TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): Oregon Department of Transportation

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project #	**Transportation Pooled Fund Program - Report Period:**
TPF 5(259)	☐Quarter 1 (January 1 – March 31) ☐Quarter 2 (April 1 – June 30) ☐Quarter 3 (July 1 – September 30) X Quarter 4 (October 1 – December 31)

Project Title: **Imaging Tools for Evaluation of Gusset Plate Connections in Steel Truss Bridges**		
Name of Project Manager(s): **Xiugang (Joe) Li**	**Phone Number:** **503-986-4115**	**E-Mail** Xiugang.Li@odot.state.or.us
Lead Agency Project ID: **TPF5259**	**Other Project ID (i.e., contract #):** **Agreement 17384** **Work Order 12-05**	**Project Start Date:** April 2012
Original Project End Date: **9/30/2014**	**Current Project End Date:** **9/30/2014**	**Number of Extensions:** 0

Project schedule status:

X On schedule ☐ On revised schedule ☐ Ahead of schedule ☐ Behind schedule

Overall Project Statistics:

Total Project Budget	Total Cost to Date for Project	Percentage of Work Completed to Date
$440,000	$142,854.18	40

Quarterly Project Statistics:

Total Project Expenses and Percentage This Quarter	Total Amount of Funds Expended This Quarter	Total Percentage of Time Used to Date
	NA	70

Project Description:

The collapse of the I-35W Bridge in Minnesota has resulted in considerable interest in steel truss and gusset plate connection performance. The load paths in many truss bridges are non-redundant and thus failure of a truss member or connection may cause collapse of the structure. Periodic inspections and structural evaluations are crucial for these types of bridges.

The most common method of evaluation that has been used to assess the safety of highway bridges is load rating, an approach used to estimate the available strength and allowable load on a bridge. Although sophisticated bridge load rating computer programs are available, these programs do not explicitly consider the gusset plates connecting the truss members. Hence, after the initial design calculations are completed and checked, it is unlikely that recalculations for load rating purposes have been made for gusset plates. As an outcome of the investigation into the collapse of the I-35W Bridge, steel truss bridge connections are required to undergo review. This additional scrutiny requires development of new tools to efficiently and effectively evaluate the large numbers of steel truss bridge connections in the inventory.

Digital imaging techniques have been developed to enable rapid collection of field geometric data from in-service gusset plates. These tools are implemented in software that allows extraction of gusset plate dimensional information to facilitate ratings. The present tools provide a basic set of functionality such as image rectification and scaling and allow geometric data extraction such as length, perimeter, and angles. However, these basic functions need enhancement to take full advantage of the advancements available to bridge inspection and management with digital imaging. Enhancements such as automation of rectification tasks and identification of features within the images are proposed that will enable transportation agencies to efficiently and effectively collect geometric and condition data and use this data to evaluate and rate gusset plate connections.

There are four main objectives of this research:

1. Develop methods to collect dimensional gusset plate connection information including surface geometry and out-of-plane deformations on in-service gusset plates. The information to be collected includes the geometry of the connectors, members, and overall plate dimensions. It also includes out-of-plane distortions of the gusset plate.

2. Develop methods to automate identification and optimization of reference target points, and to automate identification and extraction of the gusset plate edges, fastener locations and their corresponding member affiliations, as well as member orientations. These dimensional data feed directly into the connection rating tasks.

3. Develop finite element modeling and analysis techniques to directly rate gusset plates using extracted digital image data as the input source.

4. Develop software tools to manage and organize images and image data to enhance bridge management and allow identification of condition changes over time.

Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):

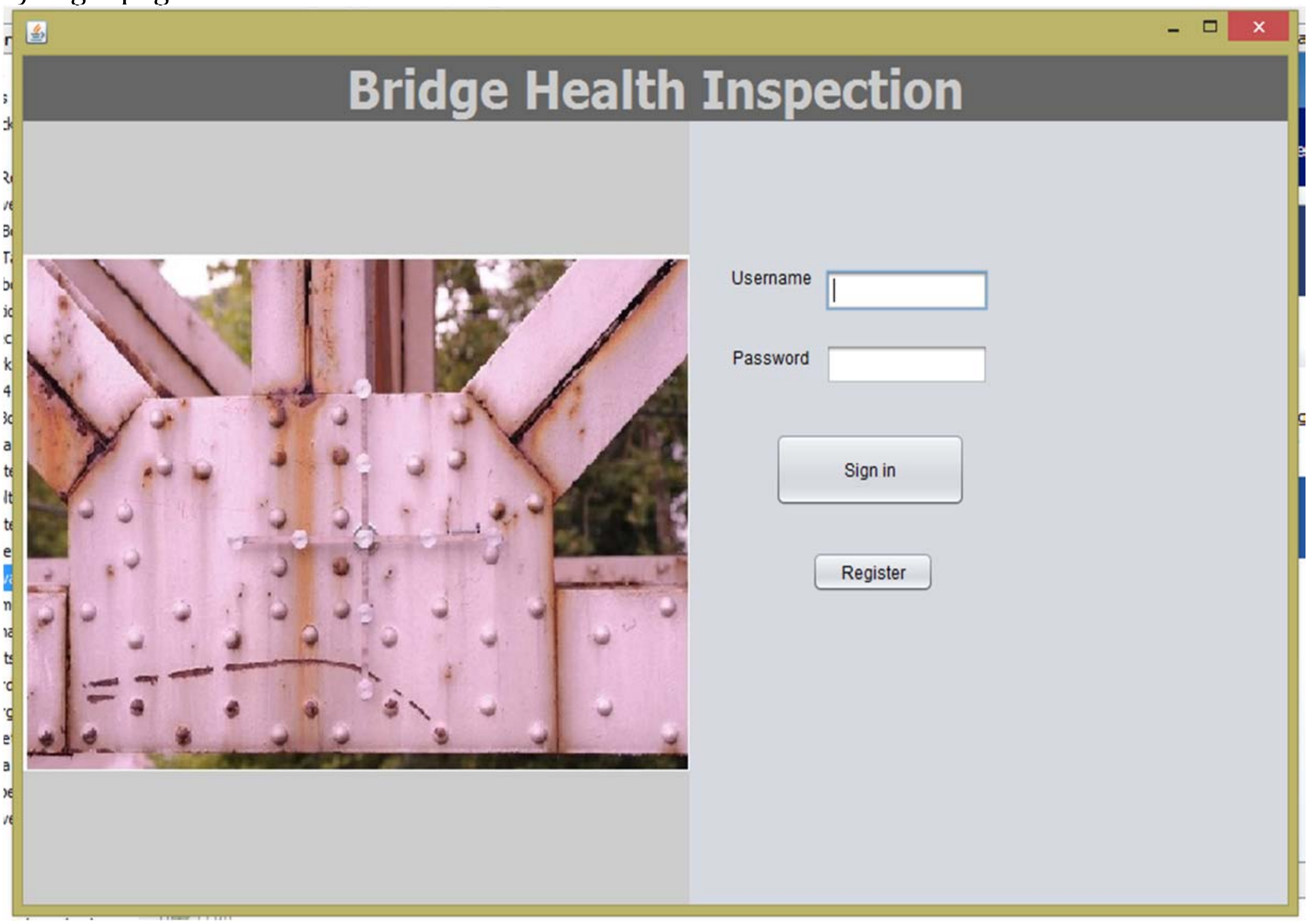
Task 1: Literature Review
Schedule status: *On schedule*
Percent complete: 75%

Task status: *Literature being collected and synthesized as research progresses.*

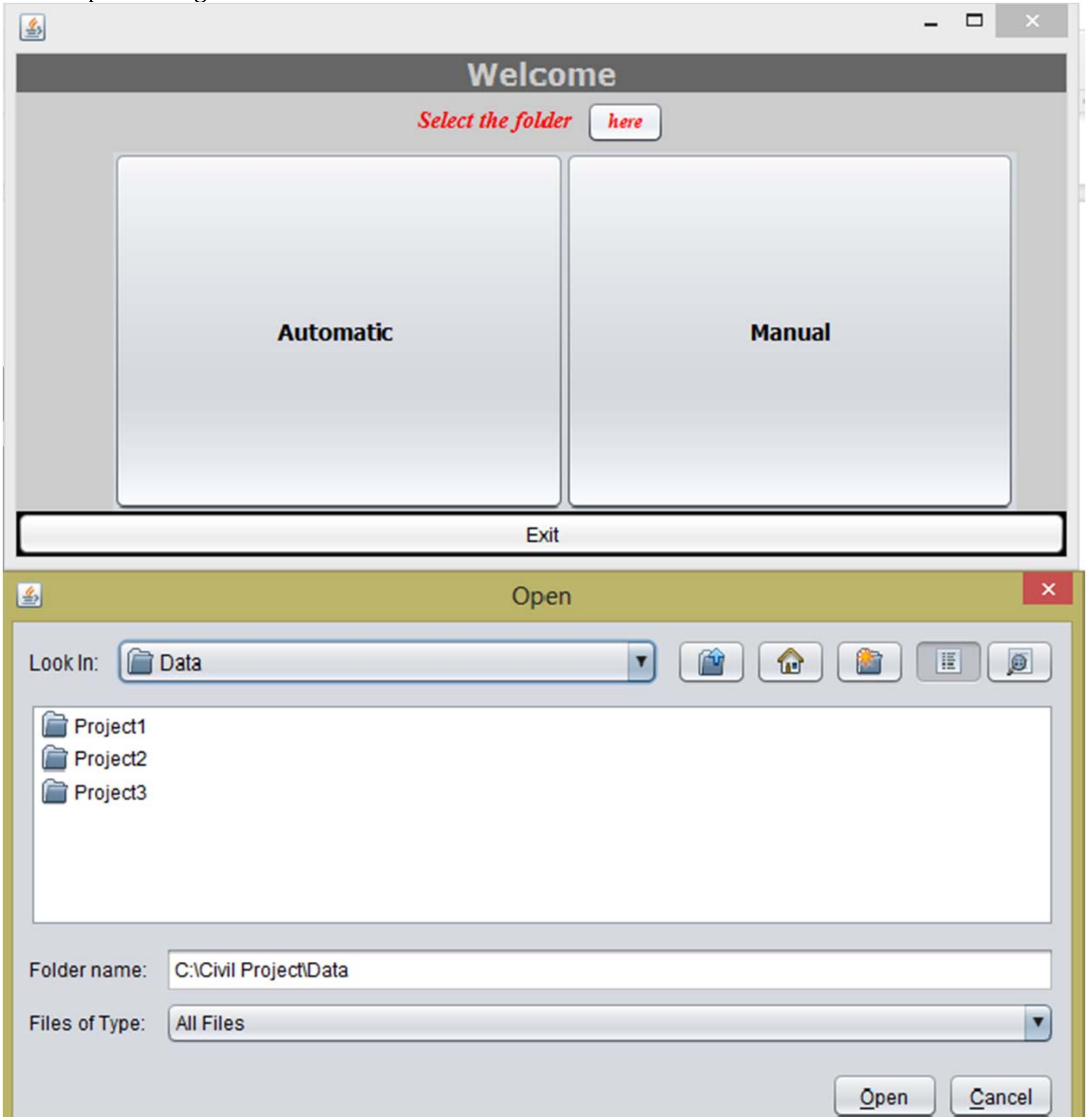
Task 2: Software Development and Data Collection
Schedule status: *On schedule*
Percent complete: 65%

Task status: *Computer Science graduate students continuing to develop software. Screen shots of the present software interface are shown here for the existing GUI:*

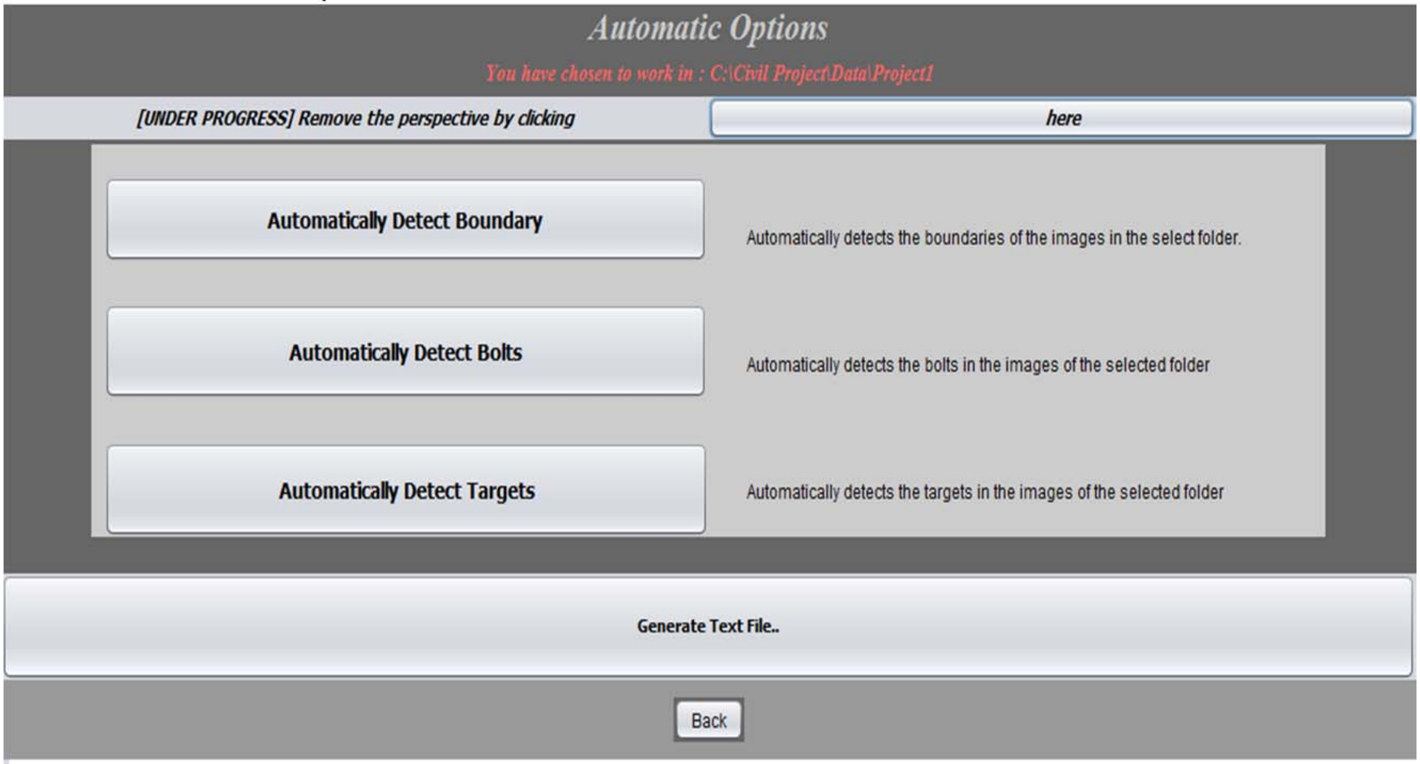
1) Login page:



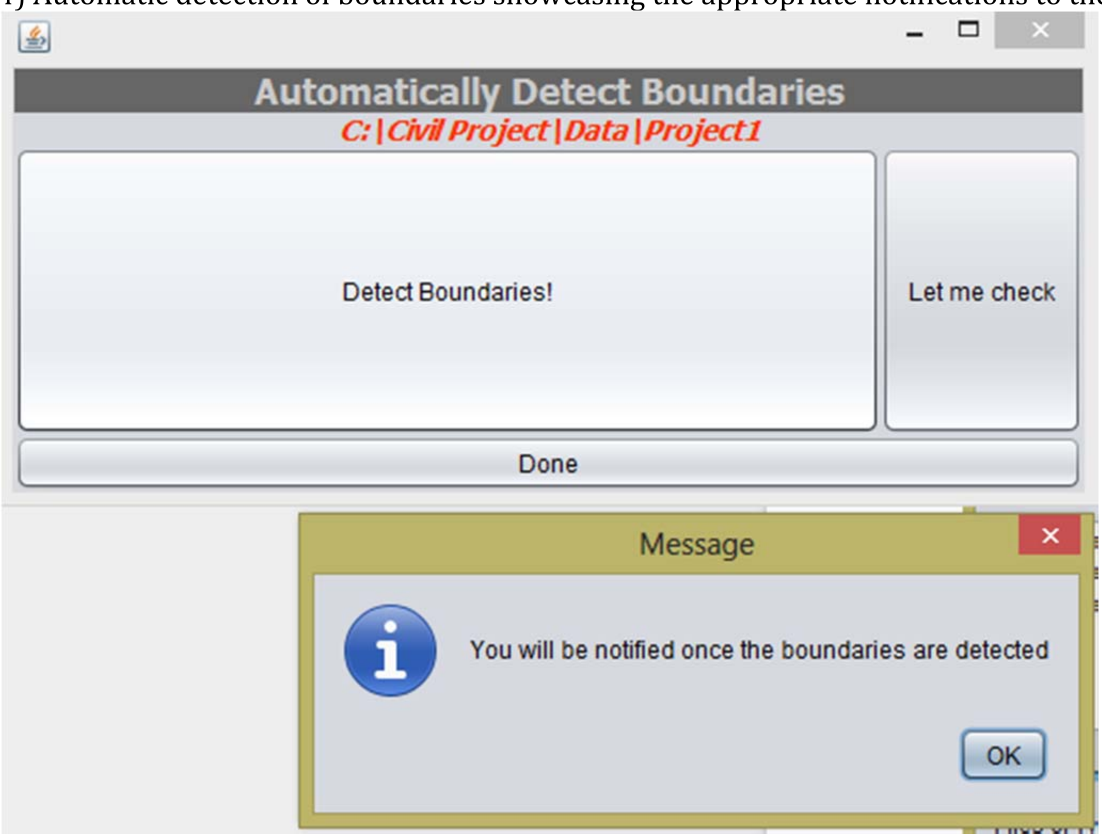
2) Window for selecting the working directory and the option to choose either automatic processing or manual processing.



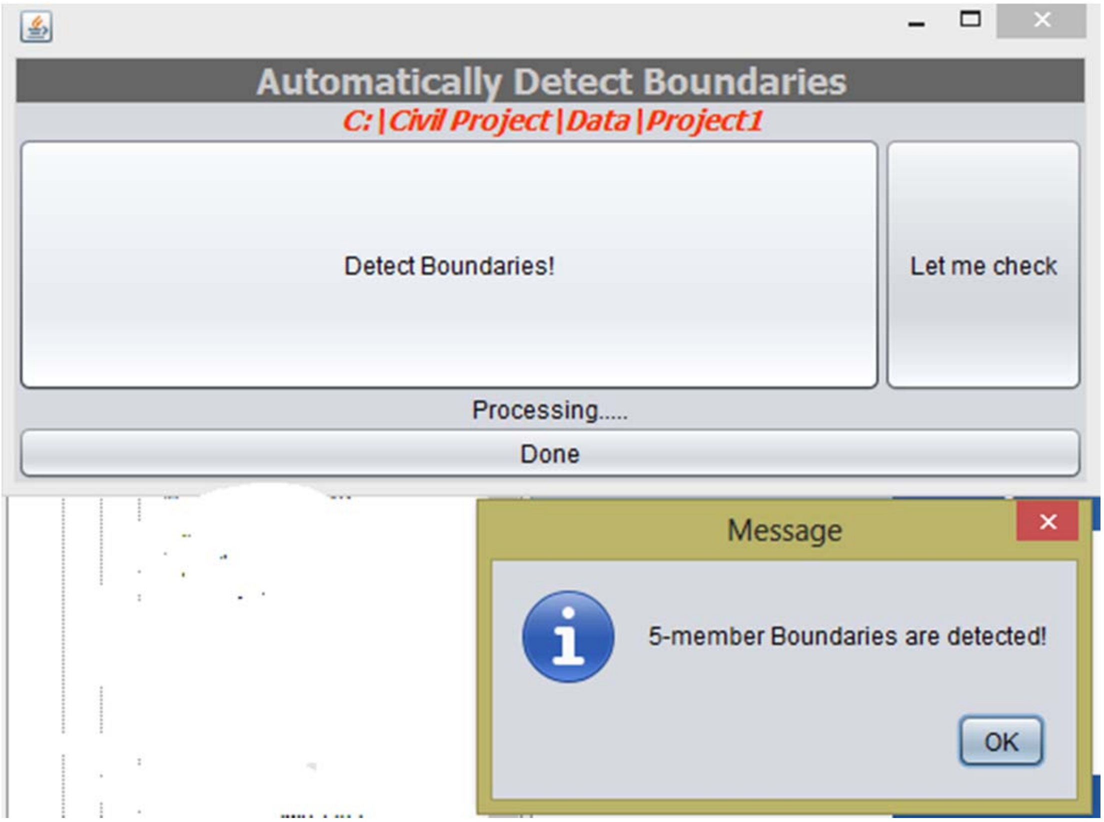
3) Automatic processing window:



4) Automatic detection of boundaries showcasing the appropriate notifications to the users:

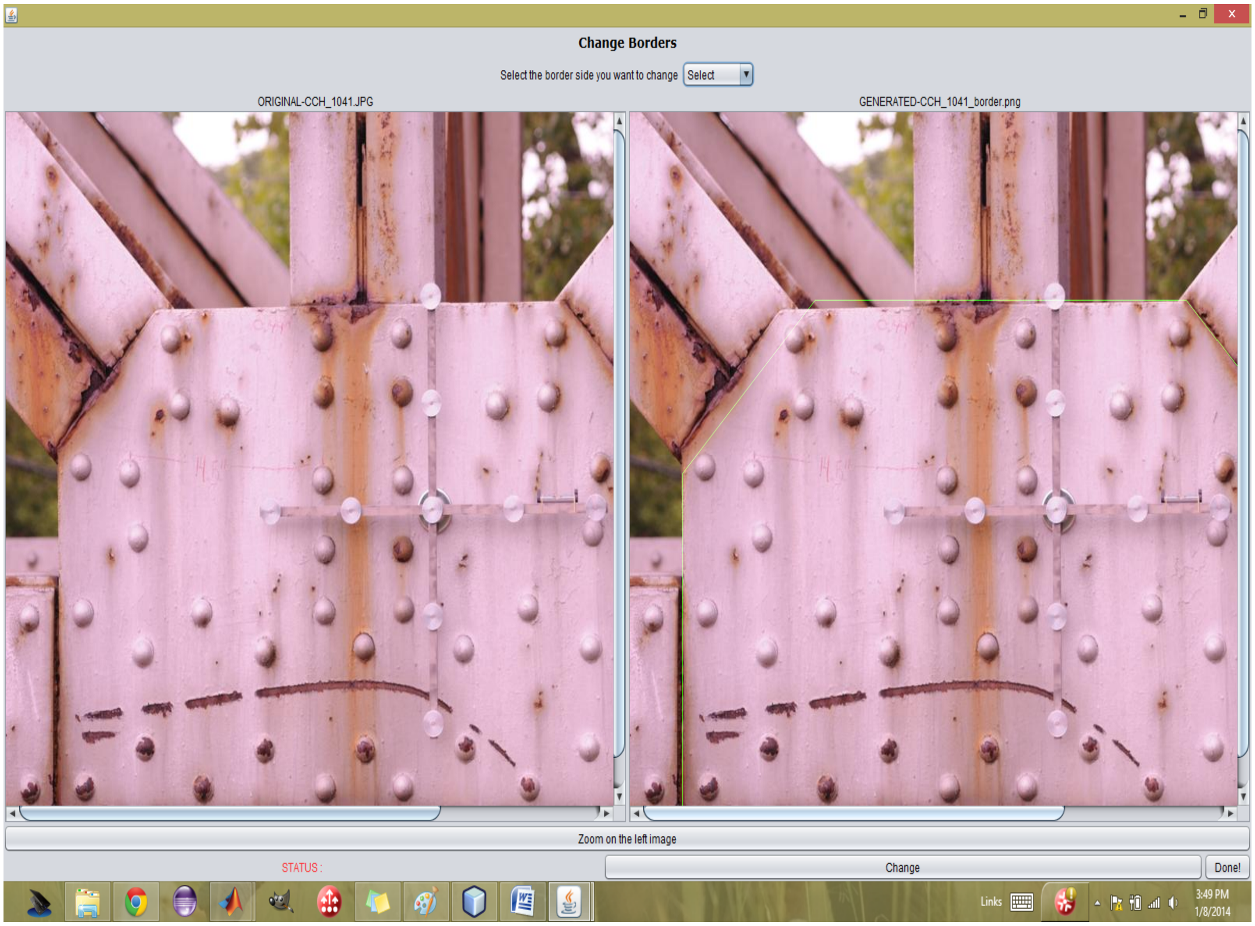


5) Up-to date notifications are made to the user as the processing is under progress.



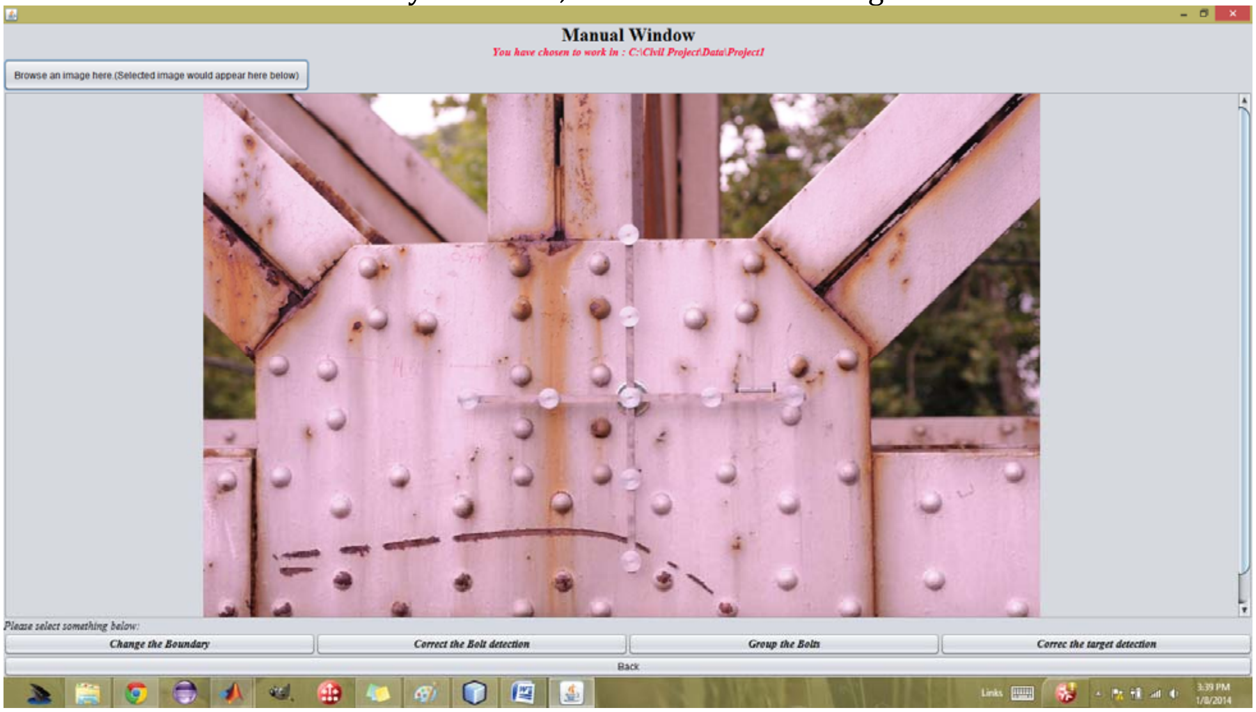
Similarly, automatic detection of bolts and targets are performed for all the available member plates at once in the selected work directory.

6) The below image shows the original image on the left hand side and the image with the boundary detected on the right hand side. The user can correct the boundary by clicking on the correct end points.

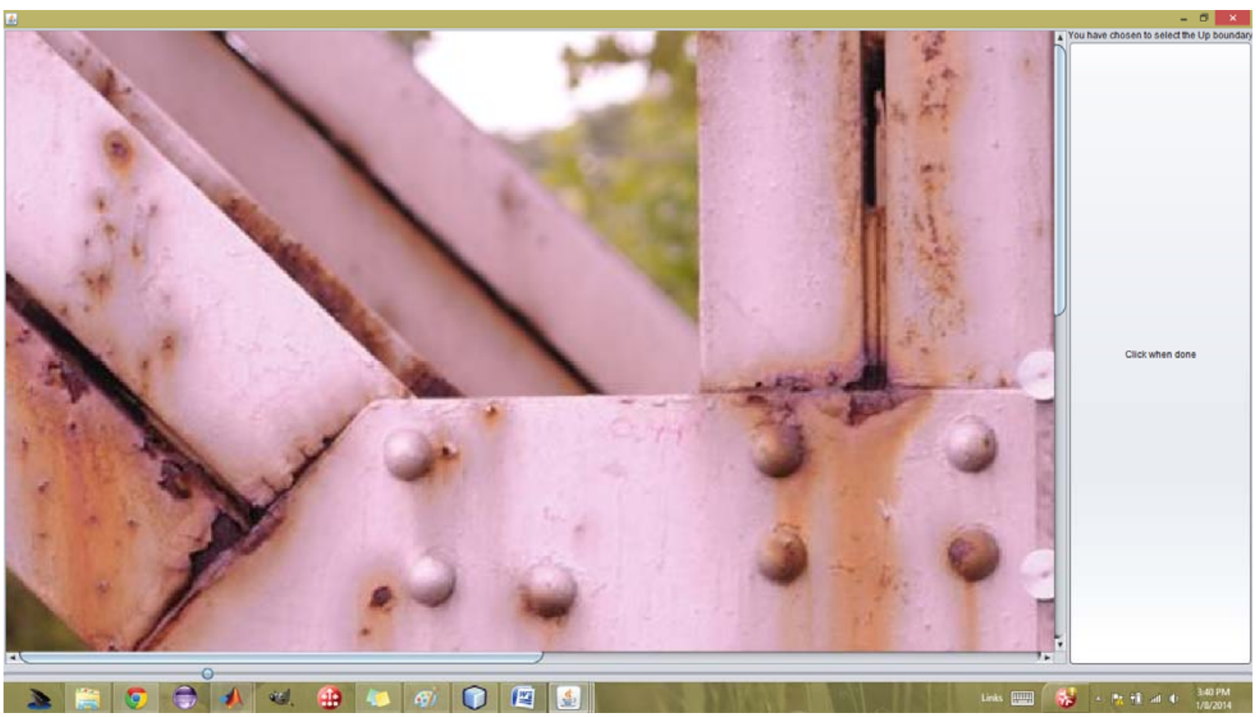


The same is the case for all the bolt and targets detected images.

6) The below screen shot shows the window where a particular image can be selected to perform the manual correction of boundary detection, bolt detection and target detection.



7) To enable a precise selection, a zooming facility is now provided. Below, the picture shows the image zoomed to approximately 400% .



Implemented Improvements in the past quarter include:

1) *Working directory** can now be located anywhere in the system unlike earlier:

Earlier it was mandatory to have all the images to be processed in a particular folder structure. This restriction is now removed. The images can now be anywhere in the system. However, they have to be segregated based on the member types. This requirement is clearly documented in the usage manual.

2) One time selection of the working directory.
The navigation on the GUI has been modified to facilitate the user selection of the working directory once for all. This selection is made using a file chooser in the beginning and all the further processing is done in the selected location.

3) Automatic processing of different member plates all at once.
Earlier, for detection of bolts and boundaries on images, selection of each member type folder was required. This is now not needed. With just a click of button, all the images in each member type folder are processed automatically.

4) Look and feel of the user interface has been improved.
A background color has been included in each window for a better look and feel of the interface.

5) Perspective removal using RANdom SAmple Concensus (RANSAC)
We developed a robust method to remove projective transform from a distorted image. The steps of the method are described as follows:

Step 1. Detect the corner points of the targets using its color information. This gives 'distorted' point locations in the image having projective distortion.

Step 2. Determine the corresponding 'reference' point locations based on the target geometry. This is equivalent to determine the point location in a frontal view image. Therefore, we get the corresponding point pairs in the distorted image and frontal view image. We denote this as"

$$(x \longrightarrow x')$$

where x is a reference point and x' is corresponding distorted point. We assume each of these points are related by the Homography matrix as follows:

$$Hx = x'$$

Step 3. For three targets we get 12 such correspondences (four from each target). Note that all the point correspondences might not be equally accurate due to the presence of noise. Moreover, any false correspondence might have considerable effect of the final output. To handle this issue, we the RANSAC algorithm to find the inliers, i.e. the correspondences which are informative, leaving the erroneous ones.

Step 4. The previous step gives us a set of error-free correspondence of the points in the distorted image and their corresponding reference points. Suppose we have 'n' such correspondences. Now the goal is to find the optimum Homography matrix (H), which corresponds to the projective transformation of the reference points to the distorted points:

$$H\,xi = xi'\text{ , for all } i = 1 \text{ to } n$$

We compute the H matrix such using Maximum Likelihood Estimate (MLE), where the goal to minimize overall error of projection:

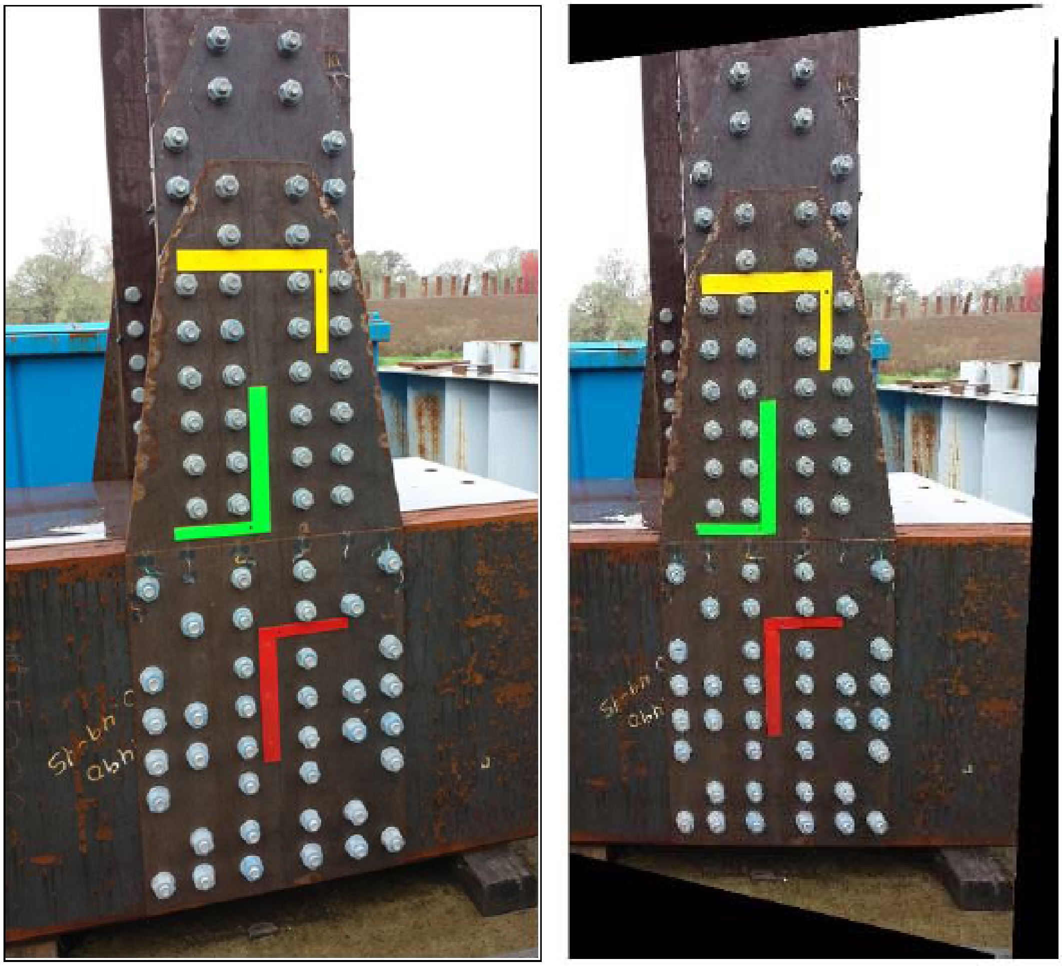
$$e\,(\mathrm{Hx}i, \mathrm{x}i'\,)ni=1,$$

where e(Hxi, x'i) is the error for a single correspondence.

Step 5. We compute the Homography matrix (H), that minimizes the overall error, or in other words, we find the H that best fits to the 'all' point correspondences.

Step 6. H gives the optimum projection matrix which maps reference points to the distorted points. But our goal to remove projection from the distorted image. We find the inverse projection by finding the inverse of H. H-1 = inverse (H). We apply this inverse projection to all the pixels of the distorted image to get the output image without projection.

Figures below illustrate the method:



a) Original image b) Rectified Image using new method

Result is improved dimensional accuracy over entire image using simple and inexpensive image targets.

Task 3: Gusset Plate Analysis
Schedule status: *On schedule*
Percent complete: 10%

Task status: *Manual calculations of gusset plate components according to the latest AASHTO MBE provisions are being coded into the image processing module. Input geometry will be collected from the image by the user and the MBE equations will be used to compute the design capacity. Reporting features and outputs are being developed.*

Task 4: Implementation Example
Schedule status: *On schedule*
Percent complete: 0%

Task status: *Not yet underway*

Task 5: Imaging Data Informatics for Bridge Management
Schedule status: *On schedule*
Percent complete: 10%

Task status: An *ArcGIS model of Bridge of the Gods is under development to link images, image data, design drawings, inspection records, rating reports, etc.*

Task 6: Analysis Software
Schedule status: *On schedule*
Percent complete: 85%

Task status: Analysis software is able to model and analyze the geometric data that are collected from imaging modules. Comparisons of OpenSees solution with ABAQUS for trial gusset plate models are still underway. Although elastic responses are well predicted, some differences have been observed at strength levels. The element formulations have been verified and the differences are attributed to the free meshing algorithms that produce different meshes in the two different analysis software. H-refinement is being studied to resolve these differences. Full-size experimental test results are also being used for analytical comparison with the OpenSees solution.

Anticipated work next quarter:

Task 1: Literature Review- *Continue review and synthesis*

Task 2: Software Development and Data Collection – *Continue working though software to make more efficient and user-friendly.*

Task 3: Gusset Plate Analysis – *Finish Incorporating features to interactively measure dimensions and perform MBE calculations.*

Task 4: Implementation Example - *None*

Task 5: Imaging Data Informatics for Bridge Management – *Continue development of ArcGIS model for Bridge of the Gods to illustrate management of images and metadata (such as drawing, calculations, finite element analysis results).*

Task 6: Analysis Software – *Finalize comparative analysis results with Abaqus and compare with past experimental results. Implement analysis with attached compression truss member stiffness properties. Continue refinement of analysis output (stress outputs).*

Significant Results:

While results are preliminary, the following results are significant:

A revised set of image targets shows good rectification with significantly reduced cost and eliminates the need for standoff correction in the scaling.

The software application can now automate image processing of a general gusset plate. It requires refinement and further development by the research team.

Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).

No significant problems. The process of refining software has been time consuming and iterative. Improvements to the interface and the logic of the work flow also has taken time. This has delayed release of a beta version to TAC members.
We do anticipate release of a trial version at the end of the quarter (Beginning of April). A conference call will be held With the TAC to walk through the beta version.

Potential Implementation:

We anticipate a working version of the software will be available for review by the project participants at the end of the winter quarter.