Digital Analysis of Historic Bridge Images

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Introduction

This long abstract summarizes work-in-progress to create a database of images of historic bridges. These images are being used concurrently to develop machine-vision systems and image-processing techniques to automatically identify, in historical and contemporary images of cityscapes and landscapes: (1) the presence of a bridge or bridge component in an image; (2) the form (or type) of bridge or bridge component; (3) the age and other features; and (4) the vantage point from which the bridge was photographed.

Database of Historic Bridge Images

A database of 4800 images of Canadian and American highway, railway and pedestrian bridges constructed between 1865 and 2019 has been created and continues to be extended. The images were retrieved from Wikipedia, Wikimedia Commons, and the Historic American Engineering Record (HAER) websites. Many American bridges are listed on the U.S. Department of the Interior's National Register of Historic Places, although those less than 50 years old are ineligible for this recognition.

Each bridge is assigned a unique identifier and is associated with the fields shown in Table 1. The Wikidata identifier links records in the bridge table with open data. A sample record (for the Lions Gate Bridge in Vancouver, BC) is available at https://www.wikidata.org/wiki/Q124352. Among other things, it contains the designer, the date the bridge was officially opened, the longest span, heritage designation, identifiers for other databases and translations of the bridge's name into other languages.

Field	Contents
Name of Bridge	Text
Bridge ID (primary key)	Number
Wikidata ID	Concept URI (to link record to open data)
Location	City/Town/County, State (Province), Country
Date of Construction	Year
GPS Location	Latitude, Longitude
Main Span Type	Main Span Type ID (foreign key to Table 2)
Approach Span Type	Deck arch, Deck truss, Girder, Half-through arch, Half-through truss, Through arch, Through truss or NULL

Table 1: Fields to Define Bridges

Each bridge is characterized by a Main Span Type, shown in Table 2. Most of the Main Span Type Classifications include Subclassification options. Each combination of Classification and Subclassification is assigned a unique Main Span Type ID number.

Classification	Subclassification
Cable-stayed	Concrete, steel
Cantilever	Warren or NULL
Covered	Burr arch, Howe, Lattice or NULL
Deck arch	Concrete, Concrete open spandrel, Steel, Stone
Deck truss	Bascule, Camelback, Howe, Lift, Parker, Pratt, Swing, Warren
Girder	Bascule, Concrete, Lift, Steel, Swing
Half-through arch	Concrete, Concrete open spandrel, Steel, Stone
Half-through truss	Bascule, Camelback, Howe, Lift, Parker, Pratt, Swing, Warren
Suspension	NULL
Through arch	Concrete, Concrete open spandrel, Steel
Through truss	Bascule, Camelback, Howe, Lift, Parker, Pennsylvania, Pratt, Swing, Warren

Table 2: Main Span Type Classifications

Each image is assigned a unique identifier and associated with the fields shown in Table 3. Each bridge is typically associated with more than one image. Rare images depict two or more distinct bridges.

Field	Contents
Photo ID (primary key)	Number
Bridge	Bridge ID (foreign key to Table 1)
Image Restriction	Public Domain or Restricted
Source URL	Wikipedia, Wikimedia Commons, or HAER

Table 3: Fields to Define Images

Computational Analysis

The compilation of the image database is accompanied by development of an automated system for analyzing historical and contemporary images of bridges, depicted in Figure 1 and based on similar systems previously developed[1] for use by historians of technology.

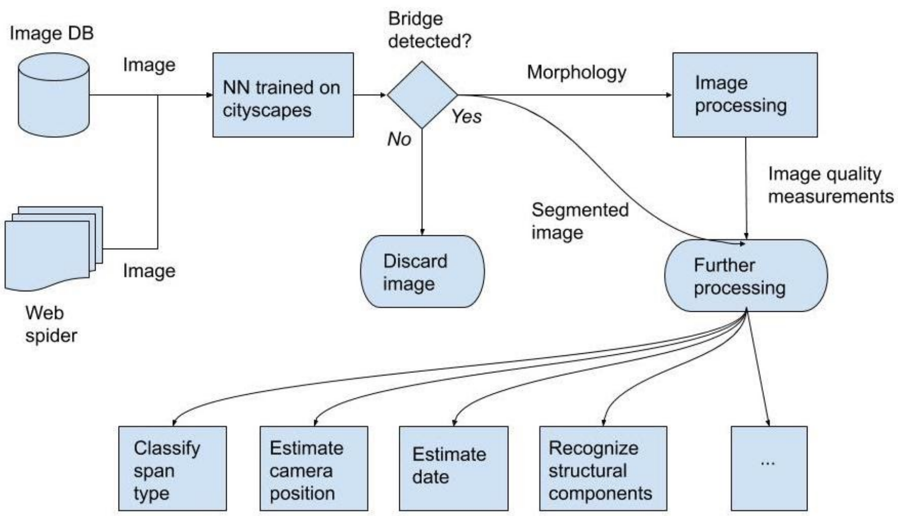


Fig. 1. Block diagram of an automated system for analyzing bridge images

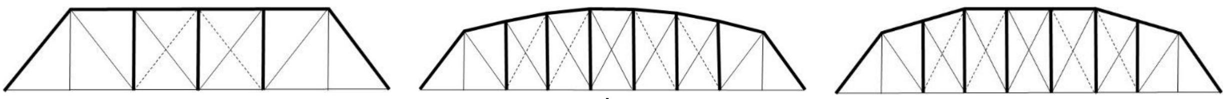
'Ground truth' images that have been analyzed by Bartlett are retrieved from the image database to use for testing and training. Test images can also be retrieved from other sources, typically collections built by web crawling. Creating a custom neural net that segments an image of a natural scene to identify general structures of interest requires a large collection of labelled image data that we do not possess. Instead we pass our images through an Ademxapp Model A1 neural net[2] that was pretrained with the ADE20K database of more than 20000 images[3] to segment scenes into semantic classes. We could have used a number of alternatives at this stage, but this model does an excellent job and was readily available in pretrained form. Figure 2 shows a sample output where the system has quite accurately identified the Pierre Laporte suspension bridge in the foreground and the Pont de Quebec cantilever truss in the background. In a preliminary trial involving 100 images, the Ademxapp Model A1 correctly identified bridge elements in 83 of 84 images that contained bridges and correctly identified that no bridge elements were present in all 16 images that did not contain bridges.

a b

Fig. 2. Machine vision identification of bridge and other features a) original image; b) identified features.

If no bridge is detected in the input image, the image is discarded and the system retrieves another. If a bridge has been detected, morphological information from the image is passed to an image processing module to assess the quality of the image for the purposes of further automated handling. The shape of the segment of the image that contains the bridge is measured to assess its orientation, how much of the whole image it comprises, and so on. These measures are used to determine what kinds of further automated processing are possible or appropriate.

We have trained other machine learners (such as logistic regression models) to categorize bridge images by main span type, typically achieving accuracies upwards of 85%. Our current work focuses on developing machine learners for a variety of automated tasks. One example is the automated recognition of structural components like truss type. Figure 3 shows Pratt (horizontal top chord), Parker (polygonal top chord) and Camelback (5-element top chord) trusses.



a b c

Fig. 3. Truss configurations a) Pratt; b) Parker; c) Camelback. (Source: HAER)

Another example is estimating the date that a bridge was constructed. 'Black-box' machine learners perform this task using features that are usually not legible to humans. Human experts, on the other hand, use a variety of construction details, as shown in Table 4. Developing the database in conjunction with an automated system for analyzing bridge images allows researchers to explore the degree to which the system should be trained to explicitly recognize construction details (like the use of pin-connected or riveted trusses).

Date	Feature
~1875	Emergence of double-intersection trusses
~1880	Transition from empirical to theoretical bridge design completed in US[4]
~1890	Emergence of steel construction instead of wrought/cast iron construction
~1900	Emergence of plain and reinforced concrete (piers, abutments, superstructure)
~1910	Milan theory of earth-anchored suspension bridges causes markedly more slender stiffening elements.
~1910	Emergence of concrete tied arch ("rainbow") bridges and concrete open spandrel deck arch bridges
~1920	Emergence of riveted trusses instead of pin-connected trusses
~1930	Emergence of rigid frame construction
~1950	Emergence of prestressed concrete construction
~1950	Transition from built-up steel members to single rolled shapes
~1980	Emergence of cable-stayed bridges instead of cantilever trusses

Table 4: Evolution of Bridge Construction Details.

Some transitions are more difficult to date, for example

- The transitions from pin-connected to riveted to shop-riveted/field-bolted to shop-welded/field bolted to welded steel construction;
- The transition to more slender, and so more graceful, elements and structures due to stronger and stiffer materials;
- The transition to more complex geometries and structural systems due to enhanced computational capabilities;
- The impact of the increased labour costs: fewer built-up steel members, more precast concrete construction and the use of concrete instead of masonry in towers, piers and foundations.

A final example of a task that is currently being automated is to use image processing and photogrammetric techniques to try to identify the vantage point from which the bridge was photographed. Others[5] identified five specific vantage points that are important for viewing bridges, "(a) travelling over the bridge at slow speed; (b) travelling over the bridge at high speed; (c) travelling under the bridge at slow speed (d); travelling under the bridge at high speed; and (e) viewing the bridge from a distance." Successfully estimating camera position with respect to the bridge will be useful for more sophisticated image understanding tasks.

References

1. Jones-Imhotep, E., and Turkel, W. J. (2019). "The Analog Archive: Image-Mining the History of Electronics." *Seeing the Past with Computers: Experiments with Augmented Reality and Computer Vision for History*, edited by Kevin Kee and Timothy Compeau. Ann Arbor: University of Michigan Press.
2. Wu, Z., Shen, C., and van den Hengel, A. (2016). 'Wider or Deeper: Revisiting the ResNet Model for Visual Recognition,' arXiv:1611.10080, accessed 20 July 2020.
3. Zhou, B., Zhao,H., Puig, X., Fidler, S., Barriuso, A., and Torralba, A. (2017). 'Scene Parsing through ADE20K Dataset', *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*. Available at: http://groups.csail.mit.edu/vision/datasets/ADE20K/, accessed 20 July 2020.
4. DeLony, E. (1992). *Landmark American Bridges*. New York: American Society of Civil Engineers.

5. Bakht, B. and Jaeger, L. G. (1983). “Bridge Aesthetics.” *Canadian Journal of Civil Engineering* 10:408-14.