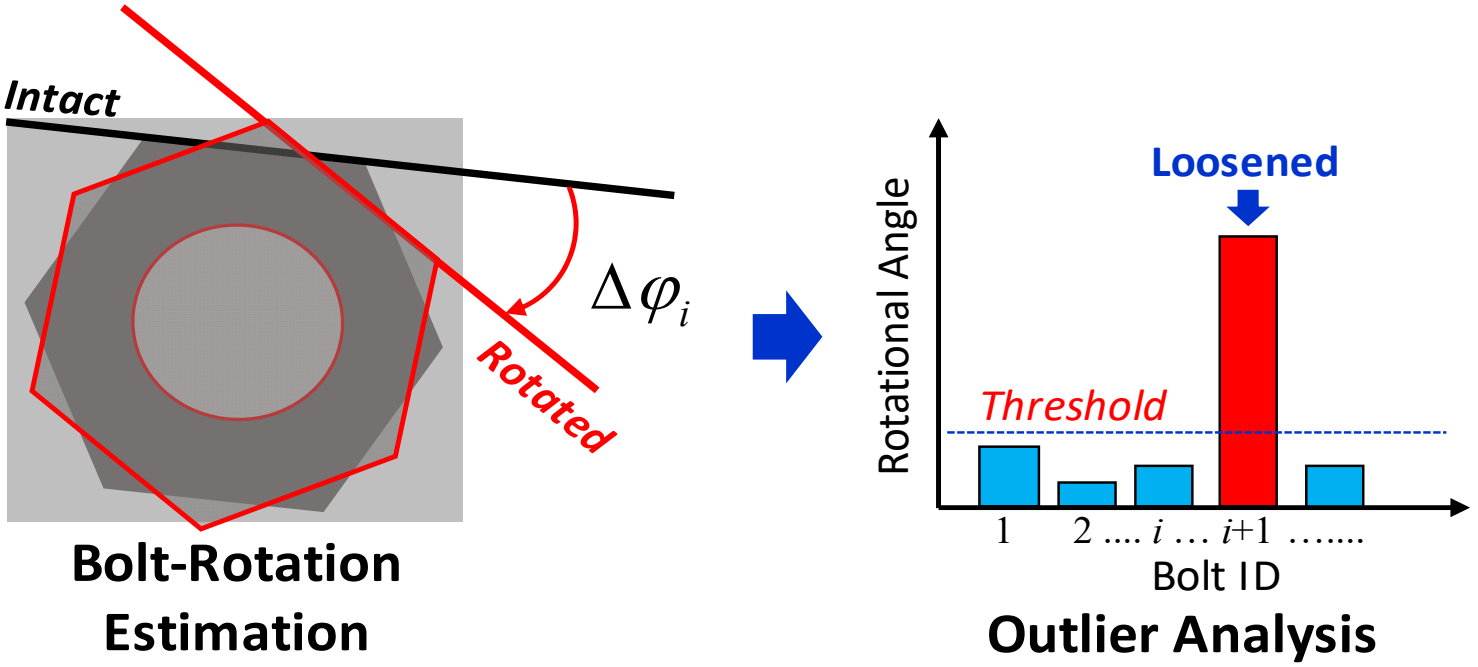
The module is composed of three steps:

(1) the perspective-corrected image is segmented into sub-images of individual bolts.

(2) the edges of the bolts in each sub-image are filtered by applying the Canny edge detection algorithm with adaptive thresholding.

(3) the angles of the bolts are automatically calculated using the Hough transform algorithm

The procedure of the ‘Loosened bolt detection’ module



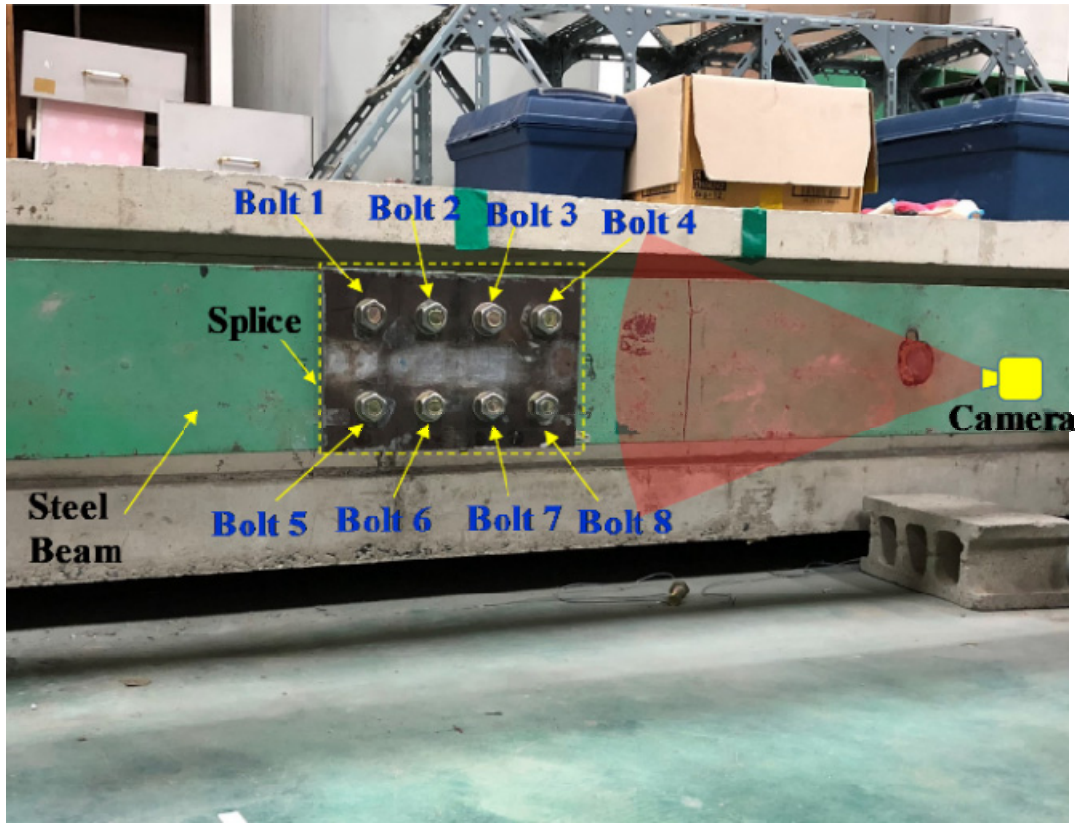
The module is composed of two steps:

(1) the angle of the rotated bolt is compared with the angle of the intact bolt.

(2) the loosened bolts in the connection are identified by comparing the loosening angles of the bolts with a threshold.

Experimental Verification

Experimental Setup

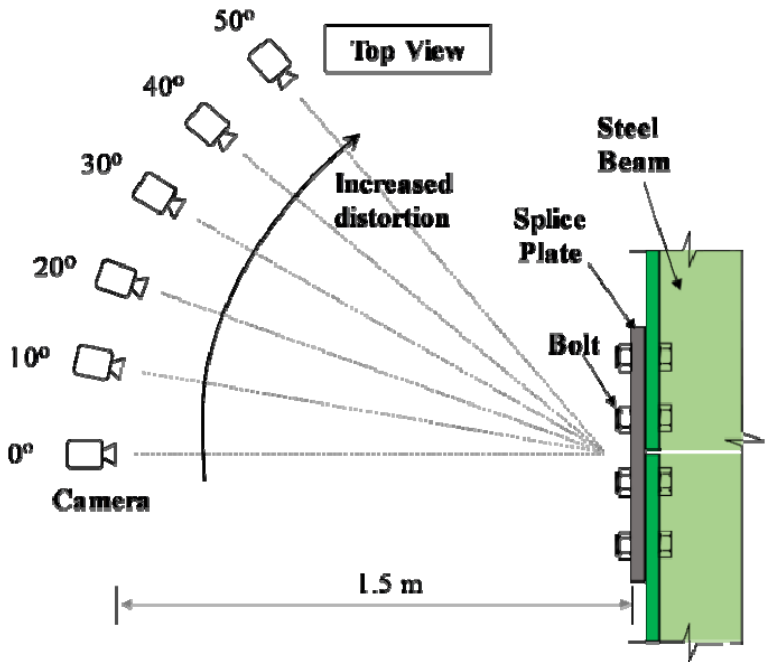


- The testing model is a steel splice joint having eight fastened bolts (Bolt 1 – Bolt 8, ϕ20) on a splice plate of 310 mm width × 200 mm height × 10 mm thickness.
- The imagery dataset was collected from the lab-scale model using the digital camera of iPhone X with 12 MP vision sensor, f/2.4 aperture, and 28 mm focal length.
- The collected images have a resolution of 4032 × 3024.

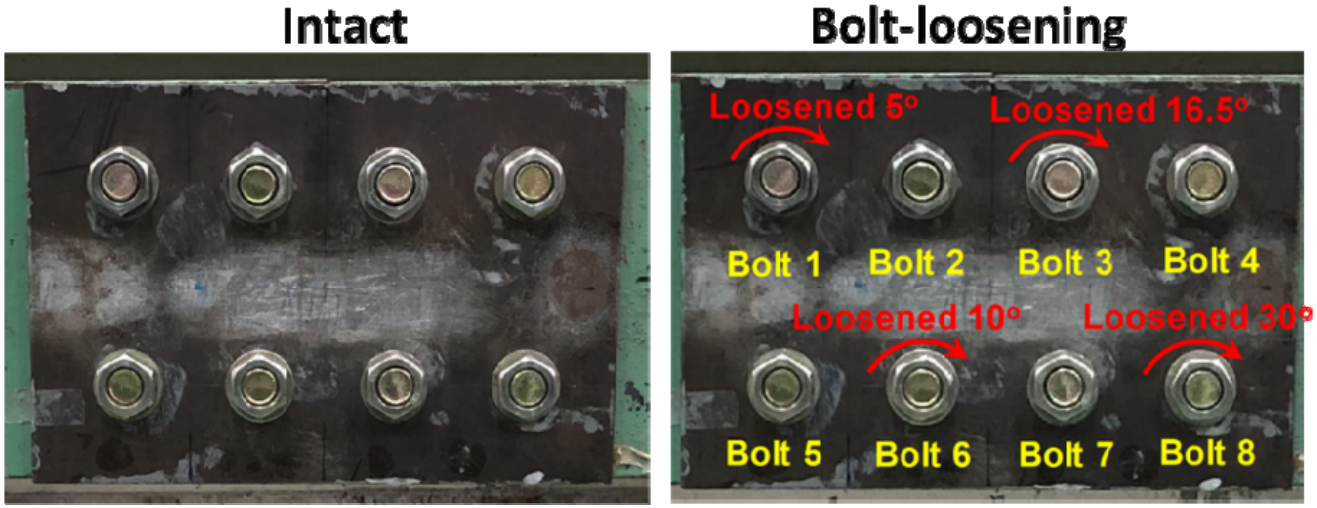
Experimental Setup

❑ **Perspective distortion test**

- Perspective angles: 0:10:50 degrees
- Shooting distance: 1.5 m



❑ **Bolt looseness test**



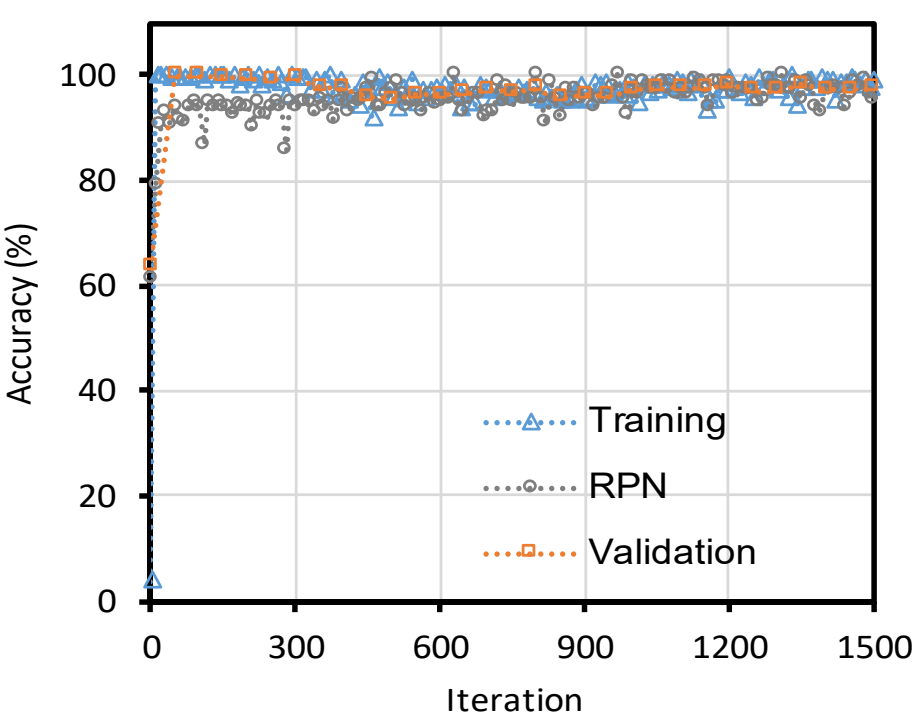
Data Preparation and Augmentation

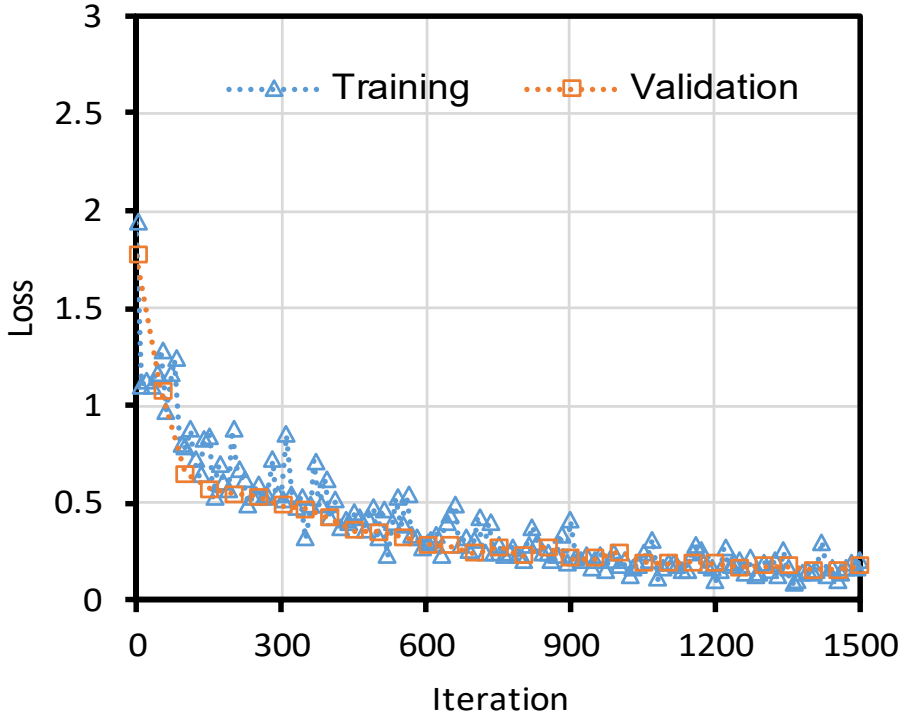
- Training + validation: 170 images (1360 labelled objects) and 30 images (240 labelled objects)
- Testing: 43 images (344 labelled objects).

Sample images of the database

Data augmentation

Training Process

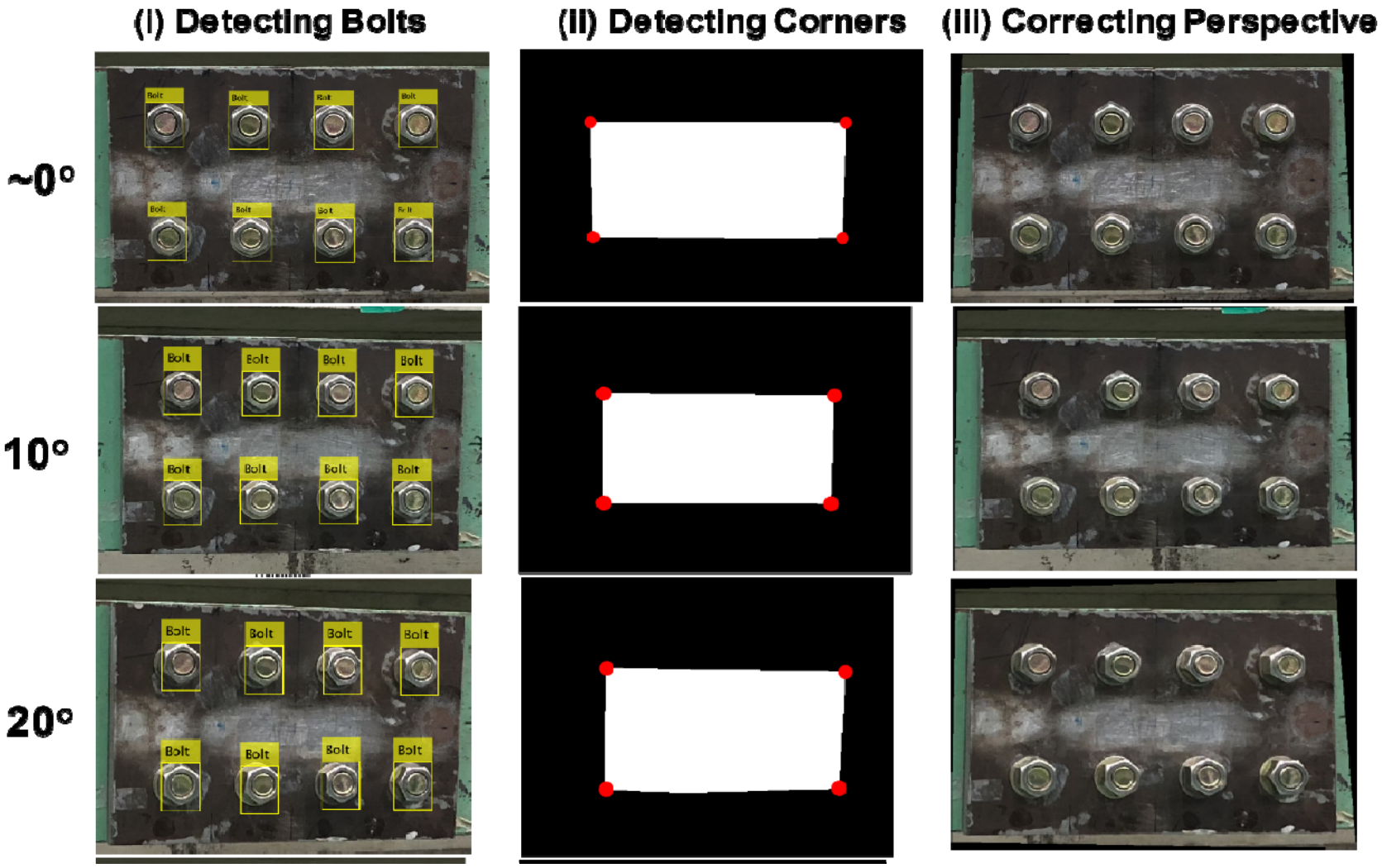




Use the open-source Faster RCNN library, CUDA, and Matlab on a desktop computer (Intel Core i7-8700 CPU @ 3.2 GHz (12 CPUs), 16 GB DDR4 memory, 2 GB GeForce GT 1030 GPU).

Result

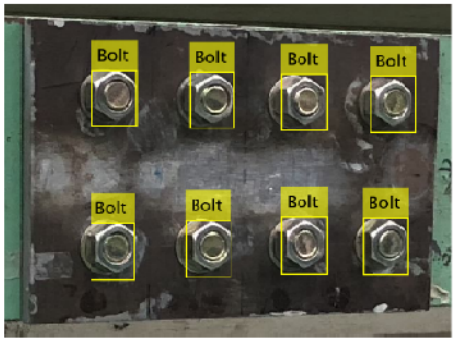
Perspective correction

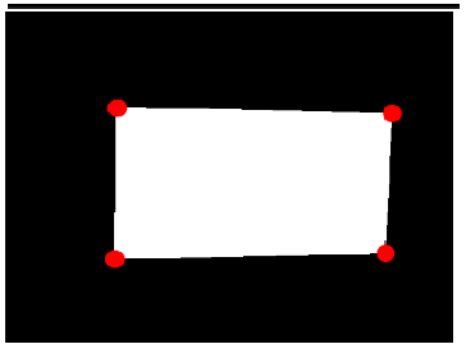


Result

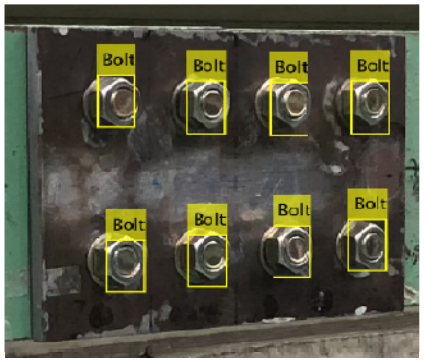
Perspective correction

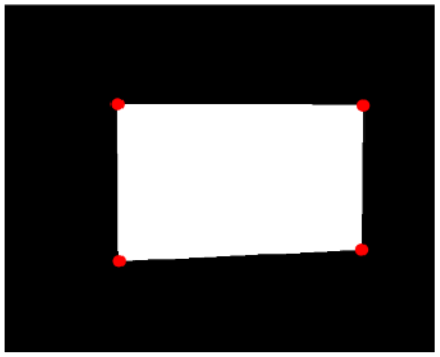
30°



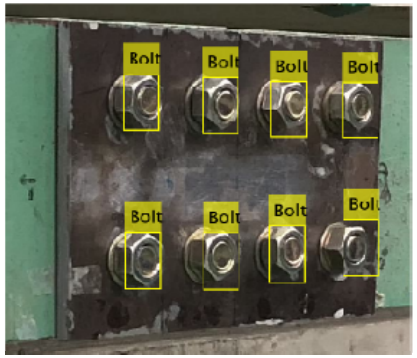


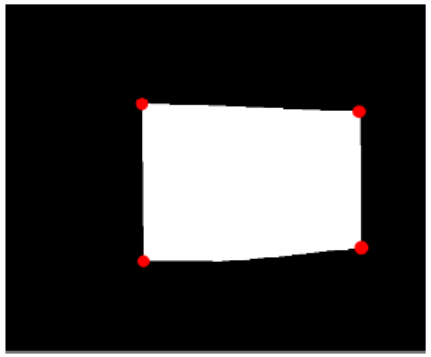
40°

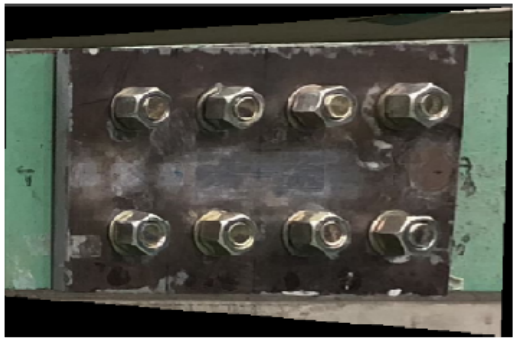




50°



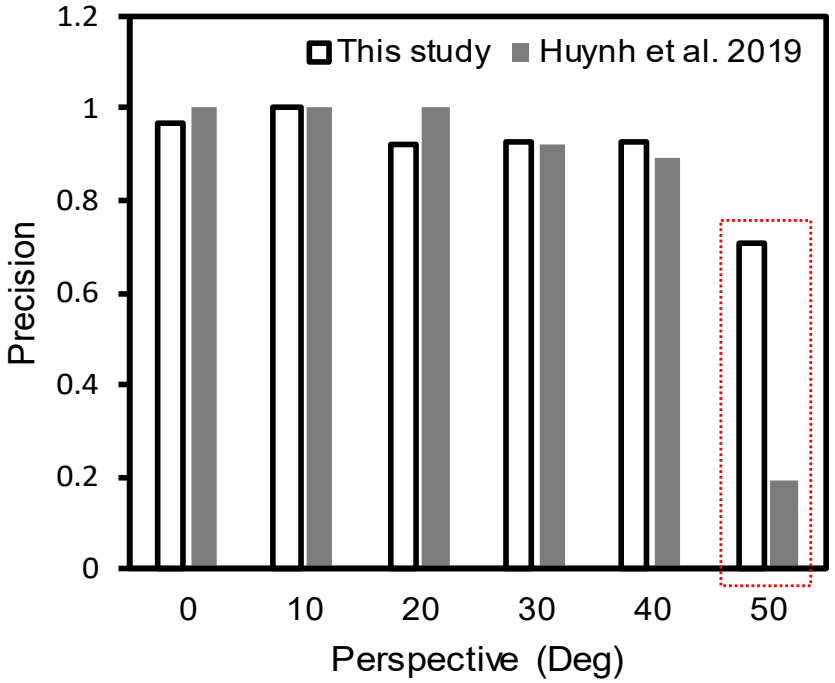




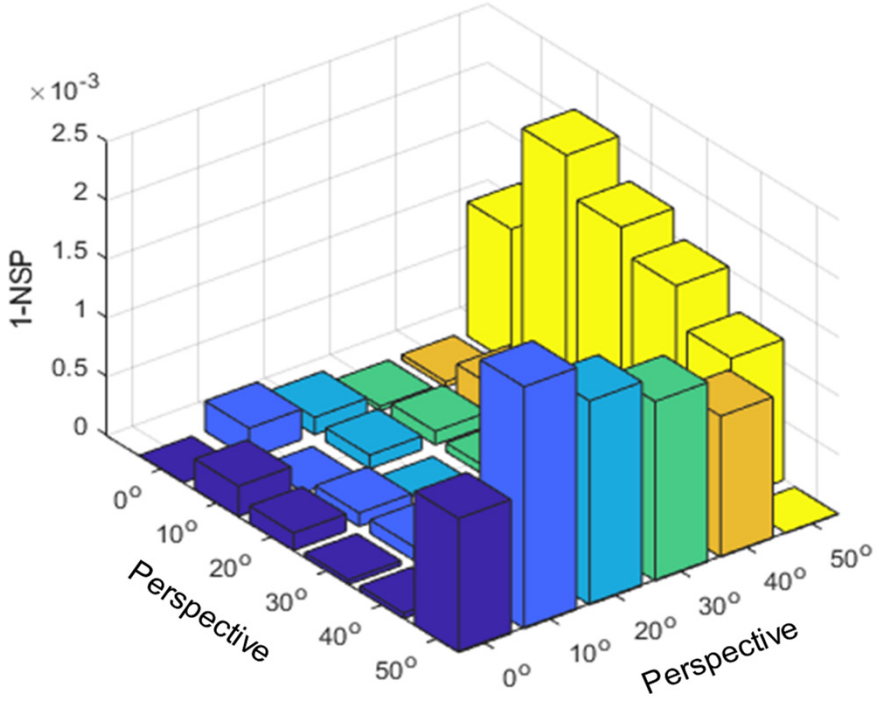
Result

Accuracy Evaluation

The accuracy of bolt detector

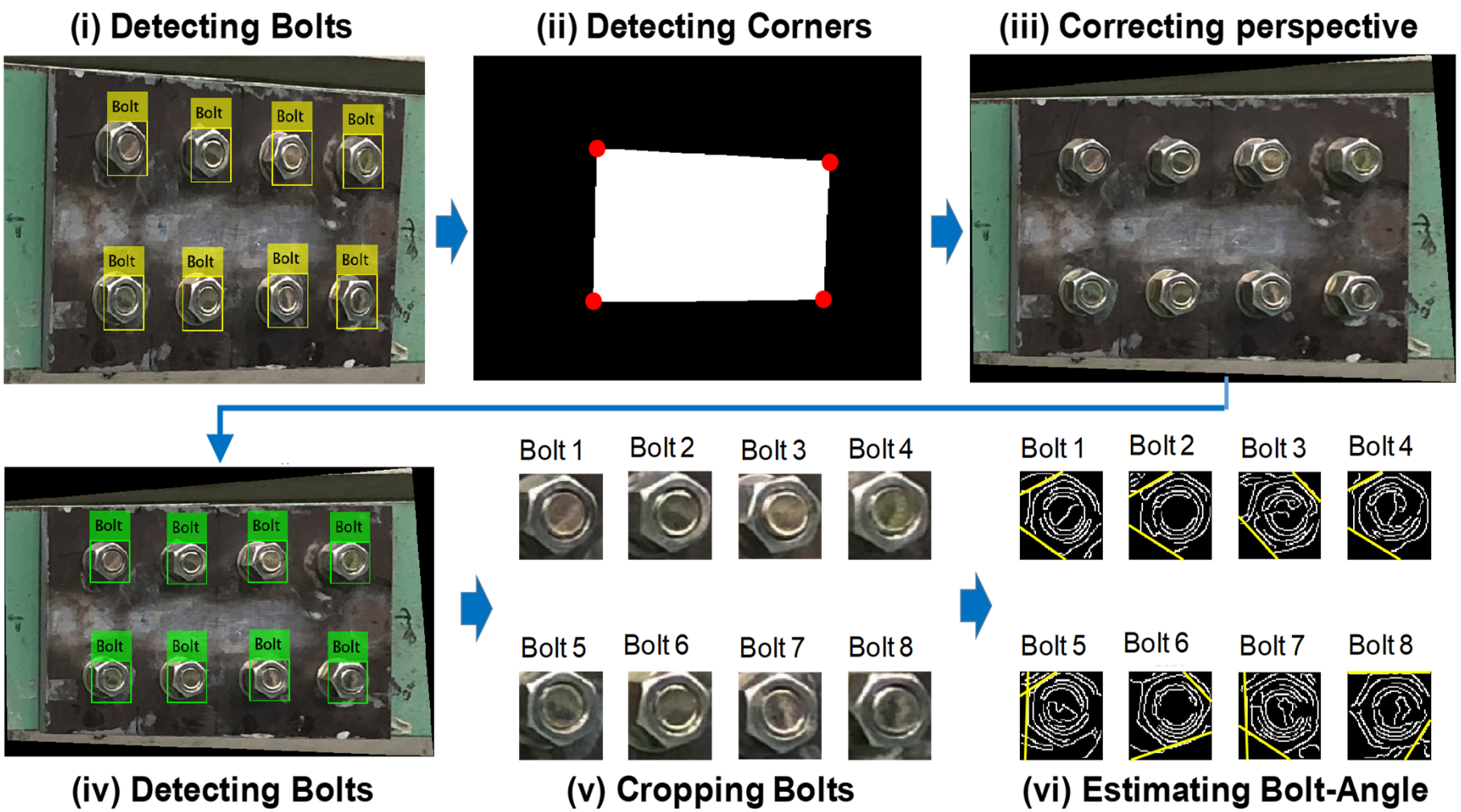


The accuracy of perspective corrector



Result

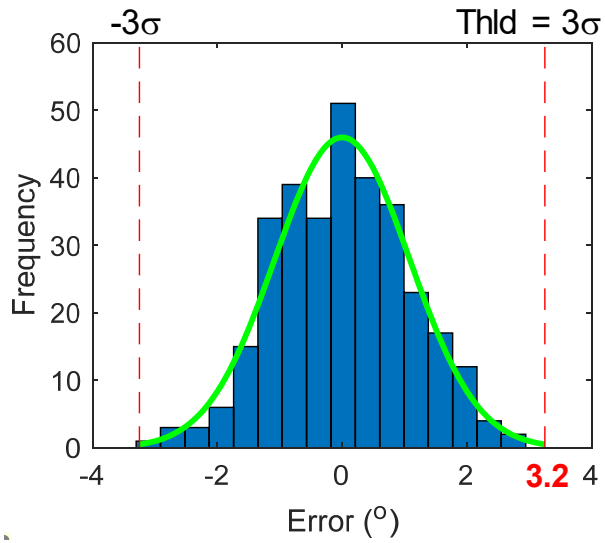
Bolt-angle estimation for 30° perspective



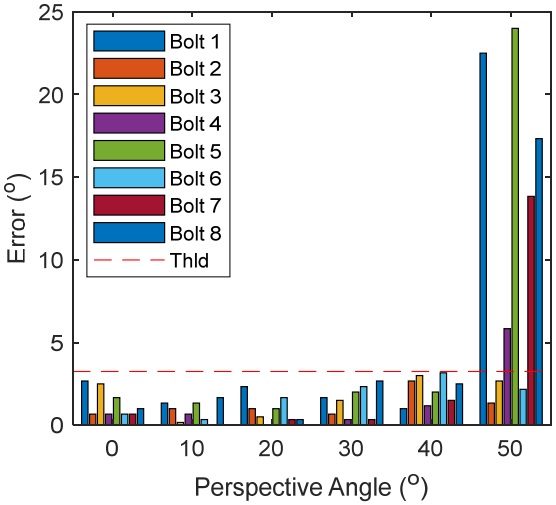
Result

Bolt-looseness Detection

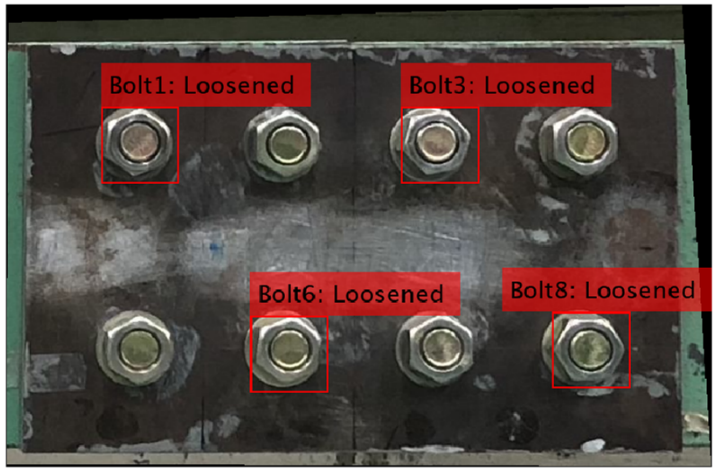
Calculating a threshold



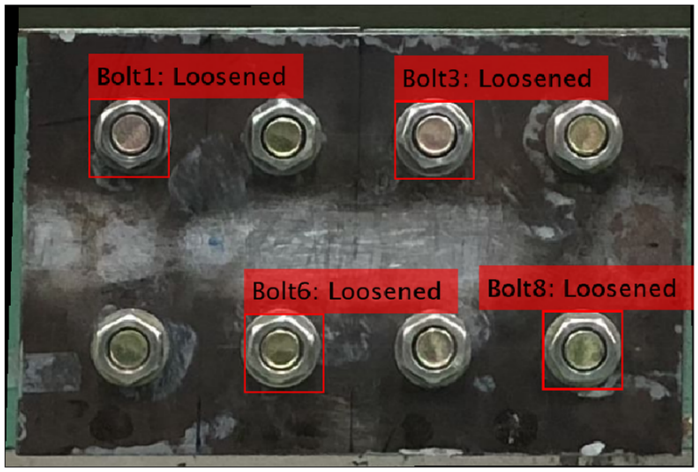
Severity estimation error



Perspective Angle of 0°



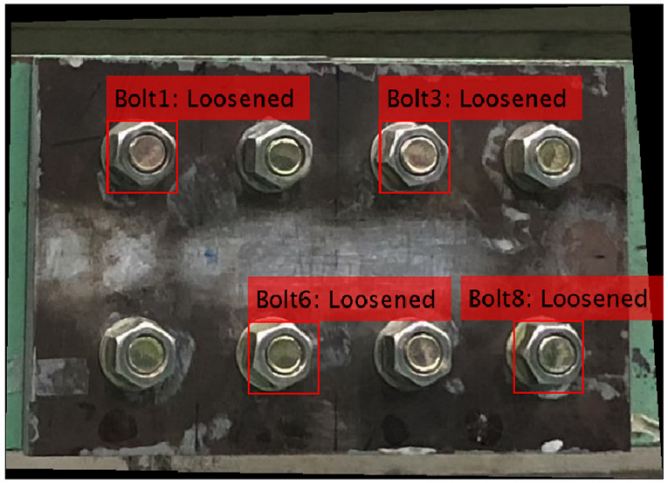
10°



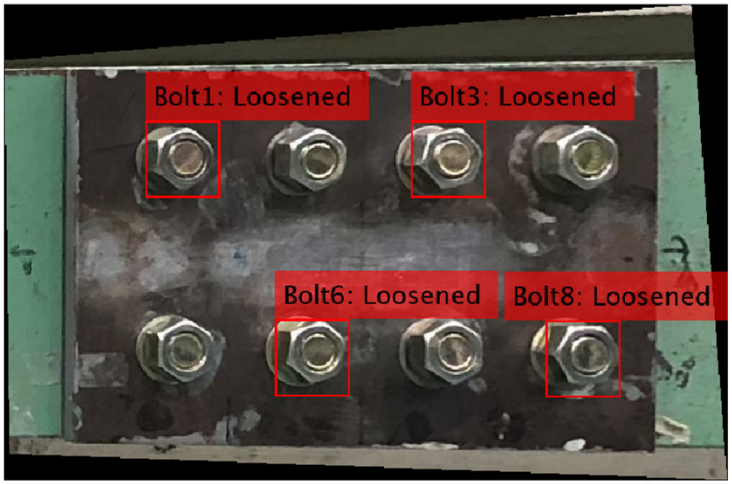
Result

Bolt-looseness Detection

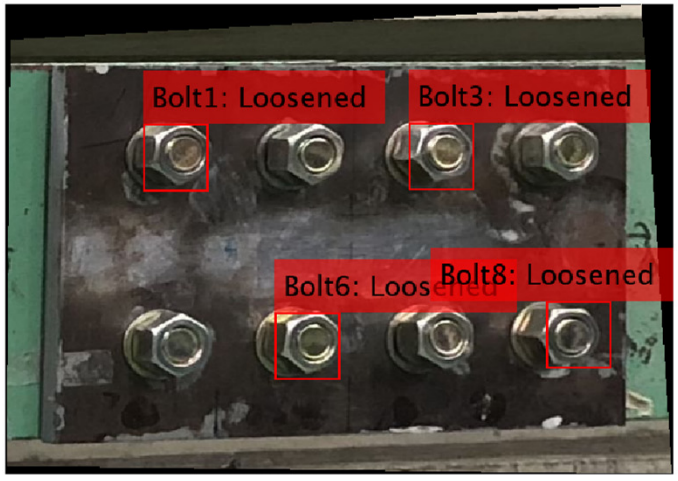
20°



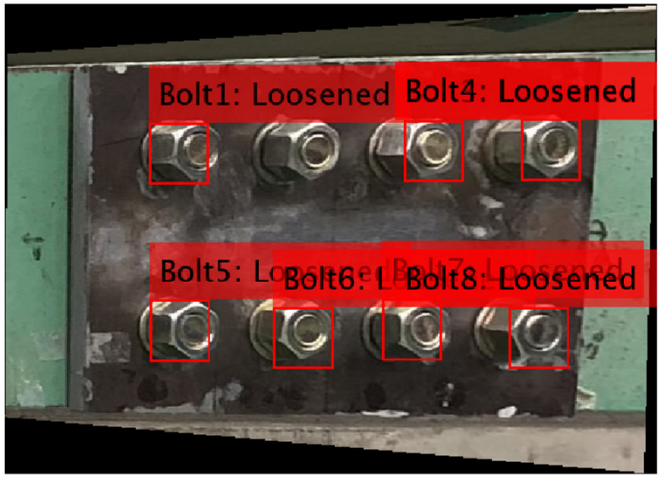
30°



40°



50°



Conclusion & Future Study

- An automated image-based bolt-loosening detection algorithm using Faster RCNN and image processing was presented
- Performance of the proposed method was evaluated for bolt-loosening monitoring of a lab-scaled bolted girder structure
  - *Loosened bolts in the girder connection were successfully identified*
  - *The rotation level of 5^o of a bolt was well detected*
  - *Allowable shooting perspective should be less than 40^o to accurately localize bolts*
- Future Study
  - *To consider the effect of lighting condition*
  - *To apply to in-situ bolted connections with numerous bolts*

Thank You for Your Attention!

Q & A

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