BridgeDex: Proposed Web GIS Platform for Managing and Interrogating Multi-Year and Multi-Scale Bridge Inspection Images

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Abstract: Current bridge inspectors commonly collect high-definition digital photographs of bridge members and connections at different scales when performing inspections over multiple years. Metric images are advantageous for bridge condition evaluation, locating defects, and quantifying and documenting changes that occur over the time. To organize and leverage multi-scale, multi-year imagery, an approach is proposed and a prototype web-based tool, named *BridgeDex*, is developed within a geographic information system (GIS) framework. Using the approach, the spatial and temporal information for each image are attributed and then linked with other bridge metadata, including inspection notes, design drawings, and possible destructive and nondestructive test results. Over the Internet, users can view the georeferenced imagery across various scales and across different inspection time intervals. The tool is designed to present high-resolution inspection imagery and metadata to users while only requiring a web browser and an

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internet connection. This tool synthesizes bridge inspection data in an intuitive way to enhance bridge management and decision and policy making.

Author keywords: Web GIS, Bridge Inspection, Imagery, Inventory, Management

Introduction

The United States Department of Transportation, Federal Highway Administration (FHWA) requires states to inspect all federally-aided highway system bridges at least once every two years (AASHTO 2011). The inspections and assessments are performed by certified inspectors in order to identify faults and distress, and assess condition. During an inspection, the inspector is required to report an inventory for a number of items on the bridge, including the materials, age, and geometry. The report also requires condition rating and appraisal of the bridge elements, including the deck, superstructure, substructure, and channel and channel protection (Ryan et al. 2006). Biennial bridge inspections produce large volumes of notes, drawings, and images which are commonly stored as hard copies in a file folder and sometimes digitally on a local server. Keeping this data organized and coherent is critical for identifying changes that occur over time, making informed bridge management and maintenance decisions, and providing guidance to policy makers (Higgins et al. 2016).

In recent years, imagery and location-based data management tools have been developed to assist with managing highway assets. For example, Balali et al. (2015) introduced a new cost-effective system for transportation inventory management. This system utilizes computer vision techniques to extract and store the location and type of traffic signs from *Google Street View* (Google Inc. 2017) imagery. Golparvar-Fard et al. (2015) presented a method to use image-based reconstruction techniques for transportation asset management. The 2-D frames extracted form video footage of a highway was processed using structure from motion (SfM) to generate a 3-D point cloud of the highway.

Similar approaches could be implemented for managing location-based data resulting from bridge inspections, such as by integrating inspection reports with high-fidelity, geolocated inspection images collected over multiple years. These approaches could be leveraged within a Geographic Information System (GIS), which is commonly used today to store the geolocation of bridges and other relevant information (She et al. 1999). Karlaftis et al. (2005) introduced a web-GIS tool for managing and manipulating the National Bridge Inventory (NBI). This tool allows users to locate the bridge on a map, and it provides methods for managing, storing, and querying the bridge at a national or state level. Another tool named, *Web-based GIS Integration (Bridge-WGI)* incorporates NBI and remote sensing data for interactive display and analytical visualization of bridge information. This system contains visual databases, bridge inspection data, LiDAR data, and aerial images of the bridge (Chen et al. 2012; Wang et al. 2009).

Despite these recent developments, these GIS tools do not provide intuitive methods for documenting or viewing the location of potential structural defects identified by inspection at a bridge scale, which is critical for evaluating the change in condition of the bridge. To provide location-based management methods, McGuire et al. (2016) presented the *Bridge Information Modeling for Inspection and Evaluation Method (BIEM)*, a tool that uses 3-D parametric models to visualize the bridge and document the location of structural defects. However, the *BIEM* is not designed for handling a time-series of high-fidelity inspection photographs taken of bridge elements.

Accordingly, this paper proposes a new tool, named *BridgeDex*, to organize and georeference high-resolution imagery collected over years of inspection of bridges within a web GIS. The date, spatial location, and imagery taken over years of inspections are first attributed and rectified. Knowing the location where the image was captured on the bridge allows the transformed and scaled image to be geo-referenced in the GIS. Afterwards, the imagery, bridge inspection reports, and bridge drawings are uploaded to an online database. Over the web, a user can download the reports and drawings and can view, pan, and zoom in and out on a time-series of imagery that is cross referenced to all relevant metadata.

The tool is mainly designed for the management of multi-scale bridge inspection images, including the close-up, high-resolution images collected during multi-year bridge inspections. The proposed approach is novel because it allows managing and interrogating time- and location-aware images for damage documentation at a bridge scale together with bridge inspection reports and metadata. This paper presents the architecture for this tool, lists the required data, and demonstrates the steps necessary for data collection, preparation, and publication. In addition, the Graphical User Interface is described, required development steps are given, and the capabilities of *BridgeDex* are detailed. As an example of the capabilities of the tool, data for a very large bridge named “The Bridge of the Gods” in Oregon is presented.

Background

Bridge Inspection

Bridge inspections can be divided into two categories: (1) initial/routine inspections, and (2) in-depth inspections. Initial and routine inspections are most commonly performed visually and are useful for deciding whether or not additional, more in-depth inspections are required (Koch et al. 2015). While visual inspection is the most common technique of data collection for bridge inventory and appraisal (Moore et al. 2001), in-depth inspections may be required for fracture-critical bridges or bridges with visual defects. In-depth inspections typically require scraping, probing or some other type of physical investigation (AASHTO 2011).

There are a variety of methods available for inspecting a bridge and assessing its condition. Initial and routine inspections are commonly conducted quickly and generally require limited equipment or access. However, in-depth inspections require the inspector to be within arm's reach of the structure (AASHTO 2011). To access the bridge, inspectors make use of ladders, temporary scaffolding, snooper vehicles located alongside or on the bridge deck and in some cases by climbing equipment. When in close proximity to the bridge, the inspector examines each member and connection in detail and provides a rating that establishes the condition of the elements. Often, the inspector will take close-up photographs of bridge elements, especially of any parts of the bridge of concern. For instance, detailed photographs might be taken of bolts and gusset plates, cracks or signs of distress, evidence of rust or decay, and more. The photographs are useful for documenting the condition of the bridge element, and the data is then synthesized into a bridge inspection report for submission to the FHWA (Ryan et al. 2006).

Today, digital cameras are a common tool, and a large volume of photographs are collected per bridge. The volume of digital photographs per bridge could grow significantly as other remote sensing technologies continue to emerge. For example, some research is underway on using digital imagery from an Unmanned Aircraft System (UAS) for remote inspection of bridges. UAS are being increasingly used for a wide range of mapping, monitoring and inspection applications (Colomina and Molina 2014; Javadnejad and Gillins 2016; Pajares 2015; Turner et al. 2015; Wood et al. 2017). Ellenberg et al. (2016) and Eschmann et al. (2013) have shown that cracks and defects can be visually detected from UAS-sourced high-resolution images. UAS-based imaging was identified as an alternative data-collection platform if inspections using trucks, bucket trucks, or under-bridge inspection vehicles are prohibitive. UAS are favorable for bridges with elements that are difficult or dangerous for the inspector to physically access, especially for remote, safe, and visual bridge inspection (Gillins et al. 2016; Khan et al. 2015; Vaghefi et al. 2012). New tools must continue to be developed for managing the growing number of images collected by remote sensing techniques per bridge.

Metric Images

Photogrammetry and computer vision tools are available for determining the scale, orientation, and location of digital imagery captured of a bridge. For only a few photographs of a bridge location, such as a bridge connection, the scale of the features in the image can be determined using an image reference target placed by the inspector. The reference target enables determination of the linear transformation between points in the real world and pixels on the image plane. Higgins and Turan (2013) proposed the placement of a reference target with nine control points. Four of the control points are required to define the transformation matrix, and the remaining, redundant points help estimate measurement errors and reduce the sensitivity of the control point selections. Because the reference target points are known precisely and are mapped to the image pixels, the direct linear transformation is performed that rectifies the image and establishes the pixel scale to real world dimensions. The method generates a two-dimensional transformation based solely on the control point coordinates and thus, camera calibration is not required unless radial distortions are present in the lens. Knowing the position of the reference targets allows the transformed and scaled image to be geo-referenced in the GIS for the bridge.

If an image set has been collected systematically with enough overlap, computer vision techniques such as Structure from Motion (SfM) can be used to generate orthomosaics by processing and stitching overlapping images together. Using a set of overlapping images, SfM can recover geometry from a series of un-oriented overlapping images through simultaneous, highly redundant, iterative bundle adjustment procedures. Using the reconstructed geometry, SfM can rectify perspective and generate orthomosaics (Eltner et al. 2016; Furukawa and Ponce 2010; Snavely et al. 2006). There are a number of commercial software packages that are capable of SfM-based image stitching, e.g., *Agisoft* (2016) and *Pix4D* (2016). SfM is a particularly popular technique for stitching and processing imagery collected with a UAS. SfM processing results in an orthomomsaic at an arbitrary scale. Applying the real world scale on the SfM-derived orthomosaics can be done by (1) providing the 3-D coordinate values of distinguishable objects (i.e., center of pins) or targets with known coordinate values (georeferencing), (2) adding known distances between objects (scaling), or (3) by assigning camera position and orientation (direct geo-referencing) (Eltner et al. 2016).

Web GIS

The term web GIS is used for any GIS that utilizes web technologies to communicate between its components. A web GIS has many advantages, such as it: enables access for a large number of users over the web, has an independent platform, can be easily updated and maintained, does not require the user to install software or download updates, and is composed of simple scripting and coding (Fu and Sun 2011; Sharifi-Mood et al. 2016). The basic components of a web

GIS is shown in Fig. 1. The GIS server is a critical component of the web GIS that provides spatial analysis services for web services, e.g., the *ArcGIS® Server* (Esri 2016a). A user will be able to view the data and any updates by accessing a web page that has a unique URL (Uniform Resource Locator).

The source code for most web pages is HTML (Hypertext Markup Language). The Cascading Style Sheets (CSS) are used to improve the appearance, style and layout of pages coded in HTML (Duckett 2011; Fu and Sun 2011). The Scripting language are often used to make the web pages dynamic and interactive. Large applications often require lengthy amounts of coding, which can be addressed by using object-oriented programming. Templates or blueprints that are used to regenerate objects are called classes. Classes are stored in the components of the system called modules (Eckel 2006). Application programming interfaces (APIs) can call modules and implement their classes in the application. *ArcGIS JavaScript API* (Esri 2016b), *Google Maps API* (Google Inc. 2016) and *Leaflet API* (Agafonkin 2016) are some common APIs for developments of interactive web mapping applications.

Proposed Methodology

BridgeDex is proposed as a web GIS tool that allows access and management of bridge images, inventory data, plans, inspection reports, and other relevant metadata. Fig. 2 shows the overview of proposed collection, preparation, architecture, and graphical user interface (GUI) and the software requirements are discussed with greater details in following sections.

Data Collection

BridgeDex was developed to manage bridge inspection data, including digital photographs, reports, and drawings. Special emphasis was placed on managing the location- and time-aware series of close-up imagery collected of a bridge during inspection.

Database Preparation

The collected images can be single images (Fig. 3b) or a mosaic of images. If a set of images is collected systematically, that is usually done by deploying a UAS, further processing of the image set is needed to generate an orthomosaic. The orthomosaics have spatial resolution comparable to the original images used in processing, so they can provide high-resolution data for visual inspection. For example, Fig. 3a shows a schematic UAS flight plan for capturing the overlapping images, which is later processed to generate an orthomosaic similar to Fig. 3c. This imagery can be an input to *BridgeDex*.

As a first step, the imagery must be georeferenced to the bridge. Fig. 4 shows an example of the use of a total station for determining the coordinates of distinguishable bridge connections. These coordinates can be used for georeferencing an orthomosaic image derived from SfM. On the other hand, scaling and rectification of single images can be performed using an image reference target. This can be done using the *ArcMap's* georeferencing toolbar where linear transformations are determined using the control points in 2-D space (Esri 2016c). The georeferenced images are later used to build a GIS database (Esri 2016d), which is published on a servers and available for online applications.

BridgeDex

Fig. 5 shows the hierarchical structure and components of *BridgeDex*. The base section of the tool is called *BridgeDex-map*, which provides a geographical plan view map of the locations of bridges included in the database. *BridgeDex-map* displays a number of markers that each depicts the geographical location of a bridge. Clicking on the marker opens a pop-up window that shows a description and a portfolio image of the bridge. The information of all the bridges required for generating the pop-up are stored in a spreadsheet file. The pop-up window also provides a hyperlink to the second section of the tool called *BridgeDex-profile* that interacts with the image services and displays them in a map container. *BridgeDex-profile* provides a profile view of the selected bridge and allows interaction with bridge imagery in two different domains: 1) at varying zoom levels, and 2) at different instances of time (inspection intervals). The raster image were stored as tiles in a map service. In addition to image data, it includes hyperlinks to metadata such as design drawings, inspection reports, notes, sketches, past repairs and retrofits associated with the current view.

All of the web pages and their components, including scripts, bridge portfolio images, and descriptive data were stored in folders placed on the website. The HTML files contain the code for the structure of the web page, including the headers, text, interactive forms, panels, and map container frame. The CSS files define the layout, style and appearance of the web page contents, and the JS files contain the JavaScript code that make the web pages interactive. In addition to communication with local codes, the HTML file also calls remote library scripts, such as mapping API modules that empower the web spatial capabilities. The *BridgeDex* uses *ArcGIS JavaScript API* (Esri 2016b) for enabling GIS tools and geospatial data on a web environment. In *BridgeDex-map*, a URL address is allocated to the folder that defines a global web address to the application.

Image services are tiles of raster data divided into smaller, more manageable chunks that are ordered in pyramidal scheme. A raster pyramid is a series of raster data of the same area that has been resampled into coarser resolutions or are generated from coarse resolution images. The coarse or fine resolution raster pyramids appear depending on the zoom level. In addition to automatically representing the raster pyramids at different zoom levels (based on the definition given in the image server), the *BridgeDex-profile* also dynamically overlays the close-up images on top of the overview image as the user zooms into a specific portion of the bridge. A reverse action occurs when the user zooms out from the close-up view, and the higher detailed image is removed from the overview image.

One important and novel feature of *BridgeDex* is that the user can view higher-resolution imagery by selecting closer zoom levels. In addition, it is also possible to select imagery from different years in order to monitor and detect changes in the bridge with time. Fig. 6 provides an illustration of time-stamped raster data (i.e., t_1, t_2, t_3) at different zoom levels (i.e., L_1, L_2, L_3, L_4) with varying resolution, stored as image tiles. BridgeDex-profile uses time-aware image tiles. Similar design can be developed using a raster mosaic dataset, which would add more automated time-series management of the raster data.

Development

The following section describes some important parts of the JavaScript code used in the *BridgeDex* tool. This is meant to present a prototype for managing tempo-spatial bridge images, where images are defined as one image service layer that is dynamically added or removed with respect to the zoom level of the map. The GIS databases can be constructed in *ArcMap* (Esri 2016e). Scaling is done either in *ArcMap* or through orthomosaic generation procedure via SfM.

The databases are then placed on *ArcGIS Server* and thereby are accessible for the online applications. More details on publishing map services can be found in Esri (2016f).

The main classes required for the application (e.g., "*Map*", "*OverviewMap*", "*BasemapGallery*", "*Scalebar*", "*ArcGIS®ImageServiceLayer*", "*ImageServiceParameters*") are from *Esri* modules (e.g., "*esri*", "*esri/dijit*", "*dojo*", etc.). These classes are used to create different parts of the tool without the need of writing new detailed code. The basic framework for both *BridgeDex-map* and *BridgeDex-profile* is a *Map* class that is defined as a *variable*, constructed inside of the given HTML container. It is possible to specify construction properties, define the center of the map extent, the zoom level, and add an *Esri* basemap.

Fig. 7 summarizes the algorithm used for development of *BridgeDex-map*. The *marker* is defined as a picture symbol, with construction properties (e.g., type, height, width, and the URL of the graphics) specified in constructer properties. Each time that the tool is loaded on the web page, the spreadsheet file is parsed, and the marker is rendered in the *map* container based on the latitude and longitude fields. The popup window displays the field information from the spreadsheet when the user clicks on the marker. The popup window loads an image of the bridge by reading the URL address of the image from the spreadsheet, and the window converts the image and its caption into hyperlinks to the *BridgeDex-profile* by reading the URL page address field from the spreadsheet. The hyperlink in the popup window opens the *BridgeDex-profile* tool.

Fig. 8 summarizes the algorithm for development of *BridgeDex-profile*. The "*ArcGIS®ImageServiceLayer*" class from the "*esri/layers*" module is used to handle the image service layers. The URL location and the parameters from the image service layer are needed to be specified. In addition, cutoff zoom levels were defined, which were used to dynamically add and remove the image services based on the zoom levels. The next step is to add a default layer to the web GIS map. For example, the default layer can be the overview image of the entire bridge for the first year.

If the *map* identifies an “*extent-change*”, the code gets the zoom level from the *map*. By using if statements based on the zoom level, imagery will be added or removed. According to zoom cutoff levels. The *year* variable is a parameter that specifies the year of the imagery. In order to load imagery for a specific time, one of the necessary steps is to read the year selected by the user from the right panel of the GUI. The input from *radio button* is read and parsed to an integer value for the given year. If the user selects a different year all of the imagery will be removed, then new imagery for the selected year will be added according to the year and the zoom level.

Typically, the maximum default level of detail (LOD) or zoom level in web GIS is 22; however, this tool must zoom into very close, high-resolution bridge images. Therefore, it is necessary to manually define the scale and resolution of each zoom level to the application. Each zoom level has a level ID, where the top level is 0, resolution value for each pixel unit, and the scale. For example, the level 22 defined for the experimental implementation (discussed later) a scale at 0.245, the resolution at 6.56E-05 in WGS84 Web Mercator (Auxiliary Sphere) units.

Software Requirements

NetBeans IDE 8.0 (Oracle Co. 2016) was used for web development. Most of integrated development environment (IDE) packages or editors, such as *Aptana Studio* (Aptana Inc. 2016), *Visual Studio* (Microsoft Co. 2016), *Sublime Text* (Skinner 2016), *Notepad++* (Ho 2016) would work for this purpose. *ArcGIS 10.2* (Esri 2016e) was used for generating raster databases and publishing online image services. To run *BridgeDex* and access the data requires the user to have only a web browser and an Internet connection.

Graphical User Interface (GUI)

The GUI for *BridgeDex* and its tools and capabilities are discussed in this section.

Map View:

A screenshot of the BridgeDex-map is shown in Fig. 9 and its components (numbered in the figure) are described below:

1. *Zooming and Panning*: The user can navigate through the map by clicking on the zoom in and out buttons or by using a mouse wheel.
2. *Home Button:* The default view of the map is currently set to the state of Oregon. If the user changes the zoom level or pans the map to a different extent, the zoom level and map extent will return back to this view by clicking the Home Button.
3. *Basemaps:* By clicking on this icon, a new box will appear that includes a list of available basemaps for display (e.g., Esri Streets, Imagery and Topography, OpenStreetMaps, USGS National Maps etc.). Once the selection is done, the user can close the box by clicking on the base map icon.
4. *Scalebar:* The scalebar is interactive and provides map scale both in metric and imperial units.
5. *Overview Map:* This coarser map shows the spatial extent of the view of the main window. The box is located on the lower right corner of the map container. The user can hide the overview map box by clicking on the arrow at the corner of the box.
6. *Address Locator:* This tool allows searching for a specific location on the map by entering its address. Running this command centers and zooms the view of the main window to the address.
7. *Marker:* Each marker shows the latitude and longitude of a bridge included in the database.
8. *Popup Information Window:* The user can access basic information about the bridge via an information window that will appear when clicking on the marker. The information window displays the name of the bridge, the name of the feature that the bridge crosses, the organization

that is responsible for maintaining the bridge, and other general information. The window also contains an overall image of the bridge and a hyperlink that takes the user to the BridgeDex-profile tool.

Profile View

A screenshot of the BridgeDex-profile is shown in Fig. 10 and its components (numbered in the figure) are described below. The crossbar shown in the figure is the setup of control points that can be used for scaling the image.

1. *Zooming and Panning*: Similar to BridgeDex-map, the zoom in or out buttons can be used to navigate the data. Changing the zoom level will load different image service tiles. In addition, image services will be added or removed dynamically based on the zoom level. For example, as the user zooms in, increasingly closer-up, higher-resolution images appear on the screen that are fully referenced to the prior coarser resolution tile.
2. *Select Year*: The user can select a year of interest for filtering the imagery. Only image services for a selected year will be shown on the screen that correspond to the current zoom level. The user can change the year at a certain level of zoom, and the raster image for that year at the level of zoom will be displayed. This enables the user to "travel back and forward in time" in order to identify temporal changes that are occurring.
3. *Reports:* The user can view available metadata such as an electronic copy of a report by clicking on a hyperlink to download the document. The hyperlinks show text that indicates the year and title of the report. The hyperlinks only show available metadata associated with the current view.

Example Dataset

The example dataset for *BridgeDex-map* includes four bridges in state of Oregon (as shown in Fig. 9). Table 1 includes the list of bridges with a simplified example of data in the spreadsheet file. The tool queries the latitude and longitude fields in this table in order to display a marker (i.e., a point) at each bridge on the digital map. The "Image Link" field provides the relative address to the bridge portfolio image of the bridge. Similarly, the "Page Link" field lists the address to the *BridgeDex-profile* web page for the bridge. When the user clicks on the marker, a popup window will appear which displays the attribute information from the spreadsheet file, the overview image, and a hyperlink that will open the profile view of the bridge.

Fig. 11 presents overview images in different years at zoom level 24 for the Bridge of the Gods in Oregon that is used as example dataset for *BridgeDex-profile*. The images of the bridge were first georeferenced (rotated and translated) to a geographic coordinate system. The overview image(s) of the entire bridge were first imported in *Esri ArcGIS* software. The overview images were roughly georeferenced to the location of the bridge using the "georeferencing tool" in *ArcGIS* by applying a reasonable scale factor. Afterwards, the closer-up, higher-resolution images of the bridge were imported and georeferenced on top of the overview images. This process was followed for all images, and the time each photo was taken was also tagged for all of the images. Fig. 12 displays high-resolution images of a joint at the same bridge captured during different years at zoom level 29, and Fig. 13 shows an example for the dynamic addition and removal of image services to the display based on the level of zoom, from the overview image at zoom level 24 to a close up image at zoom level 35. The images at different scales have reference targets placed in form of crossbars with control points for scaling the images.

Conclusions

This paper proposed a new web GIS tool to manage and query multi-scale/multi-year bridge inspection images, bridge reports, and other relevant metadata. *BridgeDex* is a web-based tool that provides the user a simple interface for viewing, panning, and zooming in and out of bridge imagery collected over the years as a result of numerous bridge inspections. The tool is meant to provide the user an intuitive, organized method for querying, evaluating, and managing bridge inspection data that is collected over time. Particular emphasis was placed on developing methods for viewing high-resolution, time-aware, close-up images of bridge elements and joints. The graphical organization of data, the ability to zoom in and out of the varying scales of the imagery, and the tools for viewing imagery by clicking backwards and forwards in time makes bridge inspection data inherently more accessible, easier to interpret, and more effective in identifying and quantifying changes that occur over time. Further, the real-scale allows for quantification of changes that are taking place. These features can improve bridge management and decision and policy making.

BridgeDex has two main parts: 1) *BridgeDex-map*, which is a web GIS tool that provides a plan view of the locations of bridges that are included in the database, and 2) *BridgeDex-profile* that is a profile view of each bridge that allows the user to navigate through large volumes of bridge images collected at different physical scales and at different times. The user is also provided links to a library of scanned bridge inventory metadata such as inspection notes, nondestructive test results, structural drawings, etc.

This paper presented the architecture for the tool, listed the required data, and demonstrated the steps necessary for preparing and publishing the required data. Example data for The Bridge of the Gods was developed and implemented in the database. Georeferenced raster photos of the bridge were published as image service layers on an *ArcGIS Server* and were used in the application. An explanation of the GUI and the capabilities of the tool was also given.

Future Recommendations

BridgeDex was designed for enhancing the management and interrogation of bridge inspection images and inventory data. Several items could be added to enhance *BridgeDex*:

1. As the number of bridges increase in the database, it may become difficult for the user to find particular bridges in *BridgeDex-map*. A tool could be developed that allows the user to search, sort, and filter the bridges in the database based on bridge attributes in the CSV file.
2. The current design only shows one profile view of each bridge. It is proposed that additional map panels be generated to *BridgeDex-profile* so that each panel can show slices of the bridge from the upstream to the downstream sides of the bridge superstructure with an associated plan view sub-map that can show the user where through the bridge the present view is located.
3. In addition to providing time-aware images of both profile views of the bridge, additional panels or pages could be developed to display imagery collected above or beneath the bridge in map view. Aerial orthomosaic collected over time can provide another tool for monitoring the bridge.
4. One of the limitations of the current development is how it handles time. Based on the current design, each image is defined as one image service layer that is dynamically added or removed with respect to the zoom level of the map. It is recommended to use

sliders instead of radio buttons in the future, and to develop web-based code that can use a raster mosaic database capable of handling time-series data in multiple dimensions instead of using a separate raster layer for each image.

5. In most cases, the close-up, higher definition images were taken for a small portion of the bridge. For example, often the imagery was limited to the areas that were identified by the inspector to be important, such as at a few connectors or along a problematic structural member. One idea is to add markers on the bridge portfolio image that allows users to quickly identify the areas on the bridge that contain higher resolution images when zoomed out. The current development lacks such highlighting markers.

Acknowledgements

The funding for the research and development of *BridgeDex* was provided by transportation pooled fund program by Federal Highway Administration, Oregon Department of Transportation, Caltrans, Idaho Transportation Department, New York Department of Transportation, North Carolina Department of Transportation, Texas Department of Transportation, and Wisconsin Department of Transportation (Higgins et al. 2016). The authors would like to thank Dr. Michael Olsen (OSU) for providing insights that helped in the development of *BridgeDex*, and Dr. Chris Parrish and Chase Simpson (OSU) for assisting with collecting the UAS imagery presented in this paper. The findings and conclusions are those of the authors and may not represent the views of those acknowledged. We also thanks two anonymous reviewers for their valuable comments and suggestions on improving the quality of this paper.

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Tables

Table 1. Example of a CSV file for storing bridge inventory data

Name	Latitude	Longitude	Cross	Image Link	Page Link
Bridge of the Gods	45.66242	-121.90128	Columbia River	/B01/bridge01.jpg	/B01/bridge01.html
Steel Bridge	45.52778	-122.66778	Willamette River	/B02/bridge02.jpg	/B02/bridge02.html
Yaquina Bay Bridge	44.62207	-124.05636	Yaquina Bay	/B03/bridge03.jpg	/B03/bridge03.html
Astoria - Megler Bridge	46.21725	-123.86291	Columbia River	/B4/bridge04.jpg	/B04/bridge04.html

Fig1

Click here to download Figure Fig1.tif

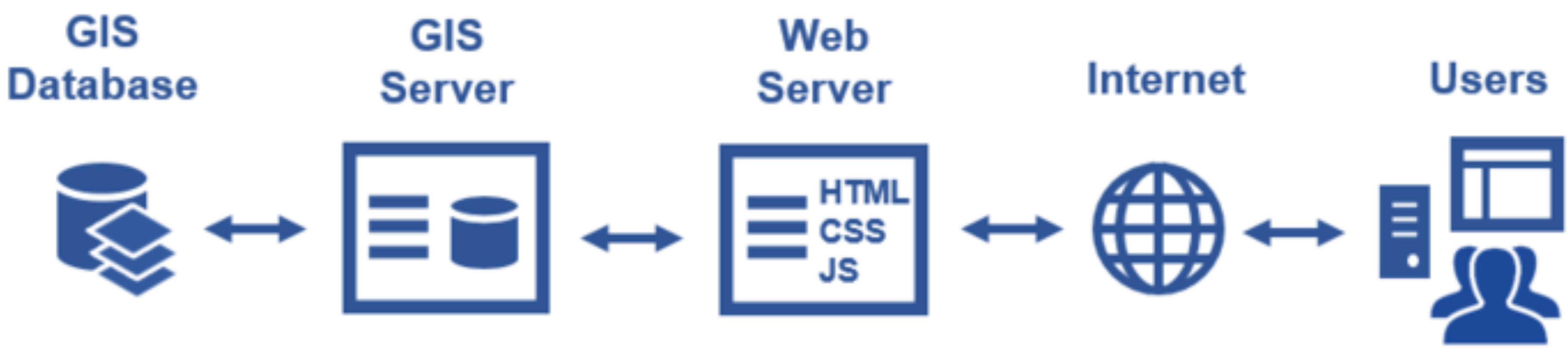


Fig2

Click here to download Figure Fig2.tif

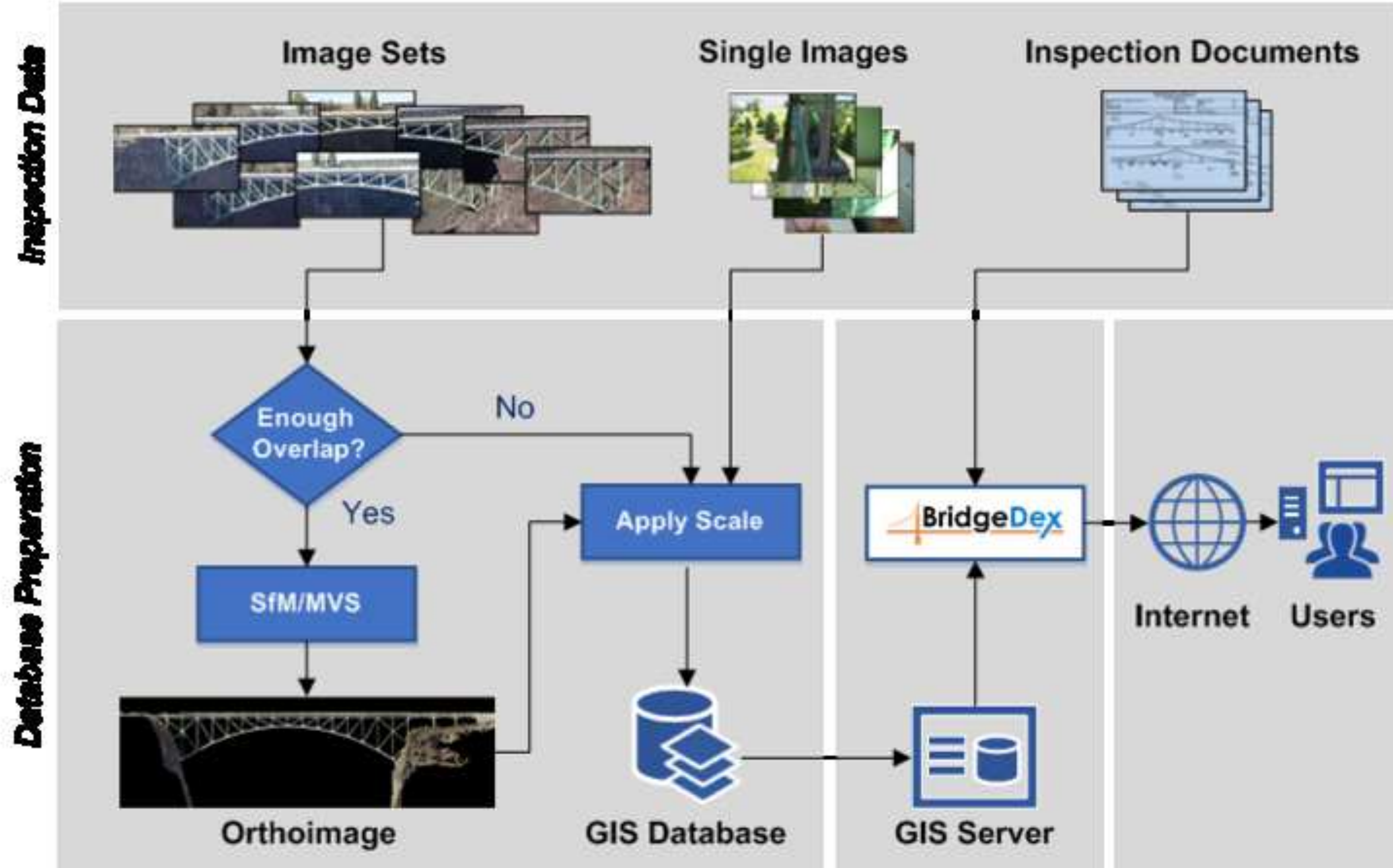


Fig3 Click here to download Figure Fig3.tif

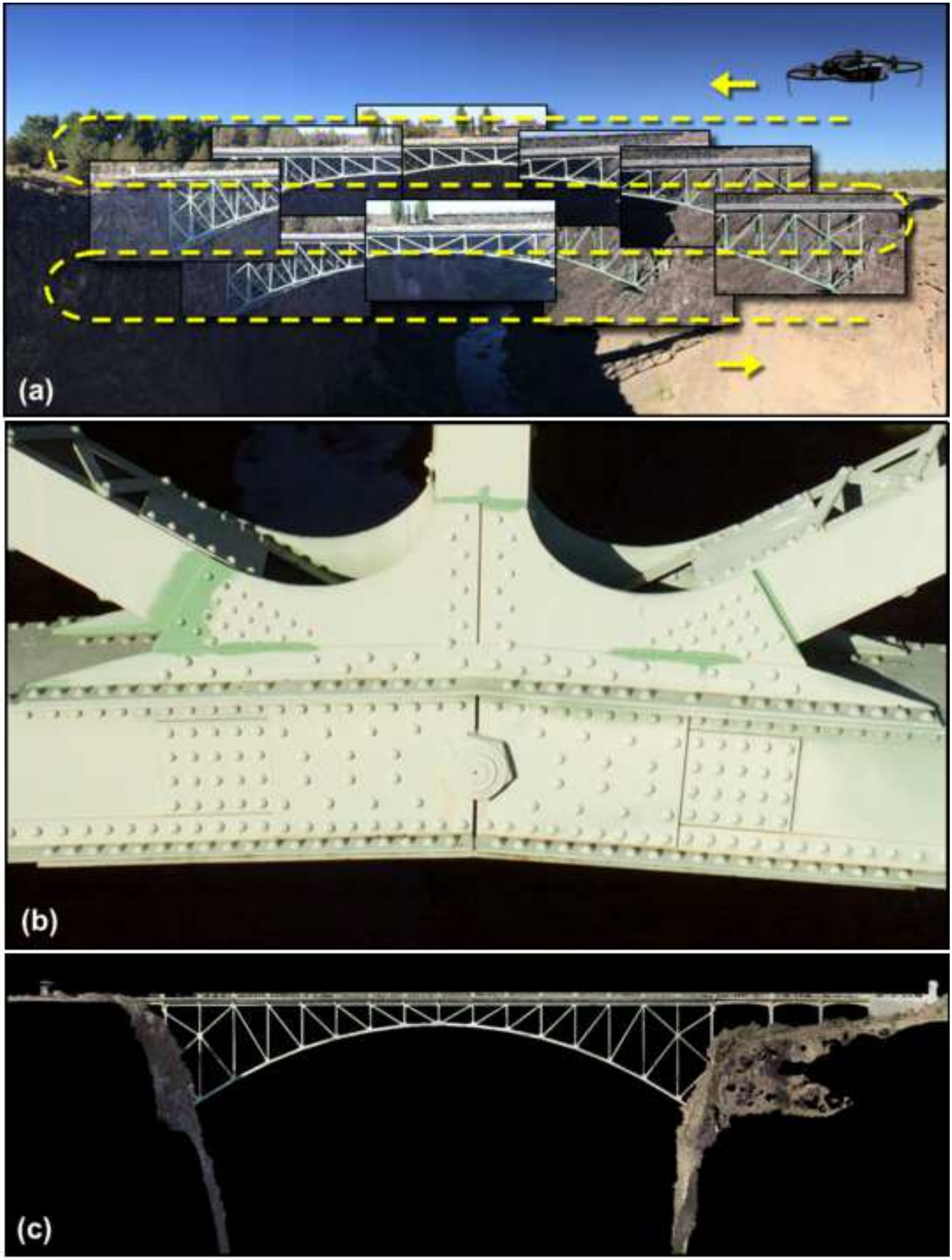


Fig4

Click here to download Figure Fig4.tif

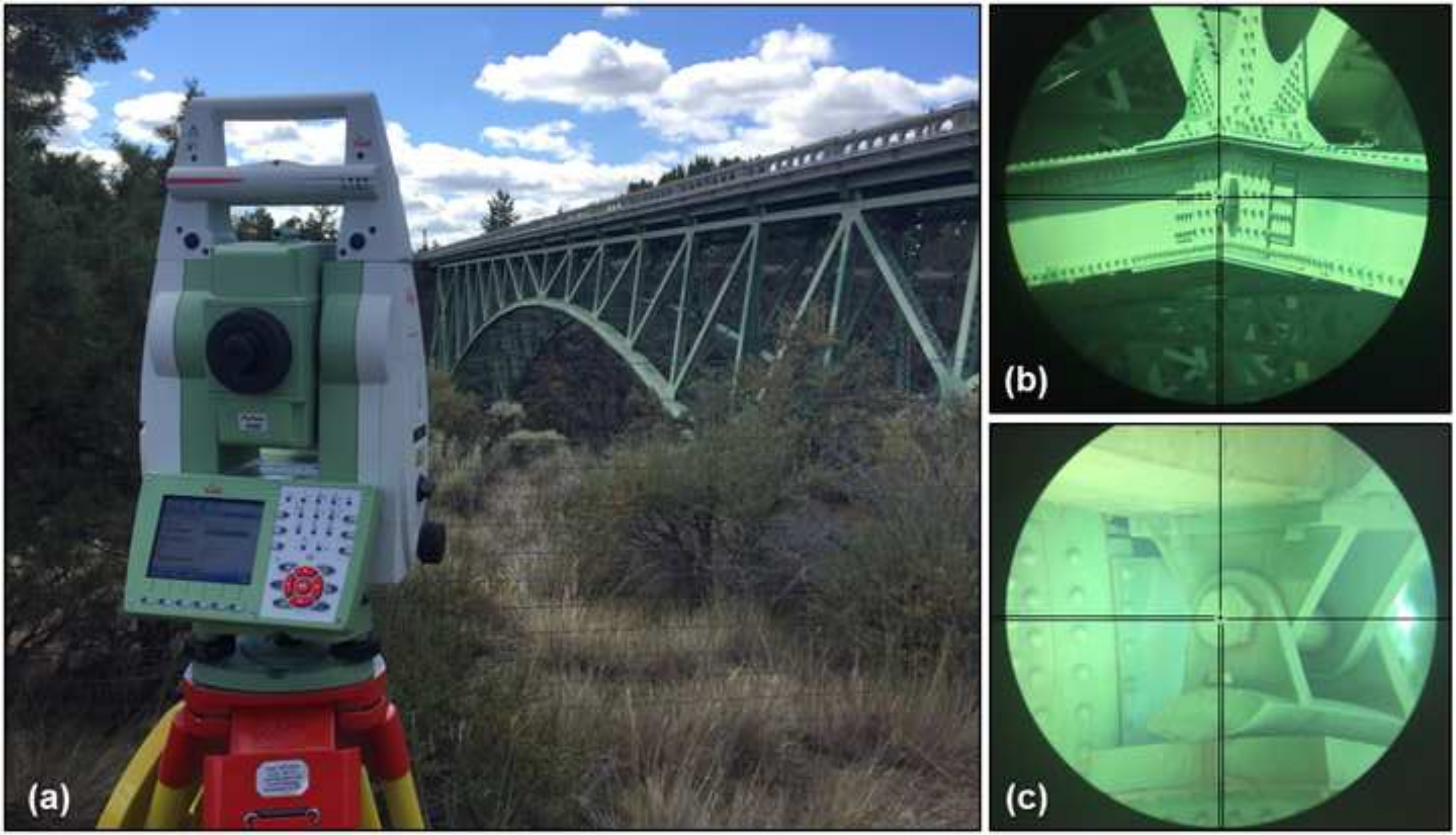
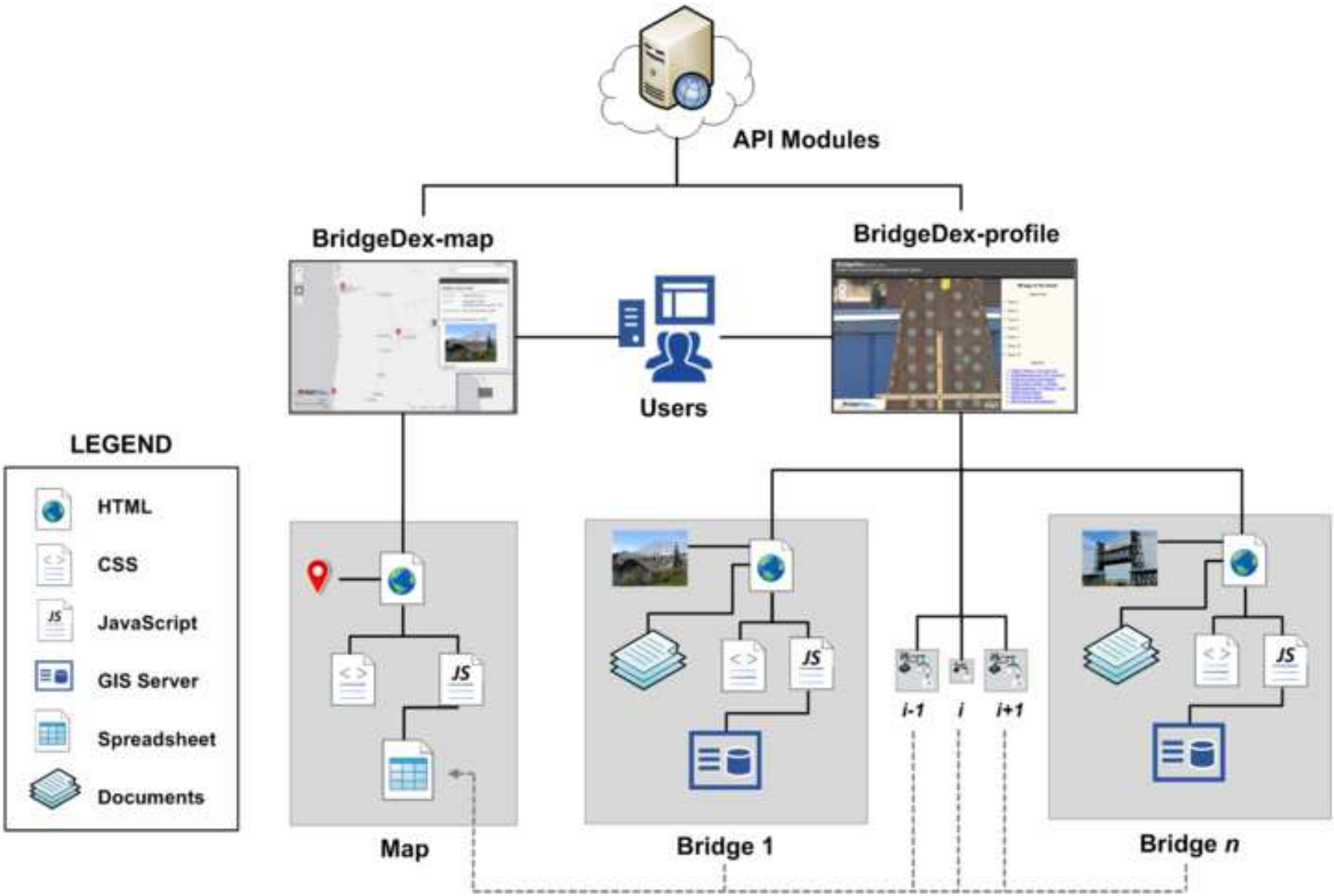


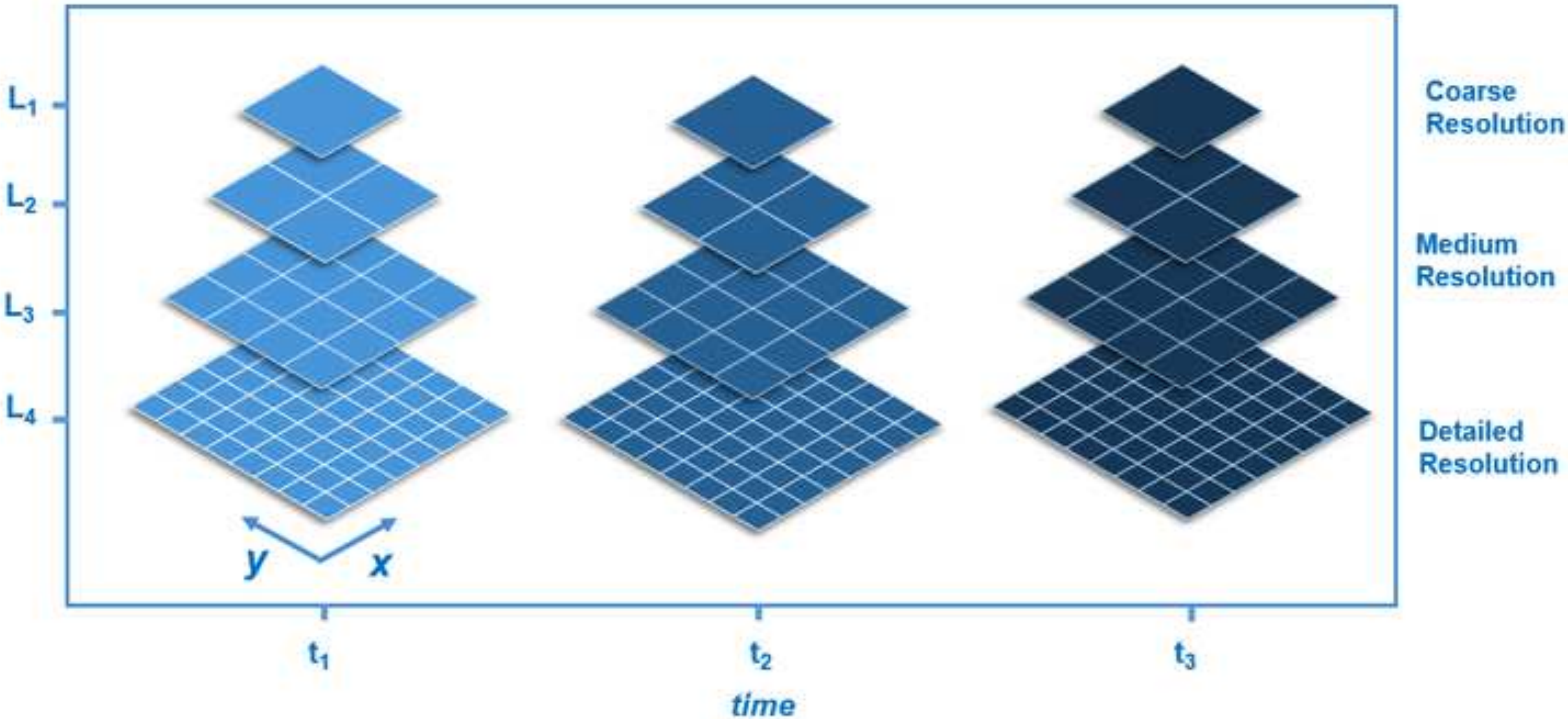
Fig5



API Modules
BridgeDex-map
BridgeDex-profile
Users
LEGEND
HTML
CSS
JavaScript
GIS Server
Spreadsheet
Documents
JS
Map
Bridge 1
Bridge n
i-1
i
i+1

Fig6

Click here to download Figure Fig6.tif



Inputs: CSV file of bridge information
Marker graphic file
Esri classes
Output: Marker displayed at the location of bridges
Popup template being updated upon click

m

Define *map*
Define *marker*
Define *dataLayer* and read CSV file
Define *renderer* displaying *marker* at the “latitude” and “longitude”
Set *renderer* to *dataLayer*
Define t*emplate*
click event on *marker*
    Assign field information to be displayed from CSV and set to t*emplate*
    Assign image type media info, read the image address from CSV and
    Set media info to *template*
    Set *template* to *dataLayer*
end event
Add *dataLayer* to *map*

Inputs: URL of image server layers
Radio-button reading year value
Esri classes
Output: Display image server relevant to *year* and *level*
m

```
Define LOD {
        Specify level ID
        Specify scale
        Specify resolution }
Define map
Define level and set a default value
Define year and set a default value
Define radio-layer
for all years
        for all levels
                Define image(year, level) as an new image service layer
                Set the URL to the attribution
                Set a min and max zoom level range for visualization
        end for
end for
Add image (year, level)
on level change event
        Set year = reading form radio-layer
        Set level = zoom level on map
        If level is not within min and max of current image
                Remove image
                Add image (year, level)
        end if
end event
on radio-layer click event
        Remove image (year, level)
        Set year = reading form radio-layer
        Set level = zoom level on map
        Add image (year, level)
end event
```

Fig9

Click here to download Figure Fig9.tif

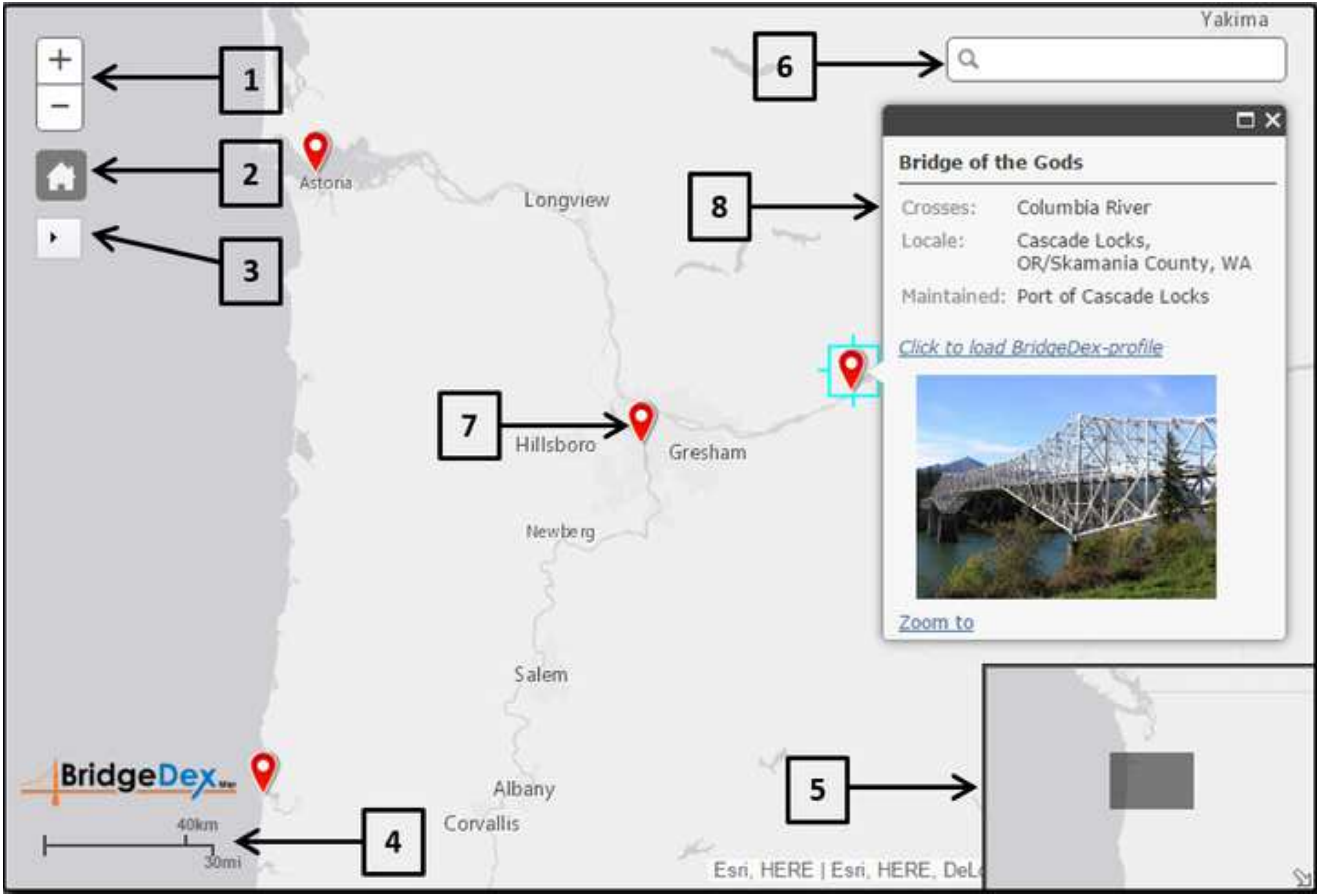


Fig10 Click here to download Figure Fig10.tif

Fig11

Click here to download Figure Fig11.tif

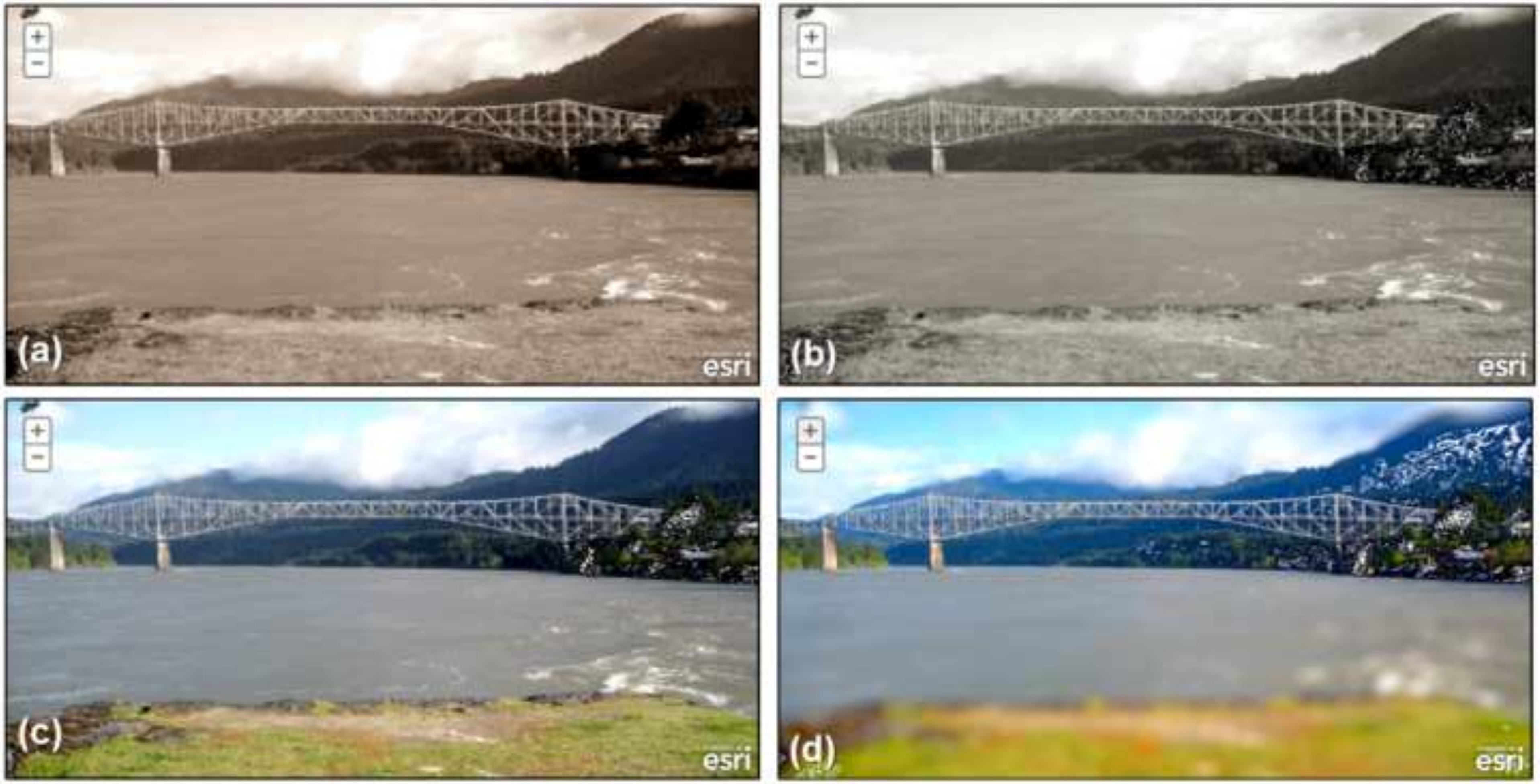
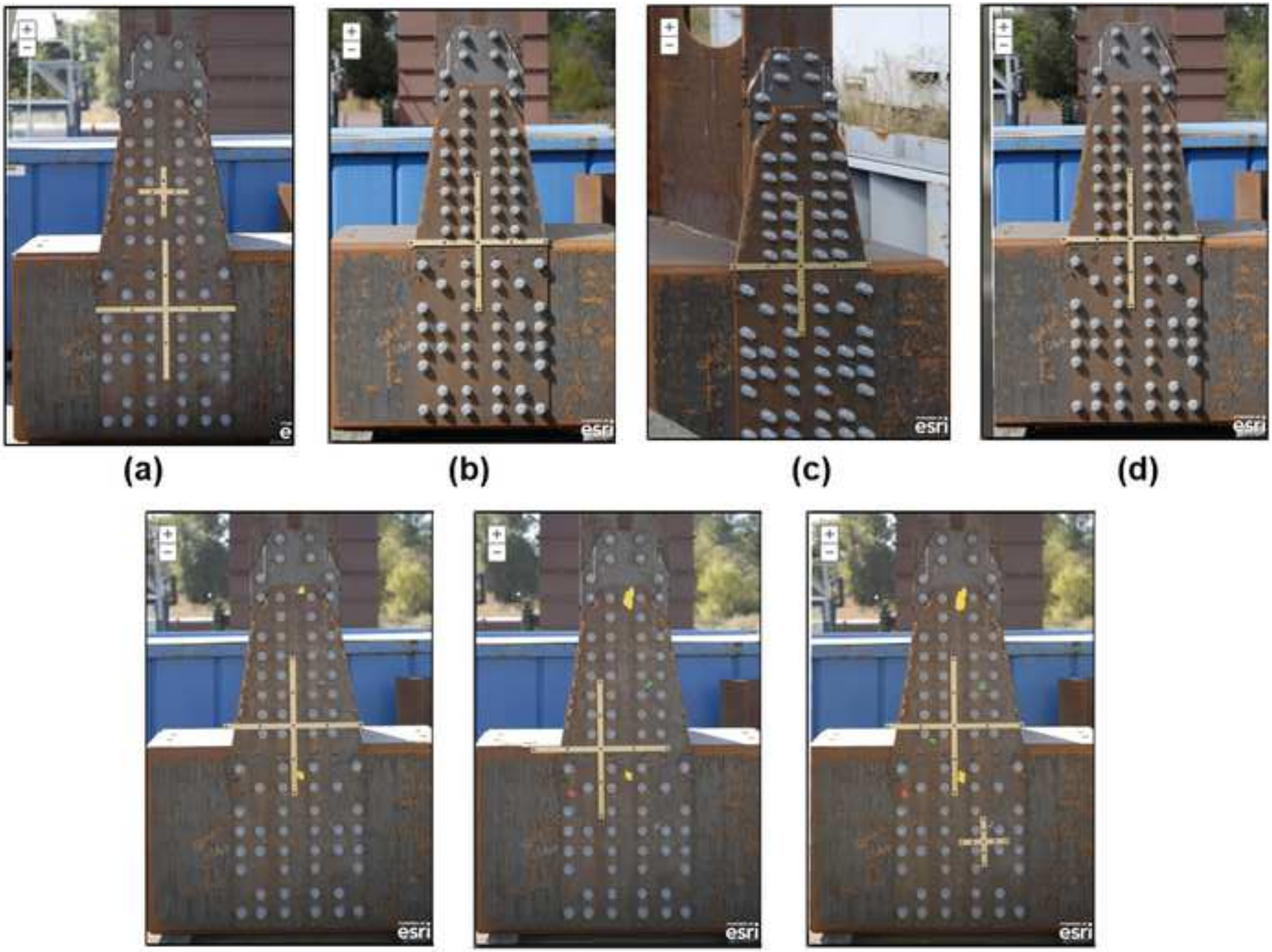
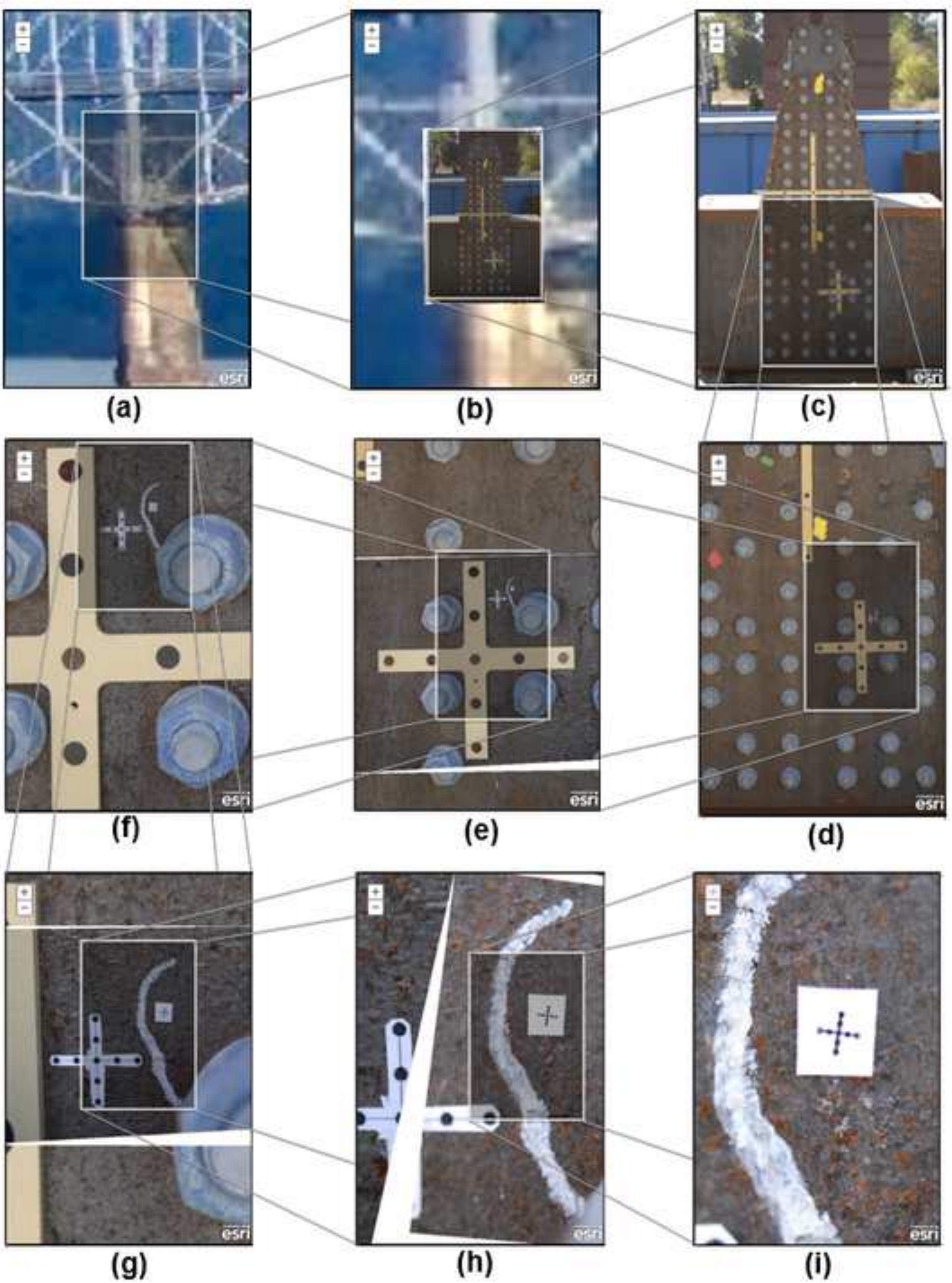


Fig12



(a) (b) (c) (d)

(e) (f) (g)


(a)
(b)
(c)
(f)
(e)
(d)
(g)
(h)
(i)
esri

Figures

Fig. 1. Basic components and workflow of a web GIS application.

Fig. 2. Overview of the data collection, preparation and proposed *BridgeDex* data management

Fig. 3. (a) A schematic representation of overlapping images taken from a UAS and the flight path, (b) an example of a high-resolution image captured from the UAS during a bridge inspection campaign at the Cooked River (High) bridge in Oregon, and (c) a mosaic image produced from processing the overlapping image collection

Fig. 4. (a) A total station for surveying the members of the bridge and, (b) and (c) distinguishable bridge connections that were surveyed with the total station for establishing control coordinates for georeferencing the digital imagery

Fig. 5. Hierarchical structure of the files and folders of the BridgeDex-Map and BridgeDex-Profile tools

Fig. 6. Time-aware tile pyramid representation of images

Fig. 7. The algorithm for development of BridgeDex-map

Fig. 8. The algorithm for development of BridgeDex-profile

Fig. 9. Outline view of BridgeDex-map with various feature tools and their screen location.

Fig. 10. The overall design of BridgeDex-profile with the time tools and report hyperlinks. The crossbar is a reference target with the control points.

Fig. 11. Example overview images for The Bridge of the Gods in different years: a) year 0, b) year 4, c) year 8, and d) year 12

Fig. 12. Images of a gusset plate in different years: a) year 0, b) year 2, c) year 4, d) year 6, e) year 8, f) year 10, and g) year 12

Fig. 13. Bridge inventory images for a gusset plate at different zoom levels: a) 27, b) 28, c) 29, d) 30, e) 31, f) 32, g) 33, h) 34, and i) 35. Image services are represented in coarse or fine resolution tiles. The image services are dynamically added or removed based on the defined zoom levels. The crossbars are reference targets with the control points for scaling the multi-scale images.