USING WEB CAMERA TECHNOLOGY TO MONITOR STEEL CONSTRUCTION

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ABSTRACT : Computer vision technology can be used to interpret the images captured by web cameras installed on construction sites to automatically quantify the results. This information can be used for quality control, productivity measurement and to direct construction. Steel frame construction is particularly well suited for automatic monitoring as all structural members can be viewed from a small number of camera locations, and three-dimensional computer models of steel structures are frequently available in a standard electronic format. A system is being developed that interprets the 3-D model and directs a camera to look for individual members as regular intervals to determine when each is in place and report the results. Results from a simple lab-scale system are presented along with preliminary full-scale development.

Key words : computer vision, steel construction, construction productivity, web camera, image processing

1. INTRODUCTION

"Construction Camera" marketing emphasizes the ability to use the internet to monitor, control, and archive job sites. 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. 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/ computer vision 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.

2. 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) [1,2]. If this model is not available, an adequate 3-D description can be generated from the project plans.

3. 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.

3.1 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.

3.2 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. If the camera has a zoom capability, a seventh parameter, pixels per radian, must also be determined. 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 an optimization approach is implemented using the Solver feature in Microsoft Excel to determine the values of the location parameters (X, Y, Z, φ, θ, γ) that minimize the sum of the squares of the distances between the input pixel locations and the calculated pixel locations for all known points. The angle φ is the orientation of the camera in the X-Y plane relative to the X axis and θ is relative to the positive Z axis (i.e. the vertical axis) with $\theta = \pi/2$ being horizontal. The angle γ is the roll angle of the camera about the axis normal to the center of the lens; it is typically near zero. 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 output from the camera hardware.

4. 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 generally 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.

4.1 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++.

4.2 Processing

Image processing begins with 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. An idealized setup was used for the laboratory system in which the cameras were looking for red members against a white background which greatly simplified the image processing algorithm. More sophisticated image processing computer algorithms are being employed in the full-scale development to work under realistic conditions.

Computer Vision and Image Processing (CVIP) tools developed at SIUE and available in the public domain were used to analyze pictures of actual steel structures. CVIPtools software consists of about 200 algorithms and functions to develop computer vision and image processing applications [3]. The CVIPtools dynamic link library was incorporated in a Microsoft Visual Basic 6.0 program to develop this application. A color bitmap of the picture is initially processed through a smoothing filter (Gaussian blur filter) to mitigate noise effects. The Principal Components Transform/Median (PCT/Median) segmentation algorithm was then applied to the resultant image to find meaningful parts of the image and features of interest. The image was then converted to a gray scale, and edge detection was performed using a Canny filter. An option for Histogram stretch is also available to improve the contrast of the image, if necessary. Each image processing operation requires the user to find values for one or more parameters to effectively analyze each picture.

Edge detection results are plotted in a black and white image with edges shown as black pixels. The on-going development of algorithms to identify steel members is discussed later.

5. 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.

6. 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 at 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 posts are known points with longer posts of varying colors used to identify each point. Figure 1 illustrates the setup step in which the pixel locations of each known point are recorded. In this example Point 5 is at pixel location (119, 176) and had a RGB color of (64, 69, 63).

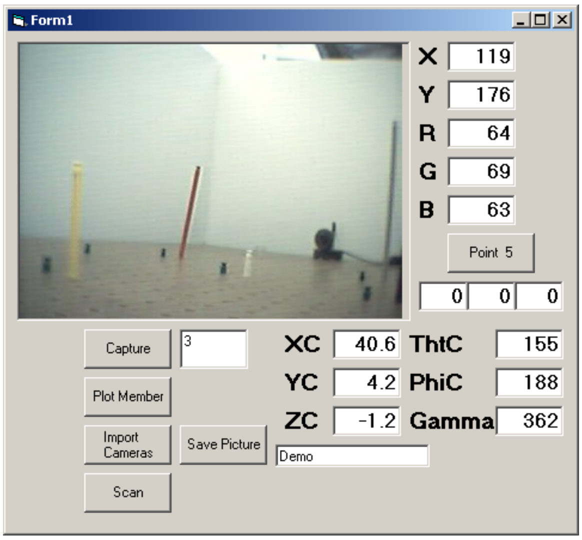

Figure 1. Known points are identified in each view

"Construction" begins after the camera locations are determined. The main members in the K'nex® structure are red. Figure 2 shows the results of the analysis after five members have been placed. In the crude approach used in the laboratory system, 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 member is in place. The program then highlights regions that are determined to be members in the structure. The total number of members placed is then displayed. Figure 3 shows the completed structure with all eight members identified by the computer program.

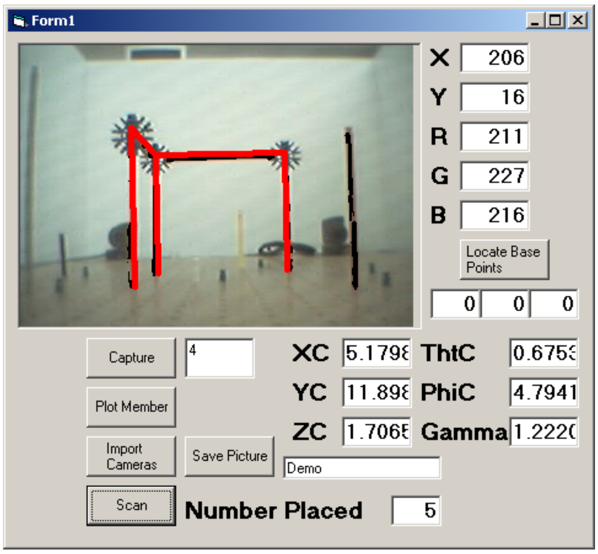

Figure 2. Partially completed structure is scanned to identify members in place

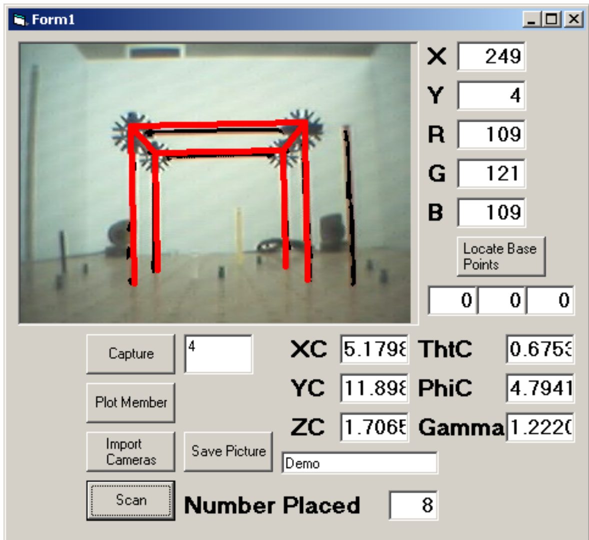

Figure 3. All eight members are recognized

7. FULL SCALE DEVELOPMENT

Photographs were taken of a partially-completed steel structure to develop and test the camera location algorithms and image processing techniques described above. The photograph is displayed in Figure 4. The spatial coordinates (X,Y,Z) of eight known points distributed throughout the completed structure were determined from the structural drawings and entered in an Excel worksheet. The pixel coordinates of each of those points in the picture were then determined and recorded. The Solver algorithm was used to estimate the camera location, orientation and zoom setting. Approximate values for each of these seven parameters are initially input in cells in the spreadsheet, and pixel coordinates for each known point are calculated based on this assumption. The squares of the distances between the calculated pixel coordinates and the actual values are summed. The Solver is programmed to change the seven parameter values to minimize the sum of the squared errors.

The results for the camera location for Figure 4 are displayed in Table 1. The position units are in feet and angles are in radians. The base elevation is Z = 100 feet. The X axis runs from left to right and the camera is pointing generally in the positive Y direction.

Figure 4. Steel frame under construction

Table 1. Camera position parameters

Parameter	Value
X0	86.90028
Y0	-114.81
Z0	99.78515
φ	1.829863
θ	1.423491
γ	0.012633
Pixels / Radian	581.328

Figure 5 shows the edges in the processed image. The image processing algorithm successfully found the edges of members in a real-world application. Obviously, existing natural features and construction around the site as well as in-place members will complicate the development of computer vision algorithms to identify newly placed members.

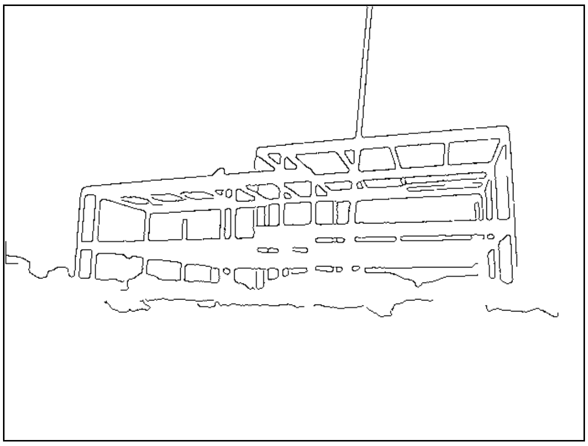

Figure 5. Edges detected in the picture

Figure 6 shows the superposition of the expected location of the first floor portion of a column edge. It falls within one or two pixels of the actual location due to expected error in the calculation of camera location. The development of algorithms to reliably determine when a member is in place is the focus of current research.

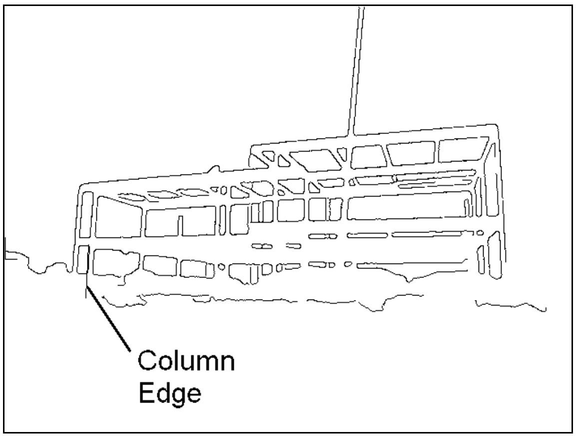

Figure 6. The expected position of an edge is displayed

8. CONCLUSION

Web camera technology deployed by many general contractors on construction sites 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. An image processing approach to detect edges in a steel frame under construction has been successfully designed. Future work will focus on the development of a system 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 improvement.

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