Using Web Camera Technology to Monitor Steel Construction

Kerry T. Slattery, Ph.D., P.E.
Southern Illinois University Edwardsville
Edwardsville, Illinois

Many construction companies install electronic cameras on job sites that can be monitored remotely through the internet. These pictures provide a qualitative historical record of the construction project, but their utility in measuring construction productivity would be greatly improved if they can be converted to a quantitative format. Currently, a person can inspect each frame and log the time at which each step was completed, but this operation is tedious and expensive. Computer vision technology can be used to interpret the images and automatically quantify the results. Steel frame construction is particularly well suited for automatic monitoring as all structural members can be viewed from a small number of camera locations. A system is being developed using software that interprets a 3-D computer model of the structure to automatically orient the camera to look for individual members. A simple image-processing algorithm can be used to determine whether or not a particular member is in place at any given time. The time at which each member is detected can then be recorded in a spreadsheet format. This information can be analyzed to determine the daily productivity and studied further to improve estimating and efficiency. Results from a simple lab-scale system are presented. Once developed for steel frames, this inexpensive system can be used to study other construction applications of the technology.

Key Words: computer vision, steel construction, construction productivity, web camera

Introduction

"Construction Camera" marketing emphasizes the ability to use the internet to monitor, control, and archive job sites (http://www.webcamstore.com/professional/applications/construction.php). These tools have given the construction professional an additional resource for managing construction; however, storing and reviewing thousands of pictures to document critical events on the job site can be expensive and time consuming. Image processing technology allows a computer to review and analyze the camera output and provide concise data documenting the progress of the construction project. While potential applications for cameras to help monitor and control construction are limited only by our imagination, serious technical obstacles will provide many challenges as this technology develops. For example, cameras may be used to verify geometrical compliance with construction drawings and drive other technology to assist with layout and placement of components. However, positioning and documenting the location of the camera to view critical areas as construction progresses will require state-of-the-art robotic technology.

Research is underway at Southern Illinois University Edwardsville to implement a system to demonstrate an application of web camera technology for construction productivity monitoring that is feasible in the near term with inexpensive technology. This effort has been enhanced by the recent acquisition of an outdoor web camera with full pan/tilt/zoom capability with funding provided by the Southern Illinois Builders Association. The proposed application is to monitor the construction of a steel frame and automatically document the placement time of each member. One camera can view all members of a moderate-sized structure from a single location and robust image processing algorithms are available to determine whether or not a steel member is present at its designed location. Computer software is under development to automatically scan the construction site and record when a member is in place using information from a three-dimensional model of the structure. The output from the system will be a list of all structural members with the time they were placed in a simple format that can be further processed to document and study crew productivity.

Three Dimensional Models

The system under development in this research is designed to provide reliable results using current technology. The strategy is based on the assumption that the software system knows precisely where to look for each member, so the image-processing algorithm just has to determine when something resembling a steel member appears at the predetermined location. Since the camera output is a two-dimensional picture, a computer algorithm is required to determine where a member will appear in that picture given the location and orientation of the camera. This can be easily accomplished if the steel frame is defined in a 3-D format. Conveniently, the structural steel industry is beginning a transition to providing 3-D plans in a standard computer file format designated as the CIMsteel Integration Standards (CIS/2). If this model is not available, an adequate 3-D description can be generated from the project plans.

Camera System

A wide range of web camera systems are available with costs ranging from less than fifty dollars to thousands of dollars. More expensive systems provide higher resolution, higher quality optics, outdoor weather protection, and pan, tilt and zoom (PTZ) control. Software available with most systems allows the user to save images at any time in a standard format.

Requirements

A system for monitoring steel construction can be implemented with either fixed or PTZ cameras. However multiple fixed cameras may be required to view all parts of the structure with sufficient resolution. A single, wide angle camera can be placed to view an entire structure, but it would be difficult to discern individual steel members given the resolution available with most camera systems. Larger structures may require multiple cameras in order to view a member from different angles to distinguish individual beams and columns that are hidden in one camera view. If properly placed, a single PTZ camera that can accurately report its orientation should be able to monitor the status of all members in a moderate-sized steel structure. Other camera configurations can be designed to provide additional coverage when required.

Location Determination

The camera position and orientation must be known in order to calculate the expected location of a member in the camera view. As there are six degrees of freedom, six location parameters must be determined – the X, Y and Z coordinate and rotations about the three axes. While the position can be determined with good accuracy using conventional surveying techniques, the rotations are best determined by observing the location of known points in the picture. An approach has been developed to calculate all six location parameters by noting the location of several known points in the camera image. The user must input the pixel location of each known point in the image using the mouse. Then a least-squared-error approach is implemented using the Solver feature in Microsoft Excel to determine the values of the location parameters (X, Y, Z, θ, ϕ, γ) that minimize the error in the distance. This method provides adequate accuracy for any camera location without the need to survey the location of the point. The incorporation of more known points should reduce the error. Known points can be anything that is clearly visible in the camera image for which the location is available, for example, existing survey markers or column footings. When a PTZ camera is used, the location is determined from one image and subsequent rotation parameters are calculated using the relative rotations.

Image Analysis

Images from the camera must be captured, stored and logged so the time and camera location are known. They may be stored in any standard format but are usually converted to a bitmap (*.bmp) format for processing. While the bitmap format is usually the most costly in terms of computer memory, conversions to and from formats that do not store the color of individual pixels should be avoided as resolution may be lost.

Acquisition

Most web cameras are equipped with software to store the current image in a picture file. Automation for construction monitoring requires access to computer subroutines to acquire the image and save it using a file name that allows the user to determine the time and location. A computer program may also perform image analysis in real time allowing the file to be deleted. Many camera vendors supply the required software to interface with the camera using popular compilers such as Visual Basic and Visual C++.

Processing

Image processing involves a pixel-by-pixel analysis of the colors. The bitmap image is converted to an array of one-byte integers with values from 0 to 255. A set of three values gives the intensity of the red, green and blue color for each pixel. Computer algorithms are used to identify significant changes in color among adjacent pixels to identify objects. Image processing is a complex technology which must frequently be tailored to each new application. The proposed system uses simple, reliable methods such as edge detection to complete the required analysis.

Result Reporting

Result reporting can be tailored to the project requirement. The only required results are the date and time each member was first identified in its design location. These are output to a text file which can be printed or read into a spreadsheet or other analysis software. Additional results from the analysis can be output as required.

Laboratory System

A small-scale system was developed to demonstrate the feasibility of this approach for monitoring steel construction. A model of an eight-member steel structure was created using K'nex™ blocks. The construction site was a sheet of "peg board" with holes spaced one inch in each direction. This provided a grid to facilitate accurate placement of the structure and "known points." Three fixed cameras were placed so they could see the entire structure and six known points. Figure 1 includes a picture taken from one camera. The short green posts are known points with longer posts of varying colors to identify each point. Figure 1 illustrates the setup step in which the pixel locations of each known point are recorded. Point 5 is at pixel location (119, 176) and had a RGB color of (64, 69, 63).

Figure 1. Known points are identified in each view.

"Construction" begins after the camera locations are determined. Figure 2 shows the results of the analysis after five members have been placed. The image-processing algorithm looks at each member location to determine whether or not the intensity of red in the pixels crosses the threshold indicating that a red post is in place. The program changes the color of those red pixels to black and highlights those that are members in the structure in bright red. The total number of members placed in then displayed. Figure 3 shows the completed structures with all eight members identified by the computer program.

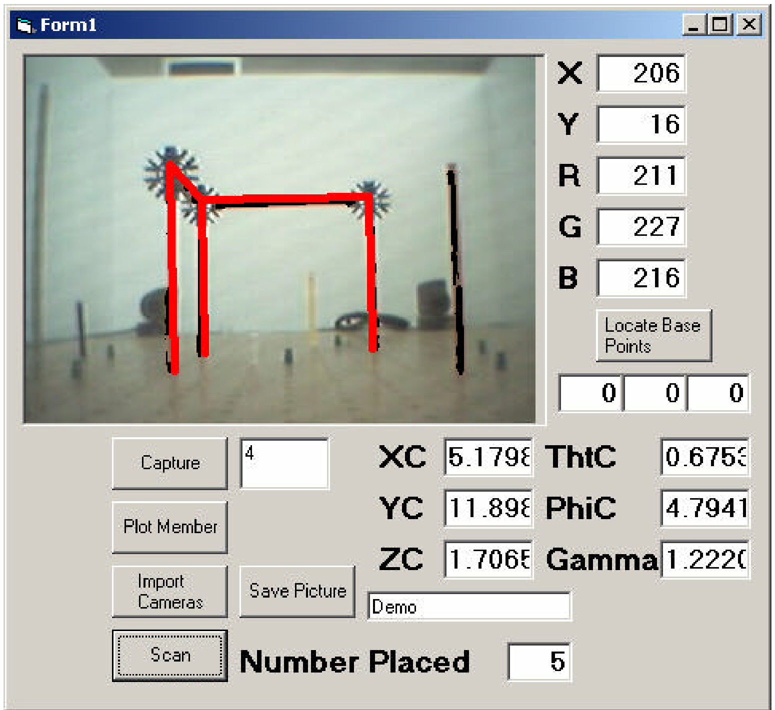

Figure 2. Partially completed structure is scanned to identify members in place.

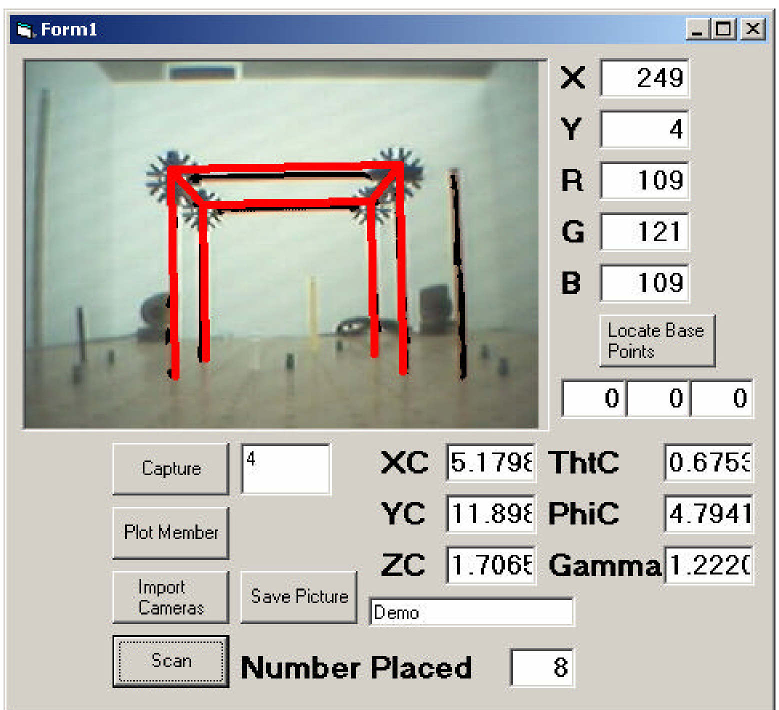

Figure 3. All eight members are recognized.

Conclusions

Current web camera technology being deployed on construction sites by many general contractors to monitor, control and archive project progress can also be used to generate quantitative data documenting project progress. An application – monitoring steel frame erection – has been selected to demonstrate the feasibility of using image processing methods to automatically identify the occurrence of significant events in construction. The work is proceeding toward full-scale implementation based on a successful demonstration using a small-scale model. The software developed will be available to be used with current cameras to provide a report of member placement times for each structural component. This data can then be analyzed to study productivity for future estimating and productivity improvement.