Automated In-Placed Brick Counting for Façade Construction Progress Estimation

Linda Hui[1], Manwoo Park[2] and Ioannis Brilakis[3]

[1]Department of Engineering, University of Cambridge,UK, lindahui.civil@gmail.com
[2]Department of Civil and Environmental Engineering, Myongji University, Republic of Korea, mwpark@mju.ac.kr
[3]Ioannis Brilakis, Department of Engineering, University of Cambridge, UK, ib340@cam.ac.uk

ABSTRACT

The prevalent method of measuring progress is through manual site surveys. These surveys are tedious and time consuming. They are also approximate, as counting the number of bricks in-place to compare against those ordered is a very laborious task compared to its end value. In previous research, the authors are able to count the number of bricks using single images. This paper presents a novel of a method for counting bricks in-placed to automate the brick site survey using digital videos. This method improves the brick counting method on image to a continuous counting in video frames. It can compare the brick detection results in successive frames and accumulate the counts when new bricks appear. The method works by the following two steps. (1) Count the number of bricks on the brick façade on a single video frame. (2) Track the detected bricks with a kernel-based tracking approach to compare the difference in successive video frames to avoid double counting, and add new bricks to the count upon the appearance in the successive video frames. This paper also demonstrated a performance comparison of kernel-based tracking approach and point-based tracking approach. Test results demonstrate that this method is capable of counting the number of bricks on a brick façade with acceptable error.

INTRODUCTION

The nature of the construction industry is characterized by its uncertainty and complexity. To alleviate the effect of uncertain factors and minimize variations from original plans, project progress should always be carefully monitored so that project managers can respond quickly to the changes and keep the project within the budgeted cost and time.

Emerging technologies have been introduced to increase the automation of measuring progress. The technologies include laser scanning (Su et al. 2006; Bosché and Haas 2008; Turkan et al. 2012) and stereo-vision techniques (Golparvar-Fard et al. 2009). Both approaches generate point-clouds to reconstruct 3D models of the buildings and structures in progress. However, the former uses expensive equipment and requires trained experts while the latter has downsides of reduced accuracy (Dai et al. 2013).

This paper addressed a bricks counting progress monitoring method (Hui and Brilakis 2013), and extend the application towards video data. By using the 2D homography to relate two images, the newly-detected bricks can be distinguished and added to the detection result. The proposed method was tested on images and videos of brick façade structures. The test results showed that 99.8% precision and 98.7% recall are achievable if the brick façade region is provided.

BACKGROUND

Traditional progress monitoring relies mainly on manual inspection of the construction site. Progress is estimated based on the completion of activities or milestones. Contractors usually organize a weekly progress meeting to estimate the progress is estimated based on the cost of materials installed as well as the work completed by contractors, subcontractors, and/or the project owner's own construction employees (U.S. Department of Commerce 2013).

As part of this research, interviews were carried out with 3 bricklaying subcontractors and 4 brick quantity surveying firms in the United Kingdom, to inquire about the current practices of progress measurement of brick wall construction. According to the interviews, current quantity surveying for brickwork is not performed accurately. In small scale sites, the quantity is generally estimated based on the specific milestone of the project, or based on the material quantity in stock. On the other hand in large scale sites, the contractor hires a quantity surveyor who pays a visit once a month to the site to estimate the construction progress. Façade area measurement will be taken and multiplied by the standard value of brick counts per unit area to estimate the total number of bricks. The quantity surveying remains a rough estimation. Thus, project managers have difficulty in acquiring accurate quantity data to make informed decisions.

Existing data collection techniques range from laser scanners to digital images and videos. LADAR (LAser Detection And Ranging) has been used to generate 3D building models (Bosché and Haas 2008; Turkan et al. 2012). The acquired data is a point cloud within a 3D coordinate system described by x, y and z coordinates. The main advantage of laser scans is the high accuracy. However, high maintenance and equipment costs limit the use of these techniques (Dai et al. 2013). Each scan takes a long time, and it allows only surface scanning. The lack of surface scans can be rectified by multi-position scans, but this even worsens the condition of long time scans significantly (Fathi and Brilakis 2011).

Another approach to as-built data extraction is to use images and videos. The most intuitive approach is pairwise comparisons of 2D image sequences from a fixed camera. The difference in the succeeding images is calculated to identify sections where changes in construction happened (Ibrahim et al, 2009; Zhang et al., 2009). 3D reconstruction of building structures using multiple view geometry has also been investigated. Images or videos of a building taken during its construction are used to generate sparse point clouds and create a 3D model of the building (Golparvar-Fard et al. 2009; Brilakis et al. 2011; Rashidi et al. 2011). However, recent work has shown that the points of the 3D reconstruction are not as accurate as the points obtained by laser scans (Klein et al. 2012). The increased effort in generating a 3D point cloud from images as contrasted with laser scan point clouds lead up to 7 hours of additional computational time for a single column for image processing (Golparvar-Fard et al. 2011).

Hui and Brilakis (2013) presented a new method for progress estimation. The method is comprised of edge map generation and brick boundary extraction. First, contours are registered from the edge map. Then, each contour is approximated by a minimum-area rectangle that encloses the contour. The erroneous rectangles are removed from the list by filtering relatively large or small rectangles. The criteria of the size filtering are determined based on the average and standard deviation of rectangles' dimensions. Rectangles, of which the width or height deviates from the average by more than the standard deviation, are removed from the list. Also, if two or more rectangles are overlapped each other, the smallest is remained in the list. The database keeps a record of the location and size of detected bricks in pixel coordinate system. However, the number of bricks in one single image may not represent whole facade.

This paper presents the improvement of the brick counting method by using a video data of the site. This research aims to: (1) improve the algorithm to locate and link each bricks, (2) devise a strategy to increment counts when new bricks appear while avoiding double counting, and (3) validate the performance of the proposed solution.

METHODOLOGY

In response to the objective stated above, this paper improves the existing method of brick counting by comparing the result with consequencing video frames. Figure 1 illustrates the overall framework of the proposed method, which consists of three main processes – brick detection, coordinate relation, and ROI (region of interest) determination. This paper focuses on the second process. While the "brick detection" results are coordinates of bricks locations independent of video frames, "coordinate relation" compares the independent results to isolate freshly-detected bricks at every frame and add counts cumulatively. Bricks should be counted only once at their initial detection. Therefore, newly-detected bricks and already-counted bricks can be distinguished. The method introduces a new coordinate system on the façade plane. The coordinate conversion between the image coordinates and the wall coordinates is made through 2D homography (Hartley and Zisserman 2004). For every detected brick, its wall coordinate is calculated and compared with previous detection records to determine whether it has already been counted in preceding frames or not. The brick count is updated every frame by adding the number of newly-detected bricks. Although this paper does not address ROI (Region of Interest) determination, it is worthwhile to note that ROI determination is required to minimize false positives and achieve higher precisions. The following sections detail the brick detection and the coordinate relation.

The use of video can resolve occlusion and incompleteness in the single image brick detection. The brick detection can be updated in every new frame. Using the detection method, a list of brick locations is generated in a pixel coordinate system. A new 2D coordinate system on the façade plane is established by manual selection of 4 points in the first frame and retained throughout the video to provide a standard measure in bricks comparison. The 4 points should be corners of a rectangle on the real façade plane. The top left point is selected as the origin, and two axes are

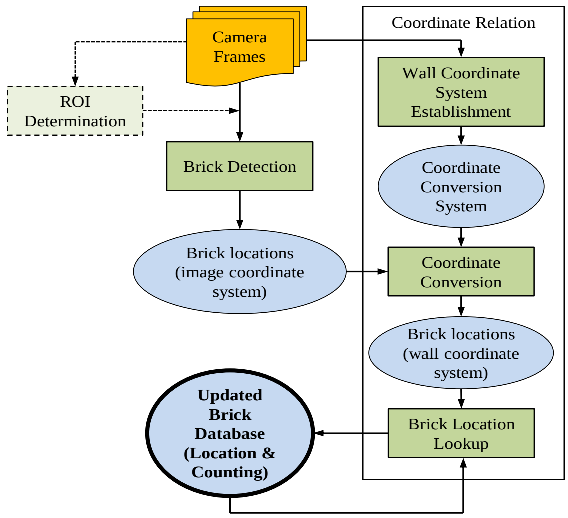


Figure 1. Overall framework of the brick counting solution

set accordingly as illustrated in Figure 2. A user picks 4 points P_1-P_4 that corresponds to a rectangle ($p_1p_2p_3p_4$) on the facade plane. The new coordinate system is created having the origin at p_1, and two axes (s, t) in the directions of p_1p_2 (→) and p_1p_4 (↓). The dimensions of the rectangle ($p_1p_2p_3p_4$), *w* and *h*, can be any values since the wall coordinate system is not used for absolute positions, but for relative positions to differentiate the bricks.

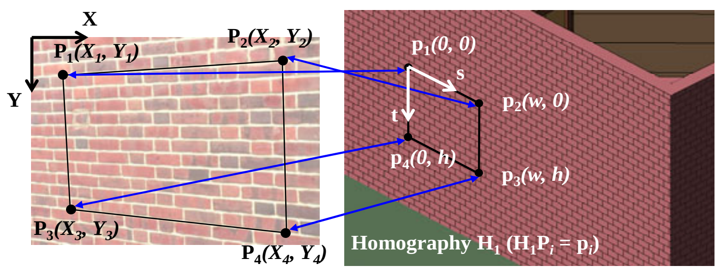


Figure 2. Wall coordinate system establishment

Once the new coordinate system is established, it is necessary to calculate a homography (H_n) that relates the new system with the image coordinate system. 4 or more pairs of corresponding coordinates are required to calculate the homography, a 3 by 3 matrix. For the first frame, the homography (H_1) is calculated such that it satisfies $H_1P_i = p_i$ for i = 1, 2, 3, and 4 (Hartely and Zisserman 2004). While the wall coordinates of the 4 points (p_1-p_4) are fixed, the image coordinates (P_1-P_4) change according to the camera movements. Therefore, the homography needs to be updated at every frame. For this purpose, 4 or more feature points are detected by the FAST (Features from Accelerated Segment Test) detector (Rosten and Drummond 2006) in the first frame, and then tracked by the KLT tracker (Baker and Matthews 2004) throughout the video. The FAST detector has the advantage of fast processing, and the KLT tracker is the most well-known point tracking method which has been used in various applications including object tracking and 3D reconstruction. Figure 3 shows the workflow of the homography calculation. The FAST detector locates good features to track ($Pt_{i,1}$) in the first frame and then their wall coordinates (pt_i) are calculated by the equation, $pt_i = H_1Pt_{i,1}$. For n-th frame for n > 1, the KLT tracker locates the detected features ($Pt_{i,n}$). Then, the homography (H_n) is calculated such that it satisfies $H_nPt_{i,n} = pt_i$ for i = 1, 2, 3, …, m_n, where m_n is the number of tracked feature points at the n-th frame.

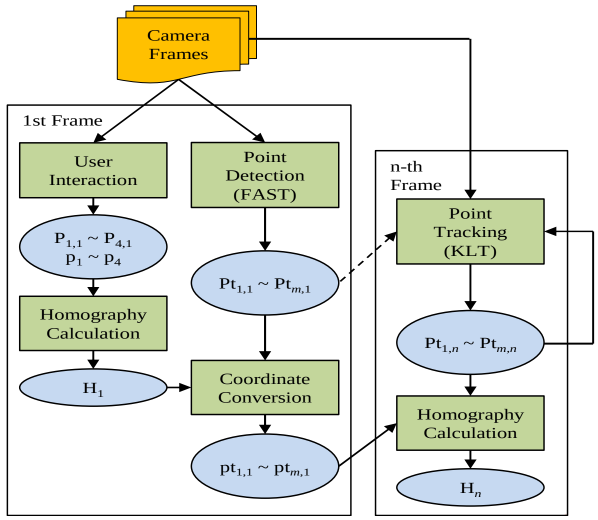


Figure 3. Homography calculation

Each detected brick is represented by a rectangle in an image. The image coordinates of the rectangle corners are converted to the wall coordinates using H_n. From the detection results, if the centroid is contained in any of the previously detected bricks, they are regarded as a same brick. Figure 4 illustrates a simple case of updating brick counts. Green and blue boundaries indicate newly-detected and already-counted bricks, respectively. In Figure 4, two bricks are detected both in the first (A and B) and the second frame (E and F). In the first frame, all detected bricks are counted and their wall coordinates are stored in the brick identity database. In the second frame, E is found same as B because of their similar wall coordinates whereas F is determined new, which increment the count by 1. The brick database is also updated by storing the wall coordinate of F.

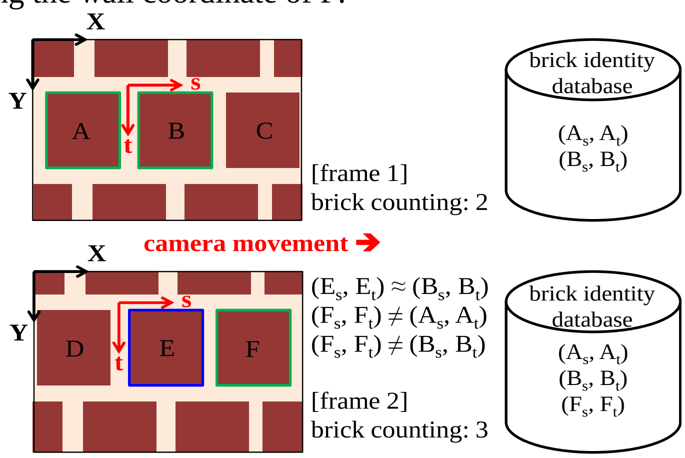


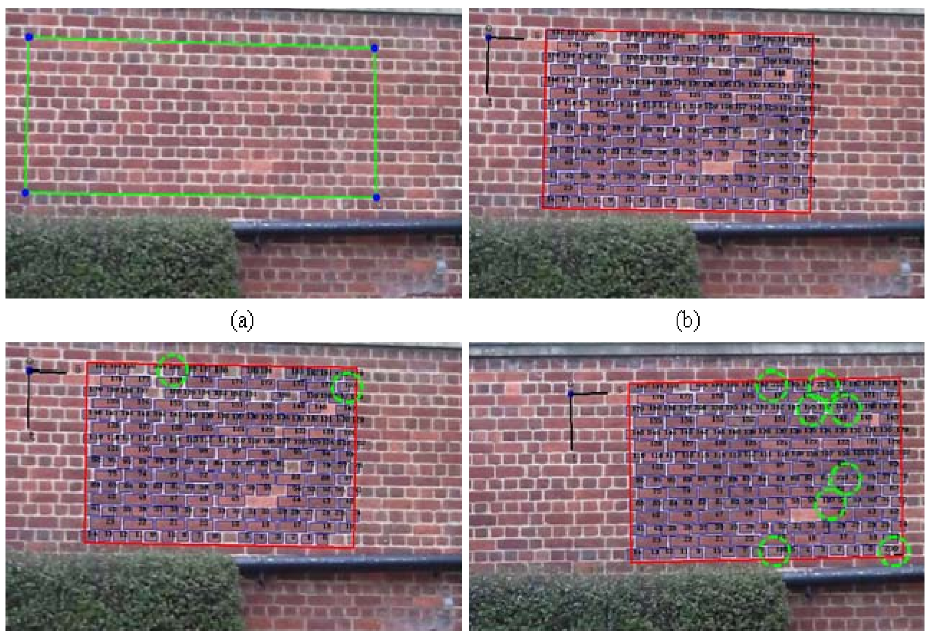
Figure 4. The update of brick counting based on wall coordinate system (s, t)

EXPERIMENTS AND RESULTS

The method was implemented using Microsoft Visual C# in .NET Framework 4.0 environment. The validation was done on images and videos of red brick walls.

The cameras used are a Canon VIXIA HF S100, and a Sony Xperia TX smart phone. The testing images are in the size of 640x480 pixels, and the testing videos have the high definition resolution of 1920x1080 full HD videos. The performance is evaluated based on precision (TP / (TP + FP)) and recall (TP / (TP + FN)). While TP (true positive) is the number of correct detections. FP (false positive) is the number of incorrect detections. FN (false negative) is the number of missed bricks. The proposed method was tested on 10 video samples. The ROI is determined manually in the first frame. The brick counting finishes when no further improvement is identified for several seconds.

Figure 5 demonstrates the cumulative counting procedures. Figure 5(a) shows the manually selected 4 points for ROI. In Figure 5(b)-(d), ROI is shown in red, and the established wall coordinate system (s, t) is displayed on the left of the ROI. The bricks are counted and numbered. The counting is terminated at the 37th frame where 8 additional bricks can be observed (dotted circles in Figure 5(d)). All previously detected bricks are retained in Figure 5(d) with the same label numbers. The origin and the directions of the wall coordinate system are maintained consistent throughout the video.



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

Figure 5. Cumulative brick counting in Video 10: (a) 4 points selected for the wall coordinate system and counting results of (b) the 1st, (c) 3rd, and (d) the last frames

Table 1 summarizes the results of the 10 videos. The actual numbers of the bricks inside the ROIs range from 137 to 579 depending on the videos. For all videos, 0.3-5.2% of increase in recall is observed. It also accompanies the enhancement of counting accuracy. On the other hand, slight decrease in precision is exhibited in two cases (Video 3 and 5), which is attributed to a few additional false positives in intermediate frames. However, the variations are limited to 0.1-0.3%, which are relatively smaller than the recall increments. Integrating the brick counts of the ten videos results in 99.8% precision and 98.7% recall. The results signify that the proposed method. can count brick more accurately by using videos.

Table 1. Precision and recall of brick counting using videos

Video (# of bricks)	Frame	Precision (%)	Recall (%)	Accuracy (%)	Increment (%)		
					Precision	Recall	Counting Accuracy
1 (192)	First	100	97.9	97.9	0	2.1	2.1
	Last	100	100	100			
2 (347)	First	99.7	98.3	98.6	0	1.4	1.4
	Last	99.7	99.7	100			
3 (579)	First	99.2	90.7	91.4	-0.1	5.2	5.4
	Last	99.1	95.9	96.8			
4 (207)	First	100	97.6	97.6	0	2.4	2.4
	Last	100	100	100			
5 (406)	First	100	92.9	92.9	-0.3	4.1	4.4
	Last	99.7	97	97.3			
6 (356)	First	100	99.7	99.7	0	0.3	0.3
	Last	100	100	100			
7 (390)	First	100	97.2	97.2	0	2.8	2.8
	Last	100	100	100			
8 (137)	First	100	98.5	98.5	0	0.8	0.8
	Last	100	99.3	99.3			
9 (364)	First	100	99.7	99.7	0	0.3	0.3
	Last	100	100	100			
10 (204)	First	100	93.1	93.1	0	5.9	5.9
	Last	100	99	99			

CONCLUSION

The acquisition of as-built information relies mainly on manual site surveys, which are labor-intensive, time-consuming, and subjective. This paper presents a automated method to count the number of bricks on a façade with video data. The method detects individual bricks in video frames and counts them by accumulating the detection results over the frames. Taking advantage of the two distinct colors of brick and mortar, the detection algorithm recognizes in video frames. The wall plane coordinate system is introduced to differentiate newly-detected bricks from already-counted bricks. Experiments are conducted on images and videos of brick wall façades. The experiments show that bricks detection results can be enhanced by using videos instead of single image. the proposed method could count the number of bricks with 99.8% precision and 98.7% recall.

ACKNOWLEDGEMENTS

This material is based upon work supported by National Science Foundation under Grants No. 1031329 and Myongji University. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of National Science Foundation and Myongji University.

REFERENCES

Baker, S., and Matthews, I. (2004). “Lucas-kanade 20 years on: A unifying framework,” International Journal of Computer Vision, 56(3), 221-255.

Bosché, F., and Haas, C. T. (2008). “Automated retrieval of 3D CAD model objects in construction range images.” Automation in Construction, 17(4), 499-512.

Brilakis, I., Fathi, H., and Rashidi, A. (2011). "Progressive 3D reconstruction of infrastructure with videogrammetry." Automation in Construction, 20(7), 884-895.

Dai, F., Rahidi, A., Brilakis, I., and Vela, P. (2013). "Comparison of Image-Based and Time-of-Flight-Based Technologies for Three-Dimensional Reconstruction of Infrastructure." Journal of Construction Engineering and management, 139(1), 69-79.

Fathi, H., and Brilakis, I. (2011). "Automated sparse 3D point cloud generation of infrastructure using its distinctive visual features." Advanced Engineering Informatics, 25, 760-770.

Golparvar-Fard, M., Peña-Mora, F., Arboleda, C. A., and Lee, S. H. (2009). "Visualization of construction progress monitoring with 4D simulation model overlaid on time-lapsed photographs." Journal of Computing in Civil Engineering, 23, 391-404.

Golparvar-Fard, M., Bohn, J., Teizer, J., Savarese, S., and Pena-Mora, F. (2011). "Evaluation of image-based modeling and laser scanning accuracy for emerging automated performance monitoring techniques." Automation in Construction, 20(8), 1143-1155.

Harris, F., and McCaffer, R. (2013). Modern construction management, Wiley.com.

Hartley, R., and Zisserman, A. (2004). Multiple view geometry in computer vision, Cambridge University Press, Cambridge, UK.

Howell, G. A. "What is lean construction-1999." Proc., 7th Annual Conference of the International Group for Lean Construction, IGLC-7, 1-10..

Hui, L., Brilakis, I. (2013) " Real -Time Bricks Counting for Construction Progress Monitoring ", Proceedings of the 2012 ASCE International Workshop on Computing in Civil Engineering, 23-25 June 2013, Los Angeles, CA, USA

Ibrahim, Y. M., Lukins, T. C., Zhang, X., Trucco, E., and Kaka, A. P. (2009). "Towards automated progress assessment of workpackage components in construction projects using computer vision." Advanced Engineering Informatics, 23(1), 93-103.

Klein, L., Li, N., and Becerik-Gerber, B. (2012). "Image-based verification of as-built documentation of operational buildings." Automation in Construction, 21, 161-171.

Mansfield, N., Ugwu, O., and Doran, T. (1994). "Causes of delay and cost overruns in Nigerian construction projects." International Journal of Project Management, 12(4), 254-260.

Rashidi, A., Fathi, H., and Brilakis, I. (2011). "Innovative Stereo Vision-Based Approach to Generate Dense Depth Map of Transportation Infrastructure." Transportation Research Record (2215), 93-99.

Rosten, E., and Drummond, T. "Fusing points and lines for high performance tracking." Proc., Computer Vision, 2005. ICCV 2005. Tenth IEEE International Conference on, IEEE, 1508-1515.

Su, Y., Hashash, Y., and Liu, L. (2006). "Integration of construction as-built data via laser scanning with geotechnical monitoring of urban excavation." Journal of Construction Engineering and Management, 132(12), 1234-1241.

Thomas, P. I. (1999). The Contractor's Field Guide, Prentice Hall.

Turkan,Y., Bosche, F., Haas, C.T., and Haas, R. (2012) "Automated progress tracking using 4D schedule and 3D sensing technologies." Automation in Construction, 22, 414-421.

U.S. Census Bureau (2012). "Construction Progress Reporting Survey (CPRS) ", <http://bhs.econ.census.gov/bhs/cprs/about.html>

Vermont-Government-Website (2003). "Reducing Vermont's Construction Waste ", <http://www.anr.state.vt.us/dec/wastediv/recycling/CandD.htm>.

Wayne, D. (2004). Builder's Essentials: Estimating Building Costs, R S Means Co, Kingston, Massachusetts, U.S.A., 2004.

Zhang, X., Bakis, N., Lukins, T. C., Ibrahim, Y. M., Wu, S., Kagioglou, M., Aouad, G., Kaka, A. P., and Trucco, E. (2009). "Automating progress measurement of construction projects." Automation in Construction, 18(3), 294-301.