CONSTRUCTION INDUSTRY COUNCIL
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DEVELOPMENT OF AN AUTOMATIC IMAGE COLLECTION AND ANALYSIS SYSTEM FOR IMPROVING ONSITE CONSTRUCTION PRODUCTIVITY

RESEARCH SUMMARY

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Development of an automatic image collection and analysis system for improving onsite construction productivity
Research Summary

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FOREWORD

While digital image processing techniques have been widely applied in medicine and security proposes, this techniques became more mature and cost effective. It does not only capture real time image for review, but also a sequence of picture for analysis. These pictures are good sources of data to study the construction procedures for planning the future projects.

While there is lack of techniques focusing on construction industry, the CIC initiated the research by engaging a research team from The Hong Kong Polytechnic University to develop a video and storage system and a productivity analysis system.

The research work presented in this report was funded by the CIC Research Fund, which was set up in September 2012 to provide financial support to research institutes/ construction industry organizations to undertake research projects which can benefit the Hong Kong construction industry through practical application of the research outcomes.CIC believes that research and innovation are of great importance to the sustainable development of the Hong Kong construction industry. Hence, CIC is committed to working closely with industry stakeholders to drive innovation and initiate practical research projects.

The research worked described in the report was carried out by a research team led by Dr WANG Yuhong from The Hong Kong Polytechnic University. The project cannot succeed without the dedicated effort of the research team. I would like to thank to all who took part in this valuable work.

Ir Albert CHENG
Executive Director
Construction Industry Council

PREFACE

This research focuses on the use of advanced computer-based information technology to process and analyze construction images or videos for assisting productivity analysis and improvement. Four typical research components were studied by the research team: (1) techniques of efficient summary and storage of construction videos from onsite monitoring system, (2) techniques for obtaining macro project progress using images from onsite surveillance cameras or ad hoc images from hand-held devices, (3) techniques for obtaining micro project progress in a construction task using images obtained at workface, (4) techniques for trajectory-based activities analysis using videos from far-field surveillance cameras.

In the introduction section, the background, aims and objectives and scope of this research are elaborated separately.

In the methodology section, the methodologies of four research components are described in each subsection: video summary, macro project progress detection, micro project progress detection, and work activity tracking at jobsite.

In the research findings and discussion section, the lab experimental results using real construction site videos are illustrated accordingly in each subsection.

In the recommendation section, the disadvantage and future research work related to this research are described.

It is believed that the described research components will benefit construction management in different applications.

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RESEARCH HIGHLIGHTS

Construction productivity is a widely concerned issue in the construction industry. This research focuses on the use of advanced computer-based information technology to process and analyze construction images or videos for assisting productivity analysis and improvement. In a construction project, productivity issues include those at the workface and those away from the workface. The video-based techniques used in this research aims at assisting productivity analysis for construction activities at the workface and project documentation away from the workface. The used techniques form an automatic image collection and analysis system.

The developed system contains four typical research components: (1) techniques of efficient summary and storage of construction videos from onsite monitoring system, (2) techniques for obtaining macro project progress using images from onsite surveillance cameras or ad hoc images from hand-held devices, (3) techniques for obtaining micro project progress in a construction task using images obtained at workface, (4) techniques for trajectory-based activities analysis using videos from far-field surveillance cameras.

The highlights of each research component are summarized as follows.

(1) With the advancement of information technologies, video cameras are frequently installed and used on construction sites in recent years. Although the videos from on-site cameras contain rich project information, they are often excessively lengthy and bulky to be effective stored, analyzed and browsed. This research used new image/video process methods for summarizing construction videos. This is not only a precondition of effective construction video analysis, but also provides valuable support for saving tracking records in construction documentation management and future worker education materials.

This developed new video summary methods are for effectively processing, condensing, and indexing raw construction videos as scene clips and key frames. Experimental results indicate the methods developed in this research performs well in video content condensing. The condensed video content can be effectively browsed in different displays.

(2) Recently, project participants use images captured by smartphones or other handheld devices routinely during the site visiting. These captured short videos or photos are used in project meetings for discussing overall project progress or used for project progresses documentation purposes. However, the progress in photos captured at random positions is difficult to obtain at a glance.

The research developed new methods for automatically detecting macro project progress from the unplanned photos using image registration method. The progress at a macro scale means the overall changes of a project, and the changes may happen in different tasks in the project.

(3) Progress can be reported by the consuming of construction materials or the substantial outputs of a construction task, named as micro project progress in this research. For detailed productivity study, progress measurement at the micro level is desired. This research developed effective algorithms for micro progress measurement in three types of construction tasks. In these three types of construction tasks, planar area, structure quantity and patch quantity in the completed work region are measured for micro-level progress tracking. Different video processing methods are used in accordance with the special characteristics of the construction tasks. Experiments show that the methods developed in this study can provide acceptable progress measurement results. The results show that the automatic micro progress measurement methods are effective in assisting on-site quantity surveyors.

(4) Automatic tracking construction entities including construction work spots, plants, and workers on construction site from surveillance videos are particularly important for activity productivity analysis. In the past, the data for activity analysis were obtained in activity sampling conducted by human surveyors. The manual activity sampling usually consumes tremendous cost, effort and time. Additionally, it is often performed at a few discrete time points. Therefore, the collected data are often error-prone.

In this research, innovative object detection and tracking methods were used to automatically track on-site working entities, typically the construction workers. In the experimental trials, the trajectories of the selected workers were processed to study the working time in each work cycle. Then, the trajectories of workers on a construction site were used to analyze the spatial and temporal utilization of the construction site.

CONTENTS

1 INTRODUCTION

1.1 Background

The construction industry of developed economies faces increasingly labor shortage problems due to various reasons, such as population aging, unappealing working condition and increasing demands for growing urbanization. The labor shortage will challenge the traditional manual monitoring and recording information methods in construction management because these methods require significant labor efforts and expertise. To ease the workforce shortage and work burden, various strategies have been used to improve the efficiency of construction management and then to improve project productivity.

One important approach is to improve the efficiency of construction management using intellectual information collection and analysis methods. Automatic project monitoring and activity information acquisition tools are largely used in construction management. Laser scanners, radio-frequency identification (RFID) devices, image/video recorders and image/video processing techniques, and augmented reality (AR) are examples of automatic information technology (IT) tools commonly adopted in recent years.

Images and videos are the most useful information to assist construction management, since many of the above-mentioned technologies require the use of expensive and complex equipment in contrast, construction videos and images are ubiquitous and inexpensive. Existing studies on productivity improvement in construction management using videos and images have been primarily focused on three aspects: at workface, on-site but away from the workface, and off-site. In the commonly used methodology, the videos and images are collected at workface or on-site but away from the workface. Then, the collected videos and images can be analyzed off-site.

Traditionally, when collecting construction videos and images at workface, a specialist or a project manager is hired to visit a construction site and captures still photos or videos from the site using hand-held cameras, and then analyzes these data manually (Abudayyeh, 1997; Oglesby, Parker, & Howell, 1989). However, the on-site data collection work is time-consuming and sometimes causes more labor cost. Additionally, recording site information by the specialist will distract on-site workers. Hence, another technique, time-lapse video recording, has been used. The pictures of construction activities were taken in the interval of one or several seconds by an on-site camera. These images are then played sequentially so that the construction process can be reviewed in a short time (Oglesby *et al.*, 1989). Recently, the closed-circuit television (CCTV) systems are widely used on the construction sites. Although the original purpose of the CCTV systems is mainly for security reasons, they have been used to assist construction communication and construction progress monitoring (Leung, Mak, & Lee, 2008) in construction management.

The collected videos and images can be used for off-site information analysis, some computer vision techniques have been used to automatically generate essential project information, measure and visualize project progress and analyze construction activities. Some researchers find that using automatic image and video processing will save up to 60% human effort in construction documentation.

Monitoring project progress and obtaining on-site activity information are important research topics for productivity analysis in construction management. Timely access to accurate information about the on-site progress and activities is especially valuable for construction personnel who are away from the workface. This will assist project managers in developing a responsive schedule and making resource adjustment, and then lead to rework reduction, cost reduction, and productivity improvement. Image and video processing techniques (Han & Golparvar-Fard, 2015; Hui, Park, & Brilakis, 2015), and augmented reality (AR) (Golparvar-Fard, Peña-Mora, & Savarese, 2009) have been used to efficiently obtain project progress information in recent years.

Some researchers have been working on construction activity analysis using working entity detection, recognition, and tracking (Azar & McCabe, 2012; Brilakis, Park, & Jog, 2011; Jog, Brilakis, & Angelides, 2011; Park & Brilakis, 2012; Park, Makhmalbaf, & Brilakis, 2011; Yang, Li, Sun, & Liao, 2014). Some researchers concentrated on more challenging problems, such as automatically recognizing construction actions (Gong, Caldas, & Gordon, 2011). Some researchers studied activity-based construction productivity analysis. For example, Gong and Caldas (Gong & Caldas, 2011) evaluated productivity using working time measurement.

After reviewing and comparing the existing work, this research focused on four applications: construction project information management, macro and micro progress tracking, and activity tracking to maximize the utilization of construction videos and images collected from various sources and to indirectly improve future productivity.

1.2 Aims and Objectives

Construction productivity evaluation normally comprises two stages: data collection and data analysis. This research also consists of two components: 1) a video collection and storage system that collects useful on-site work information and 2) a productivity analysis system that processes the collected images and then generates useful information for productivity improvements.

In the video collection and storage system, useful data in the videos are extracted and logically stored according to the analyzed information structure. Since videos recorded by on-site cameras usually contain redundant and disordered image frames, this system aims to provide a useful and structured video database of a construction project for productivity evaluation, project documentation, and future staff training.

In the productivity analysis system, first, progress which was made on a macro scale, i.e., the overall project on a jobsite, is obtained by comparing the images taken at different times and locations. Then, the micro progress of major construction tasks is measured and quantified using images collected at workface. The results will facilitate the development of schedule management, inventory control and project planning during project implementation stage; results may also be used to provide useful information for cost estimating in the future. Finally, this system aims to establish a prototype framework for tracking and analyzing the involved construction entities (completed construction components, workers, construction plants) on a construction jobsite. The tracking results help to analyze the efficiency of a construction entity in activity sampling. The work activities are classified and modelled based on trajectories of involved workers on a construction site. Space and time utilization of the jobsite is analyzed for optimal project management.

1.3 Scope

The proposed prototype system comprises four main components, including (1) automatic video summary based on key frame extraction, (2) automatic macro progress measurement based on image registration, (3) automatic micro progress measurement based on work quantity measurement, and (4) automatic activity sampling based on trajectory classification and modeling.

The scope of this research is limited to methodological development and validation of analyzing construction site videos and extracting information for productivity studies. Actual productivity measurement, analysis and improvement methods are not part of this research. However, these contents will be described in the recommendations for implementing this system for construction management practices in the future.

2 RESEARCH METHODOLOGY

This research consists of two functional systems: 1) a video collection and storage system which collects and saves useful project information and 2) a video analysis system that processes the collected images and video clips, and then assist in generating useful productivity analysis results. Fig. 1 shows the methodological framework of this research

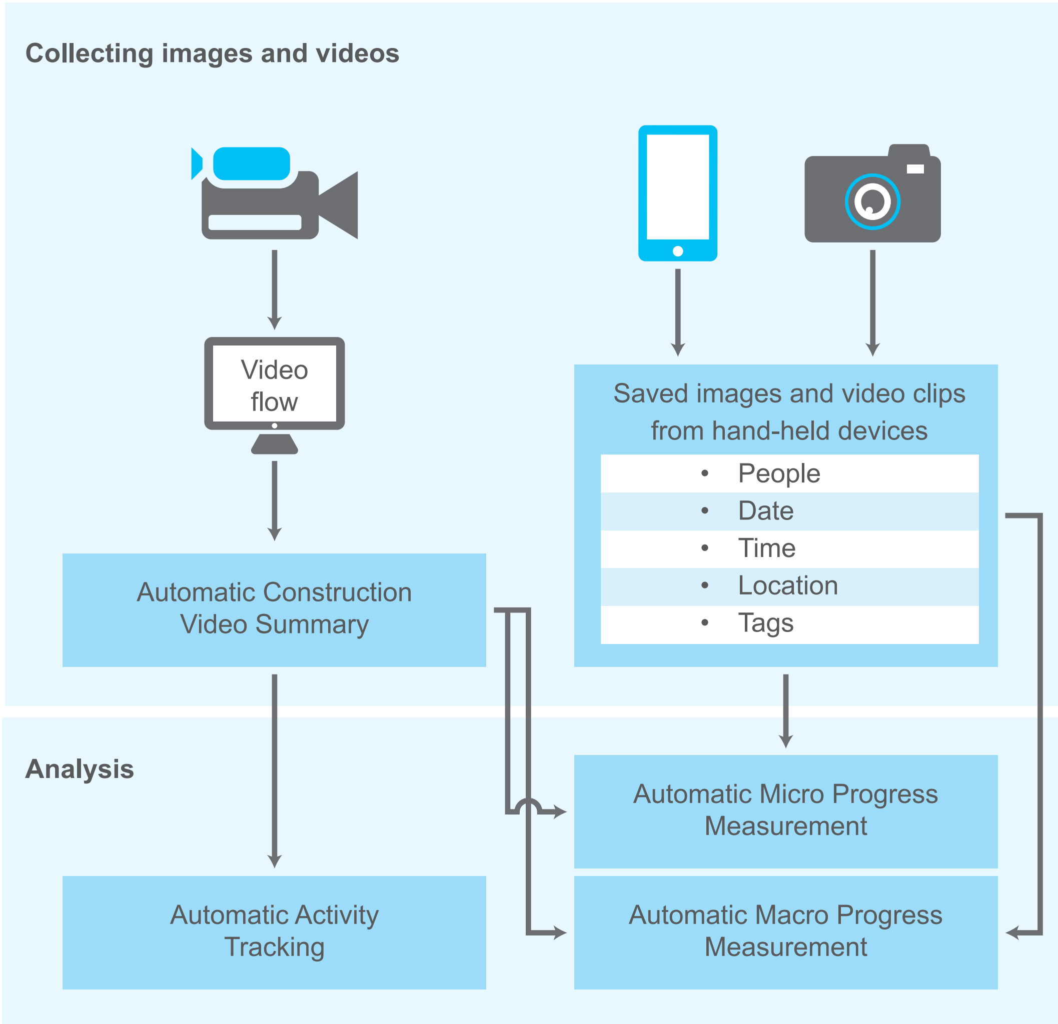


Figure 1 The methodological framework of automatic image and video collection and analysis systems

In the video collection and storage system, monitoring system and hand-held devices are used to collect images and videos of project site or workface. The useful information in video flow from on-site monitoring system is extracted. The extracted images or video clips are informative and instructive and can be used in project documentation. The photos and video clips from portable devices are processed differently since they are captured selectively by project managers. When saving these photos and video clips, the inherited information such as date, time and camera and labeled tags which are edited by photographer can be used to index data accordingly. In the system, useful and concise information about construction projects are extracted and logically stored.

In the video analysis system, firstly, progress made on a large scale, i.e., the overall project which may include several construction tasks, is obtained by comparing the images recorded at different dates or time points. Secondly, micro-level progress of a single construction task is tracked and quantified using images/videos collected at workface. Finally, a prototype framework for tracking the involved construction entities (completed construction components, workers, and construction plants) on a construction jobsite and analyzing tracking results was developed. The tracking results are used to analyze the efficiency of on-site construction activity..

2.1 Video summary

Videos continuously obtained by on-site cameras contain useful information for project management. The useful information, however, is only a small portion of the videos. Therefore, a video summary system to extract concise, salient and useful information from raw monitoring videos was studied. The aim of the proposed process flow is to extract key image frames and informative video clips which can be used to form a concise project information dataset for easy storage, browsing and query. The methodological diagram of the video summary system is illustrated in Fig. 2.

In this flowchart, the primary steps are feature extraction, scene boundary detection and key frame extraction. First, effective image features are extracted from frames after analyzing the content of each frame. Then, scene boundary detection is accomplished by locating the abrupt changes in frames after measuring the difference of a single feature or multiple features of two successive frames. The operation is based on that the contents in two successive scenes largely differ with each other. Finally, key frames are detected in each scene. Key frames are the most representative frames in a scene. They can be defined as the frames with either the most or the least common content with other frames in a scene. The key frames can be used to form a concise project image/video dataset for easy storage, browsing and query.

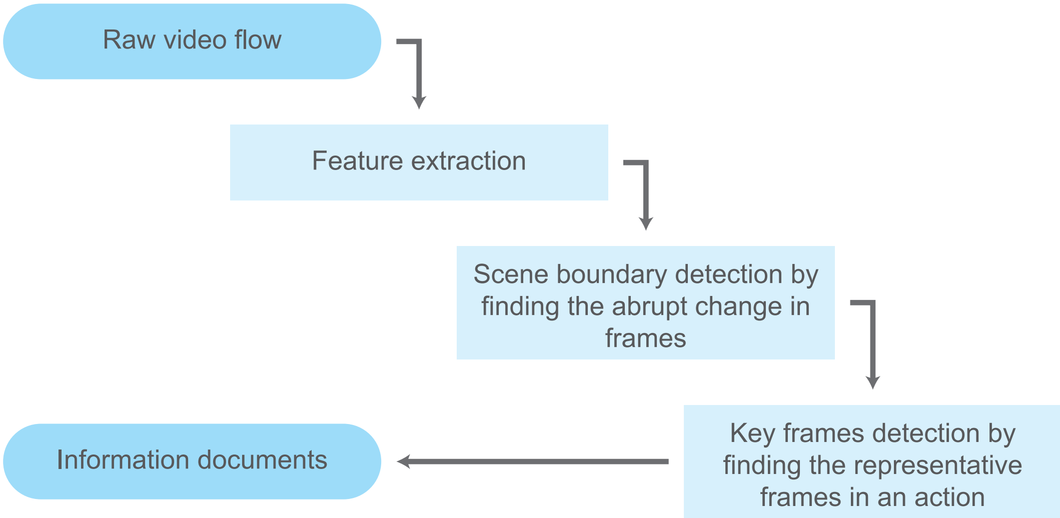


Figure 2 Flowchart of the video summary for continuous video flow

2.2 Macro project progress detection

Project managers often capture real-time photos or video clips about the construction project during their periodic site visiting. These photos or video clips are parts of their project records revealing overall project progress. These photos or video clips are often unplanned, unstructured and captured in an ad hoc way. Progress information must be obtained by carefully observing and comparing these photos.

This research proposed a convenient method to compare these photos which are captured in an ad hoc way. By the proposed method, the project progress is obtained by comparing two images after image registration. The overall project progress obtained may contain progress in several construction tasks, and hence is named as macro project progress.

The methodological flowchart of macro project progress detection is illustrated in Fig. 3. In this flowchart, the primary steps are key points detection, key points matching and homography estimation. First, key points are detected from each image after analyzing its content. Then, the correspondences between two images are established by matching features which are calculated to describe the extracted key points. Finally, homography between two images is estimated using the obtained correspondences. The differences (progress information) between two images can be visualized by aligning two images by using the estimated homography.

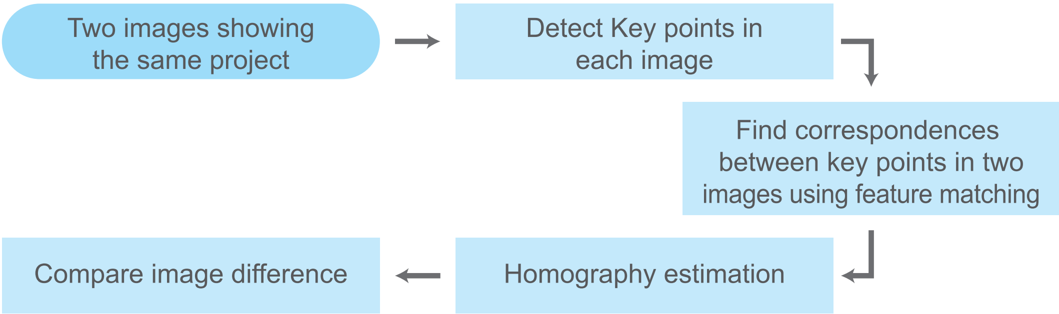


Figure 3 Flowchart of macro project progress detection

Fig. 4 shows an example of obtaining macro project progress. In this example, progress of an under-construction building is visualized by using image registration method. Fig. 4(a) and Fig. 4(b) show two images of the same building project; the second image (b) was captured one week after the first image (a). The building project contains steel structure and concrete structural components. A climbing formwork is used to in the concrete structure construction. The difference between these two images cannot be obtained by subtraction operation, as shown in Fig. 4(c), since they were captured at different time using a hand-held camera at random locations. To identify the difference between these two images, image registration is used in the proposed application. The difference obtained after image registration is shown in Fig. 4(d).

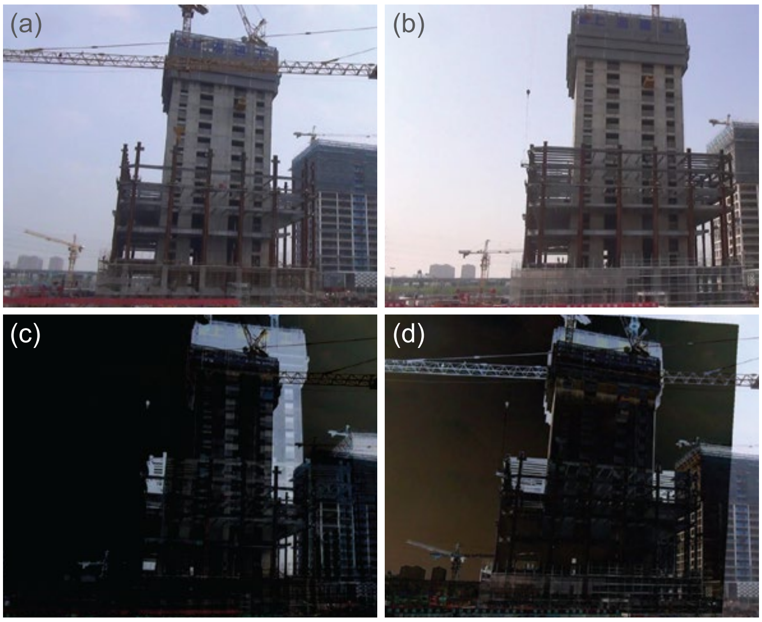


Figure 4 The images of an under-construction building captured on the different dates: (a) the image captured before; (b) the image of the same building captured one week later; (c) the difference of images in (a) and (b) by image subtraction; (d) the difference of images in (a) and (b) after image registration

In this application, image registration for these two images is difficult. It is affected by three major problems. The first problem is the difficulty in differentiating permanent structures from those moving structures. During the period of one week, about one more storey had been added, which were the changes of the permanent structures. During the same period, the moving structure, climbing concrete formwork, had been raised by about one storey in height. Image registration in these images may end up matching the moving structures instead of the permanent structures.

Another problem is lower inlier ratio of correspondences obtained in construction images. This may be caused by different reasons. Firstly, the construction sites are inherently complex and dynamic. Therefore, the proportion of valid image features (those not affected by noise) is low. Secondly, there are many similar and/or repetitive patterns in human-made structures in the buildings. Consequently, the ratio of correct correspondences obtained through measuring feature similarity is low. Thirdly, the images are commonly captured in an outdoor environment and perhaps using different devices. The interference of factors such as illumination is unneglectable, which decreases the accuracy of feature matching. To solve these problems, a modified image registration method was studied. Fig. 5. shows the obtained correctly matched key points in image registration.

333 (13.08%) inliers out of 2545 matches

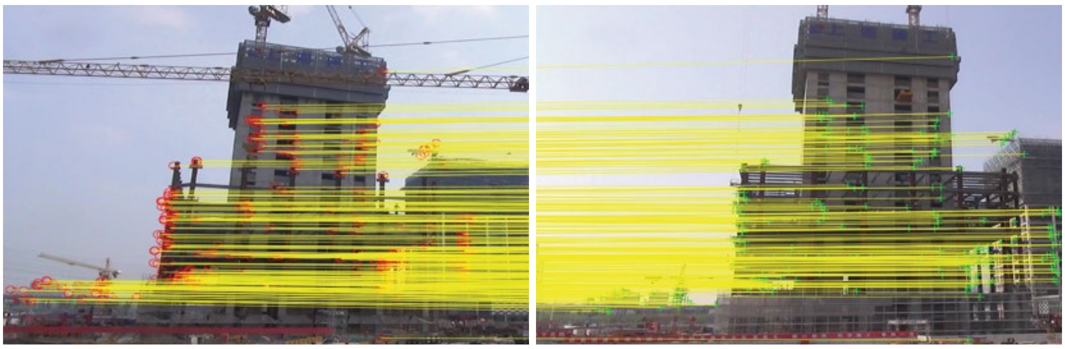


Figure 5 The matching of key points in two images

2.3 Micro project progress detection

The images/videos of major construction tasks at workface can be used to tracking micro project progress of the construction tasks. Comparing with macro project progress in the last section, micro project progress focuses on measuring the substantial output of one construction task.

The completed work regions of different construction tasks have different visual characteristics in the captured images. This research attempts to identify suitable image processing methods to extract the completed working regions in the videos which were captured from different construction tasks. Progress is subsequently measured from different image frames in a video.

According to the different characteristics (shape, colour, and texture) of image regions which display completed work, three micro-progress measurement methods were adopted (Fig. 6). Using these three methods, the completed work regions are extracted by using flat image region detection, line segment detection and edge-based patch detection algorithms, respectively. The micro project progress can be measured in different construction tasks using a suitable method.

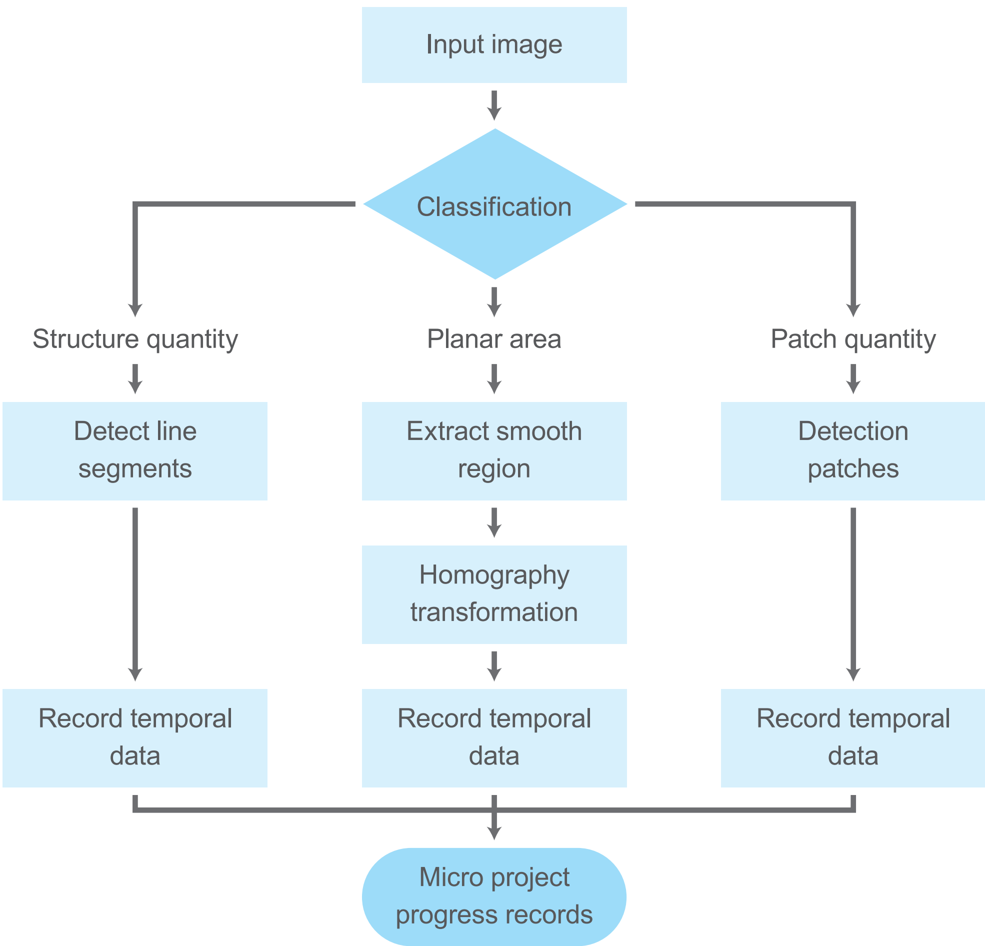


Figure 6 Flowchart of micro project progress measurement

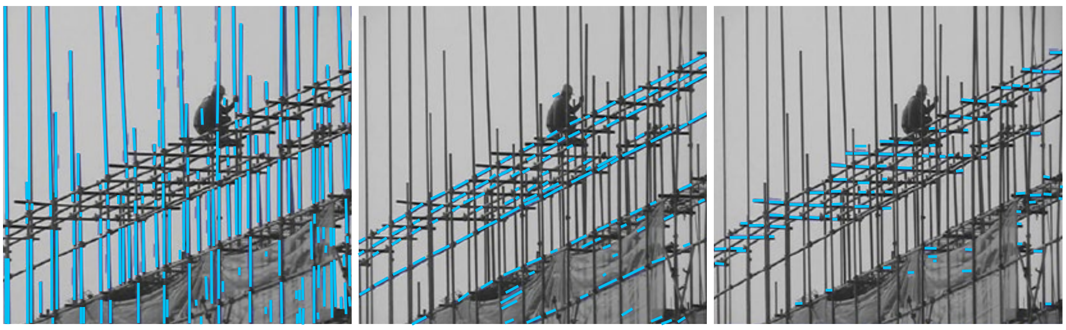
(a) (b) (c)

Figure 7 Completed work region detection in concrete casting work:
(a) test image frame of concrete casting; (b) the extracted completed concrete region in the test image; (c) the result of perspective transformation on the image

Fig. 7 presents an example of detecting completed work region in a video showing concrete casting by using flat image region detection algorithm.

Because of the perspective of the camera, the planar objects in reality are not the same as the image captured by a camera. Therefore, perspective transformation is implemented before the progress is measured. After perspective transformation, the percentage complete measured in the transformed image is equal to the real-world percentage, since the percentage is a unit-independent metric. Other physical progress measurement metrics, such as planar area, are proportional to the measured result in the transformed image by a constant scale coefficient. The constant scale coefficient can be obtained using a reference object.

Fig. 8 presents an example of detecting completed work in a video of steel rebar installation using line segment detection algorithm.



(a) (b) (c)

Figure 8 Completed work detection in steel rebar installation work:
(a) rebars on vertical direction; (b) rebars on one horizontal direction;
(c) rebars on another horizontal direction

Line segment detection method used in this research can detect rebars installed in different directions. In the example above, (a) shows the installed steels on the vertical direction; (b) and (c) shows the installed steels on two horizontal directions.

Fig. 9 presents some examples of counting full-shape bricks in images of brick wall or brick pavement using the edge-based patch detection method.

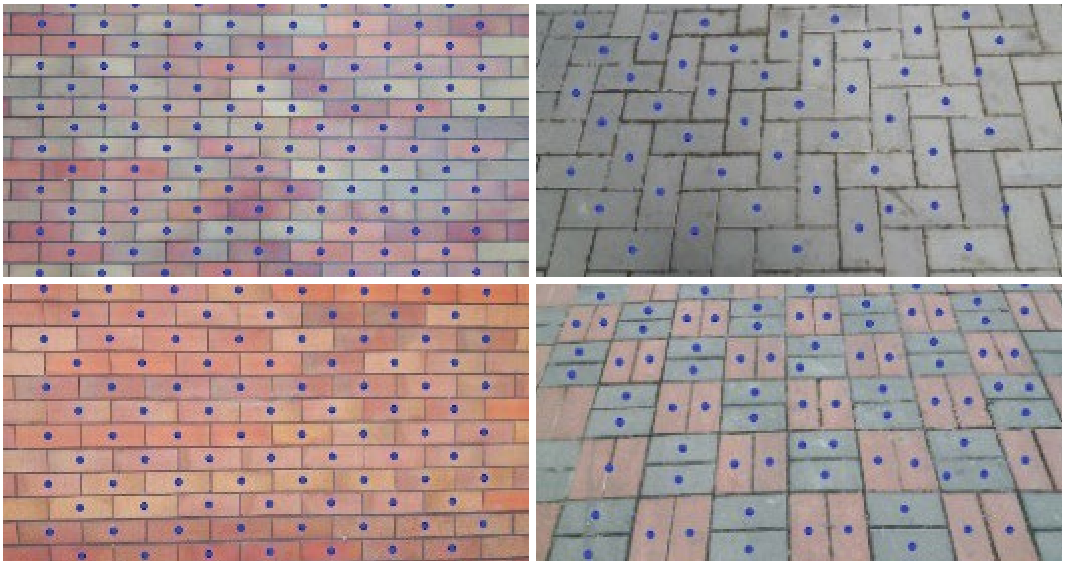


Figure 9 Brick counting in images of brick wall or brick pavement

The trials show the results are reliable when the angle of camera is not largely deviated from the normal direction of the work surface. The miss-counting can be reduced when the patch detection is performed in a continuous video because that same bricks are detected in multiple image frames. Using image registration, same bricks can be identified in different image frames. The detection results in a frame can be corrected using the results in another frame. Because of the similar appearance of bricks, the image feature for image registration needs to be carefully selected to obtain correct results. The trials show that the corners detected using Eigen-value method and block feature descriptor computed from the detected corners provide reliable results in brick image registration.

2.4 Work activity tracking at jobsite

In the construction industry, construction productivity can be evaluated by using activity sampling and analysis. However, manual methods of activity sampling (field rating) and activity analysis suffer from laborious work with large labor and time expense. Therefore, this research proposed a prototype with automatic activity sampling and analysis using videos which are captured by a far-field monitoring system.

The methodological flowchart for construction activity analysis system is shown in Fig. 10. In the flow diagram, the moving subjects at the jobsite are detected and tracked from input videos by using computer techniques. The tracking results, i.e., the spatial and temporal information of working entities, are stored. By working with object recognition method, some on-site static entities also can be detected when the clear profiles of on-site entities can be obtained from videos. Useful object recognition methods have been studied in many types of research. Therefore, it is not within the scope of this research. Finally, the trajectories can be clustered based on the site space knowledge. Time utilization of entities and spatial utilization information (e.g., working spots) are analyzed to obtain the activity information. This resulting information will provide a guide for the future productivity analysis.

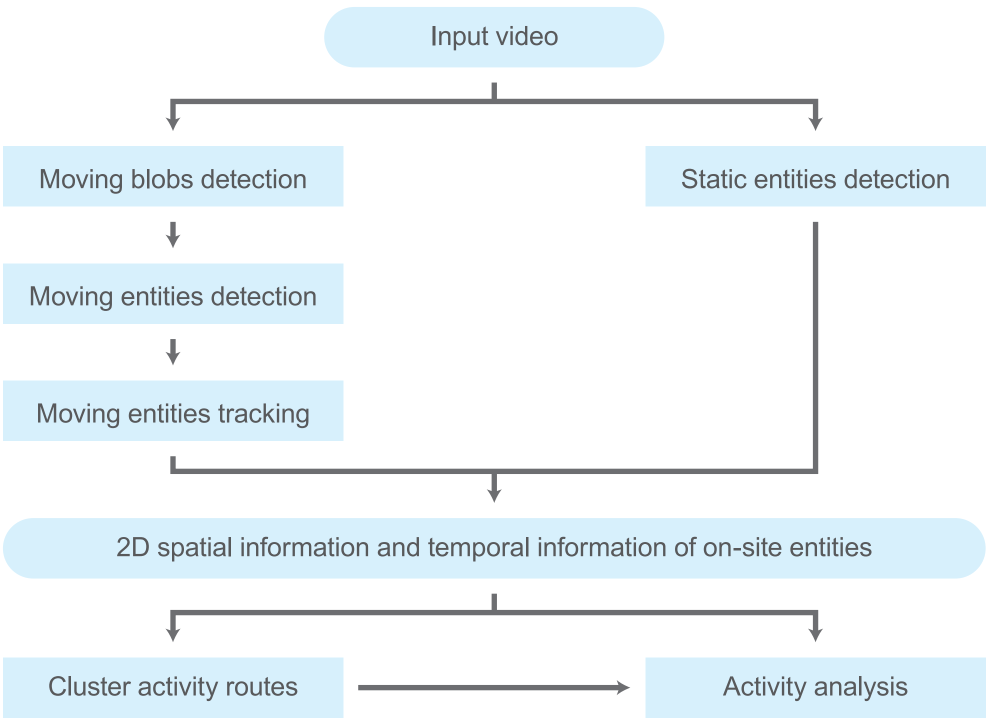


Figure 10 Flowchart of construction activity analysis

3 RESEARCH FINDINGS AND DISCUSSION

The in-time acquisition and analysis of construction video data are valuable in different aspects. Firstly, it is useful for on-site project management by reducing human effort and processing time in data collection and data analysis. This improves on-site productivity directly. Secondly, it is useful for informing in-time project information to off-site managers and supporting the communications across several parties. In-time communication then improves construction productivity away from the workface and eventually improves productivity at workface. Last but not least, it can be used as educational material and help to improve productivity in future projects.

This research attempted to develop automatic video processing and analysis systems from four aspects:

(1) video summary which is focused on obtaining useful information from the on-site video recording system;

(2) macro project progress acquisition using unplanned and unstructured construction site images;

(3) micro project progress measurement which is focused on the construction output measurement in a construction task;

(4) automatic construction activity tracking and analysis.

By combining these four research components, different construction site information can be obtained with less laborious effort. Such construction information is very useful for practical and systematic construction management, and will benefit worker training in future construction projects. The experimental results in different components are shown separately in the following sections.

3.1 Video summary

Three types of feature, colour, gradient and texture, were tested for scene boundary detection in this research. The experiments of scene boundary detection show the performance of each feature may be affected by video's characteristics. In general, colour feature performs better when images have a large variation of colour values, but it may be affected by illumination. Gradients are calculated by the Roberts kernels. Therefore, the gradient feature is a fine scale texture descriptor. Consequently, it may not perform well in texture-smooth images. However, the gradient feature tends to have the fastest computational speed. Texture feature, i.e., Gabor feature, can detect image texture on different scales and directions. However, it appears to be computationally demanding and sensitive to minor changes in the image. It has been proposed to use multiple features as a feature description set in object recognition. However, this solution is at the expense of computational speed. According to the experiments, a suitable colour feature or gradient feature generally leads to satisfactory results for construction videos.

An example of the output of the key frame detection is shown in Fig. 11. Only the video frames that contain non-redundant information was retained in a scene. As shown in the results, the crane was used to transport materials three times.

Figure 11 Example output of key frame extraction in a scene

The developed video summary system can be used to effectively archive videos taken from construction sites. In this research, the videos are decomposed according to the hierarchy of videos, scenes, action sequences and key frames. In the descending order of the abilities of storage saving, video structure levels are listed as key frames, play sequences, scenes, video clips. For storage saving, users can choose to keep video data at an appropriate level. If the users only want to store key frames, large hard disk space can be saved by keeping the essential information. As shown in Table 1, the raw construction video data can be compressed by more than 99% by only saving key frames. In this experiment, the test videos were captured from a construction site in Shenzhen during a site visiting. The project managers suggested that the results could be used in project records saving.

Table 1 Key frame extraction results of two video clips

Feature	Clip 1/2704 frames			Clip 2 / 2588 frames		
	nS	nKF	CR	nS	nKF	CR
CbCr in YCbCr	12	32	0.9882	6	14	0.9948
UV in YUV	12	35	0.9871	6	11	0.9959
IQ in YIQ	12	29	0.9893	6	13	0.9952
ab in CIEL*a*b*	11	34	0.9874	6	15	0.9945
Gradient feature	6	27	0.9900	2	12	0.9956
Texture feature (Gabor)	12	22	0.9919	3	19	0.9927

In Table 1,

YCbCr, YUV, YIQ and CIEL*a*b* are colour spaces;

nS: the number of detected scenes in a continuous video;

nKF: the number of detected key frames in a continuous video;

CR: the information compression ratio by only saving key frames in a continuous video. The value of CR ranges from 0 to 1; a larger value indicates a better performance in information compression.

The decomposed videos can also be conveniently indexed and viewed by using common web browsers. This is valuable for all stakeholders in construction to understand construction progress and implementation details. The video structure was stored in an XML file and key frames were presented using a web browser. This function is convenient for video content browsing because structure-based browsing is more efficient than directly searching through the original videos.

3.2 Macro project progress detection

In this research, the overall project progress is identified in two randomly captured photos by using image registration method. In the image registration, the PROSAC method is modified for the application of data registration in images of under-construction buildings. Three modifications of PROSAC method, tentative correspondences refinement, modification of progressive sampling and local optimization, were proposed according to the characteristics of data registration in images of the under-construction buildings. In this section, comprehensive verifications were conducted using image pairs with different time intervals, i.e., three days, one week and two weeks. The modified method obtained correct registration results in the total fifteen images pairs.

To demonstrate the proposed application, a high-rise building with 280-meter height in construction is used as an example. The building was built with site-cast concrete and steel structure outside the concrete structure. In site-cast concrete work, self-climbing concrete formwork was used. During the site visiting, as-built photos of this building in three successive weeks (from Monday to Friday) were captured. The progress of the major project components (steel structure and concrete structure) between two days can be identified using modified image registration method. An example is shown in Fig. 12.

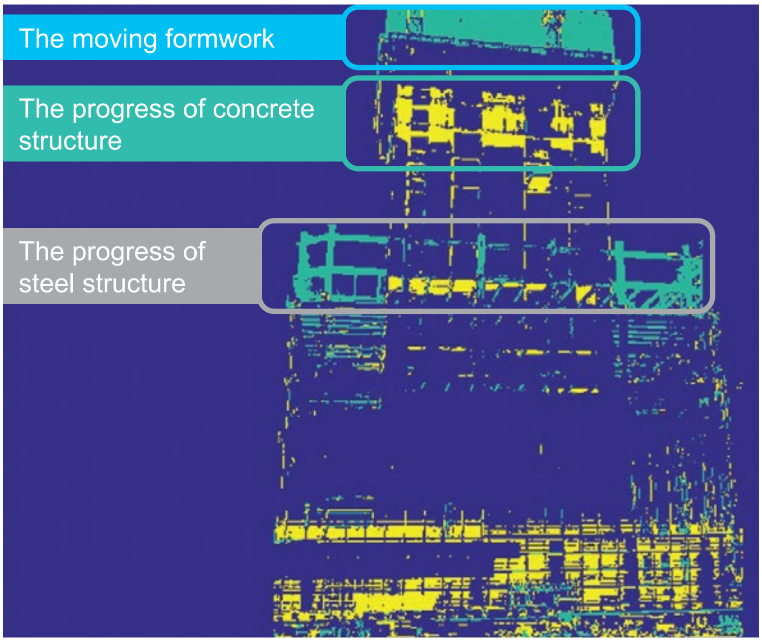


Figure 12 The identified progress in two main components

Fig. 13 shows the progress information within every two successive days in three weeks. For example, the first column in Fig. 13 shows the differences between photos of last Fridays and Mondays; the second column shows the differences between photos of Mondays and Tuesdays. As shown in this figure, the progress of steel structure in the second week was faster than the other two weeks; the progress of concrete structure was faster in the first and third week. The internal of two moves of self-climbing concrete formwork is 3-5 days. The project managers suggested that this application would be helpful, for the progress in different work components could be labeled.

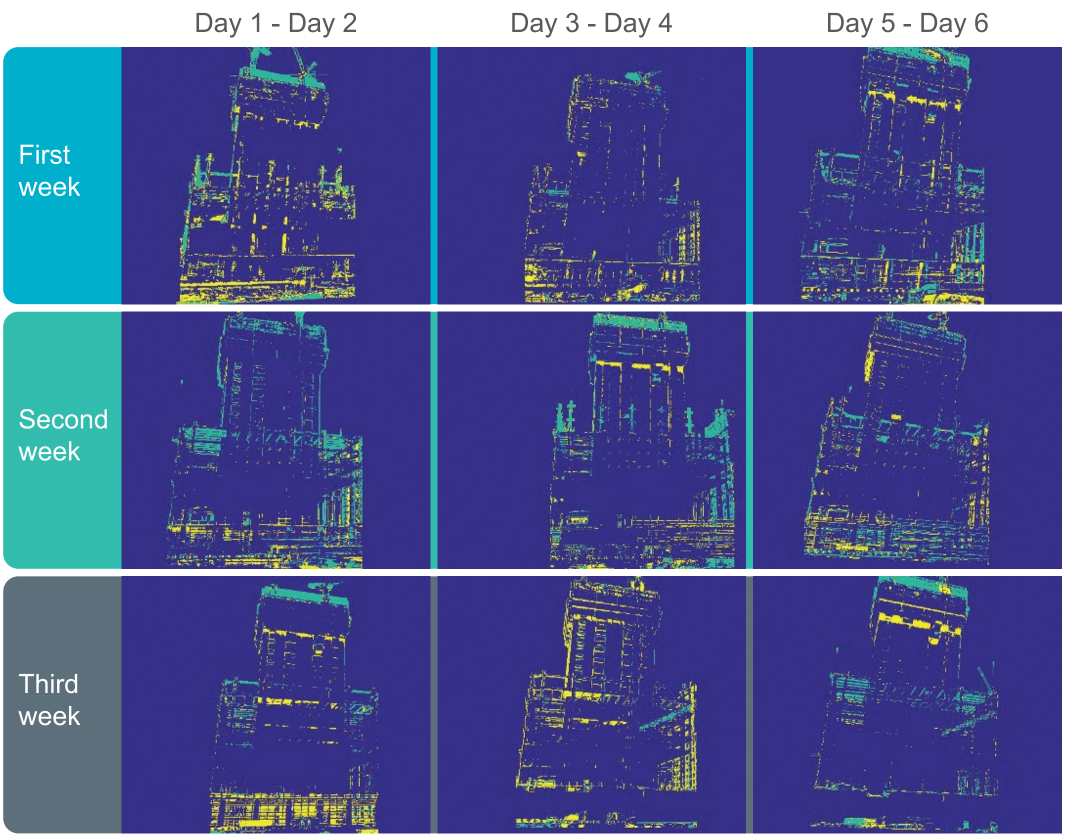


Figure 13 The progress of a building project during three successive weeks

3.3 Micro project progress detection

Automatic micro project progress measurement helps to save the effort of quantity surveyors in manually measuring the quantity of completed work. Then, off-site project managers can obtain construction work quantities timely, and adjust work plans for productivity improvement accordingly. In this research project, the micro project progress measurement methods were studied for some chosen major construction tasks. According to the different characteristics (shape, colour, and texture) of image regions which display completed work, three micro-progress measurement methods were proposed. In these three methods, the completed work regions were extracted from captured images/videos by using flat image region detection, line segment detection and edge-based patch detection algorithms respectively. The trials show the feasibility of the proposed methods in this application.

An example of the work progress measurement in a video of concrete casting is shown in Fig. 14. The micro project progress was measured every minute using square meter as a unit.

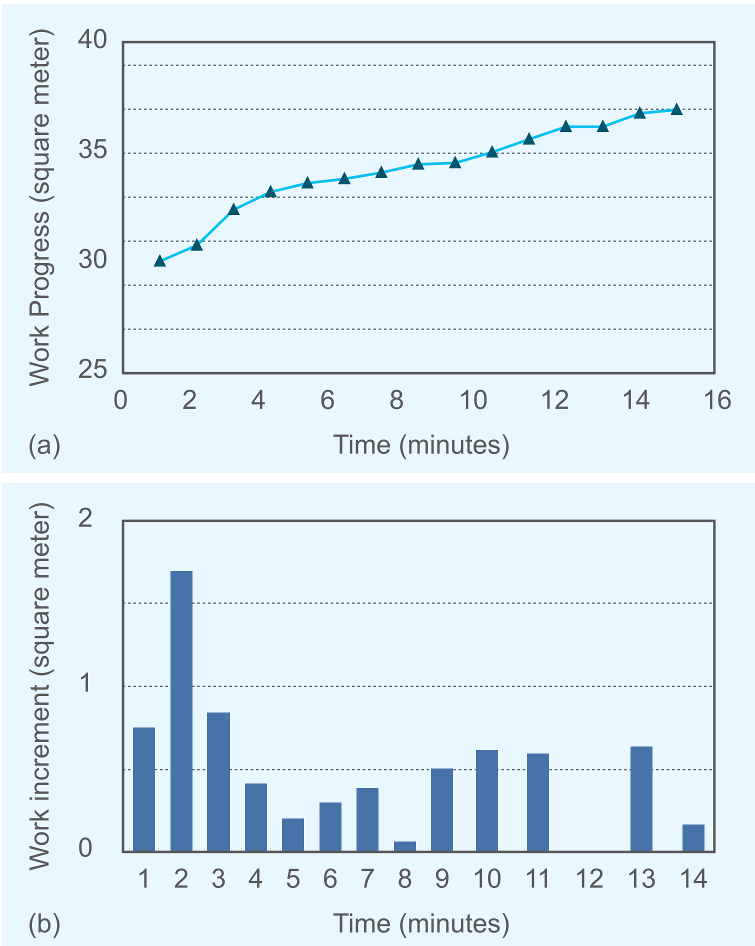


Figure 14 The progress measurement results of concrete work:
(a) concrete progress measurement in each minute;
(b) progress increase in each minute

Ground truths were used to validate the resulting planar areas and patch quantities. The validation results revealed that the proposed methods were efficient for measuring planar area and counting patch quantities in construction tasks.

In the validation experiment, a total of fifteen image frames with one-minute intervals were extracted from the video sequence for concrete region detection and planar area measurement. The results from automatic detection were validated using ground truth which was obtained from manually labeling. The validation results of the proposed flat region detection method are shown in Table 2. F-measure (ranges from 0 to 1; and a large value indicates a good result) and error percentage in planar area measurement are used as the metrics. As the results illustrate, high F-measures were obtained in the fifteen images, and less than 2% average error percentage was obtained. The results show this automatic workflow can be used in construction practice.

Table 2 Completed region detection in concrete slab casting

Image No.	F-measure	Area of manual labeling (square meter)	Area of automatic detection (square meter)	Error percentage
1	0.9051	28.9521	29.8774	3.20%
2	0.8840	30.9667	30.6334	-1.08%
3	0.9128	32.3933	32.3336	-0.18%
4	0.9083	33.9832	33.1777	-2.37%
5	0.9229	34.1611	33.5982	-1.65%
6	0.9053	34.6050	33.8003	-2.33%
7	0.9168	34.7566	34.0989	-1.89%
8	0.9063	35.2372	34.4924	-2.11%
9	0.9195	35.3646	34.5603	-2.27%
10	0.9243	35.5565	35.0707	-1.37%
11	0.9299	36.0488	35.6861	-1.01%
12	0.9348	36.6063	36.2845	-0.88%
13	0.9465	37.7547	36.2845	-3.89%
14	0.9252	38.1382	36.9224	-3.19%
15	0.9294	38.5841	37.0934	-3.86%
Average	0.9181	------------	------------	-1.66%

Fifteen images were used to verify the proposed methods for counting the patch quantity of bricks and pavers. The validation was accomplished by making a comparison with the results of manual counting (ground truth). False positives and false negatives were used as metrics to evaluate the results of the proposed methods. The validation results are summarized in Table 3.

Table 3 Results of brick and paver counting

Image No.	Brick quantity		False positive (FP)	False positive (FN)	FP percentage	FN percentage
	Manual counting	Automatic counting				
1	302	289	5	18	1.66%	5.96%
2	384	376	3	11	0.78%	2.86%
3	254	261	7	0	2.76%	0.00%
4	78	79	3	2	3.85%	2.56%
5	58	56	0	2	0.00%	3.45%
6	51	46	0	5	0.00%	9.80%
7	48	47	1	2	2.08%	4.17%
8	96	99	8	5	8.33%	5.21%
9	72	65	2	9	2.78%	12.50%
10	112	80	0	32	0.00%	28.57%
11	55	57	2	0	3.64%	0.00%
12	90	90	0	0	0.00%	0.00%
13	105	105	0	0	0.00%	0.00%
14	64	64	0	0	0.00%	0.00%
15	56	57	2	1	3.57%	1.79%
Average	-----	-----	2	6	1.96%	5.12%

The experimental results revealed that the developed algorithm performed well in most test images. However, in the first and tenth images, the false negatives were larger than those in other images because the mortar colour was close to that of the bricks in these two images. As a result, the edges were not detected in some regions. The false positive was larger in the eighth image than in the other images because some vertical smudges were present on the brick wall, and this issue caused the false detection of edges. These two problems often happen when the mortar and bricks have been aging since construction projects were completed. When images are captured from ongoing construction projects, the proposed methods work more effectively.

In the patch detection, false negative was generally larger than false positive. In patch quantity counting, the error percentage equals to the subtraction value between FP percentage and FN percentage (e.g., Patch quantity error percentage = FN percentage - FP percentage). In the experiments in Table 3, an average error percentage, 3.16%, was obtained. This error is acceptable in construction practice, which means that the proposed processing flow can be used to assist material counting task. In the inventory control at workface, to ensure the construction work continues smoothly, the inventory should be 3.16% more than the counted quantity

3.4 Work activity tracking at jobsite

In this research, a test system of object tracking was developed, as shown in Fig. 15. In the test system, single object tracking, and multiple object tracking were used in different applications. The single object tracking using mean-shift method works well in trials. However, the commonly used multiple objects tracking methods are not reliable in construction site videos according to trials. More efforts are needed to obtain more reliable multiple object tracking results.

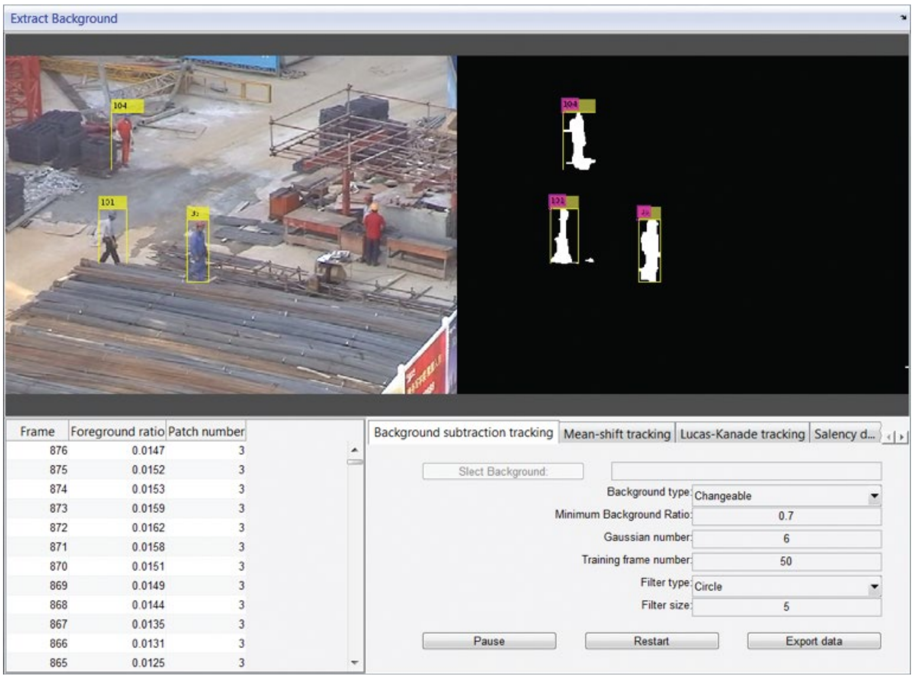


Figure 15 The user interface of the activity analysis system (lab test)

Single object tracking is used to automatically track the objects which are interested by project managers. The objects may be construction workers, construction materials, or construction plants. The tracking information is then summarized and analyzed. The analysis results can be used to evaluate the work efficiency at the micro level in automatic activity sampling and offer the opportunity of workface productivity improvement. An example of trajectory-based activity sampling of a selected target is shown in Fig. 15. In this example, a worker transporting the processed rebars from the workshop to the working area was selected. The spending time was calculated for four work cycles according to the tracking results

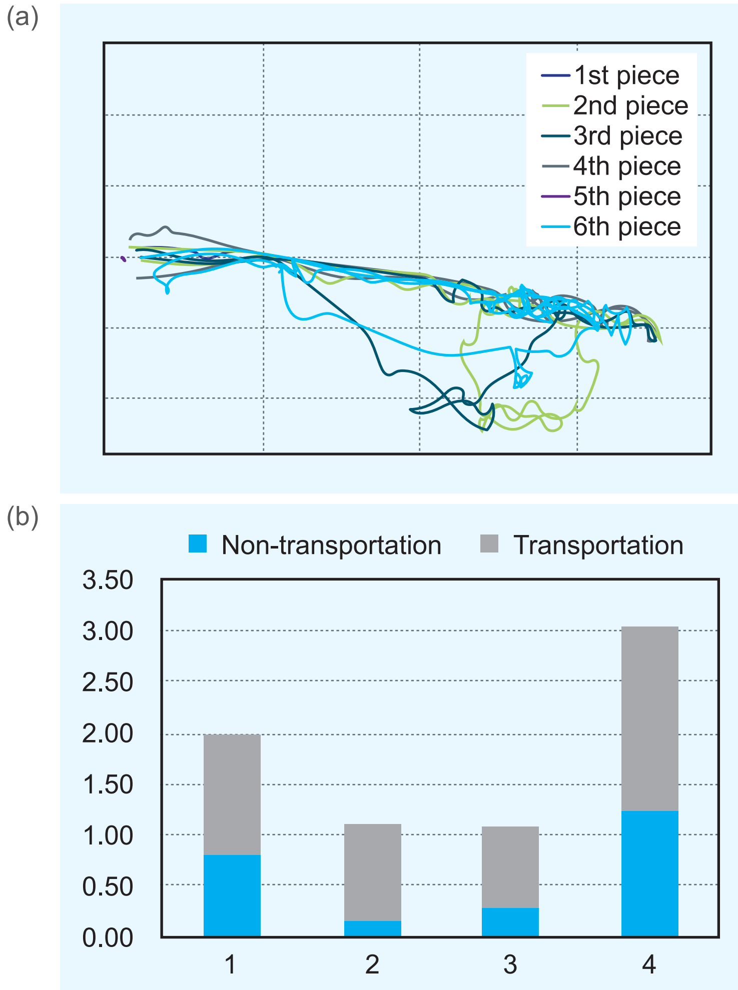


Figure 16 The example of trajectory-based activity sampling of a selected target. (a) The trajectory of the selected target. (b) The time utilization of four cycles in the activities

The trajectories of multiple objects tracking were used for activity classification and site utilization analysis; specifically, work hot spots analysis in a selected case. In the case study, a six-minute clip of the test video was used to demonstrate the trajectory classification and hot spots detection. The results of trajectory analysis are shown in Fig. 16. In Fig. 16, (a) is the trajectories from multiple object tracking (the blue curves are the trajectories); (b) is the detected hot spots on the test site according to the trajectories (the red dots are the stationary spots of objects, and the transparent circles are the hot spots).

According to the trajectories and hot spots detection results in Fig. 17, two activities existed in the test site. The time utilization of each activity can be analyzed as well. The analysis results in a period of six minutes are shown in Fig. 18. This application can assist temporal site and resource utilization when the activities are not executed.

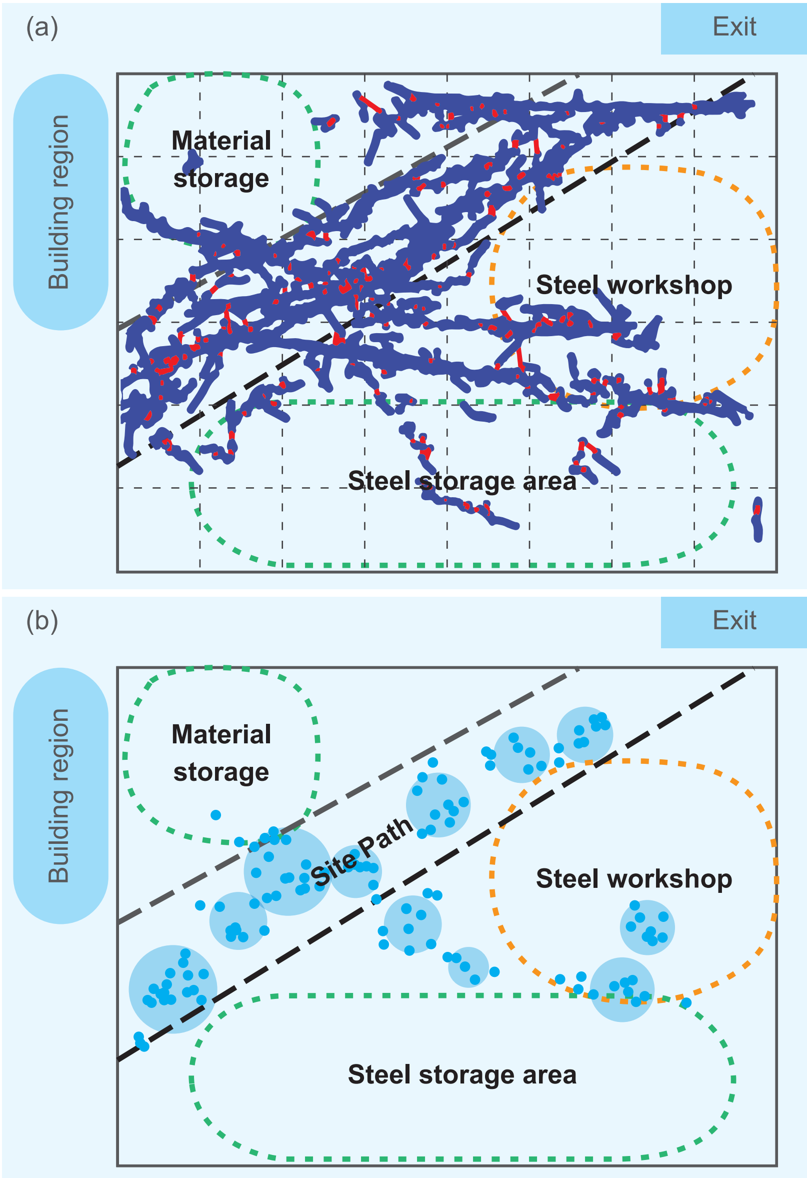
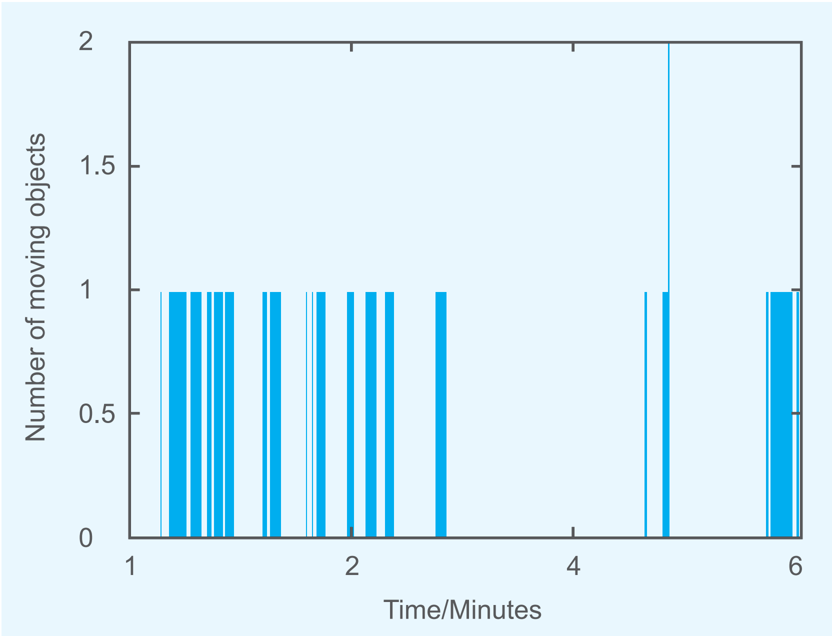
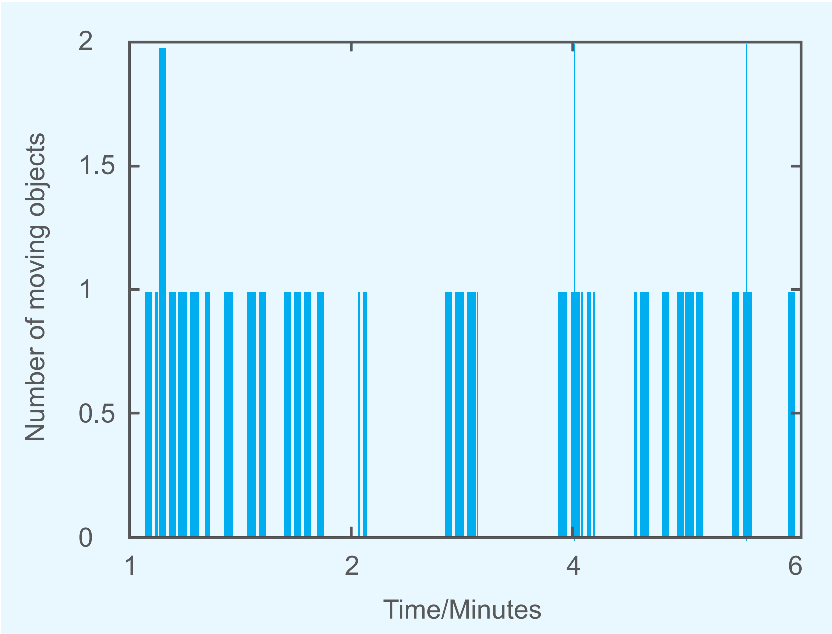


Figure 17 The results of multiple object tracking and work hot spots analysis.
(a) is the trajectories from multiple object tracking (the blue curves are the trajectories);
(b) is the detected hot spots on the test site according to the trajectories (the red dots are the work-intensive spots of objects, and the transparent circles are the hot spots)



(a)



(b)

Figure 18 Time utilization of activities. (a) The first activity. (b) The second activity

The preliminary case studies show that the prototype of the construction activity analysis system may be further developed for detailed micro-level productivity study. The system may be used in automatic construction activity sampling and generate detailed information about work time utilization of the selected target. This would benefit the evaluation of the efficiency of individual construction elements and the analysis of collaboration of different construction elements, and identify the factors that affect construction productivity. The system also can be used in monitoring spatial and temporal utilization of a construction site by tracking the activities on a construction site. This would benefit the optimization of site layout for temporary resources.

4 RECOMMENDATIONS

In this research, four main research tasks are accomplished, including the development of on-site construction video summary system, automatic macro and micro work progress measurement system, and construction activity analysis system.

The on-site construction video summary system adopts/develops innovative video summary techniques to extract the salient and useful information from the raw monitoring video flow. The useful scenes and key frames can be used for progress measurement and construction activity analysis. The study found that colour features generally outperform gradient and texture features, and the performance of the colour, gradient and texture features developed are better than the existing popular ones. It is also found that the method developed in this study generally results in higher fidelity measurement value for all the features; hence, it is appropriate to be used for key frame extraction. After scene segmentation and key frame extraction, the compression ratio of the tested construction video reaches 99% or above. This helps save significant storage space and perform video data analysis.

In this research, the overall project progress is identified in two randomly captured photos by using image registration method. In the image registration, the PROSAC method is modified for the application of data registration in images of under-construction buildings. Three modifications of the PROSAC method, tentative correspondences refinement, modification of progressive sampling and local optimization, were proposed according to the characteristics of data registration in images of the under-construction buildings. In the validation experiment, the modified method obtained correct registration results in the total fifteen images pairs. The results are better than the RANSAC and the original PROSAC method.

In this research project, the micro project progress measurement methods were studied for some chosen major construction tasks. According to the different characteristics (shape, colour, and texture) of image regions which display completed work, three micro-progress measurement methods were proposed. In these three methods, the completed work regions were extracted from captured images/videos by using flat image region detection, line segment detection and edge-based patch detection algorithms respectively. The trials show the feasibility of proposed methods in this application.

Single object tracking is used to automatically track the objects which are interested by project managers. The objects may be construction workers, construction materials, or construction plants. The trajectories of multiple objects tracking were used for activity classification and site utilization analysis; specifically, work hot spots analysis. In the case study, the integrated approach developed in this study was tested by real construction videos, and was approved to be feasible.

The proposed research components are currently standalone applications and focus on the research gaps of existing studies. Therefore, the future work is to integrate the results of these components and other research work to provide a more comprehensive construction video analysis system, which will facilitate construction communication and management.

In addition, each individual component needs to be improved accordingly. For the automatic video summary, the research work can be extended. For instance, extracting key frames representing a meaningful activity. For the macro project progress measurement, the progress of different work can be classified and labeled. For the micro project progress measurement and activities analysis, more case studies should be performed, and suitable validation experiments should be conducted by working with on-site project managers.

It needs to be recognized, however, the developed systems have their limits. Due to the dynamic and chaotic nature of construction sites, it is inherently challenging to directly apply many algorithms in computer vision to the analysis of construction videos. In this research, a large amount of effort has been spent on developing robust methods for construction video processing. Although the developed methods can be used for processing construction videos, a large number of construction videos from different types of construction activities need to be used to calibrate the developed methods. Ideally, a comprehensive database needs to be developed to “train” the methods developed in this study and serves as a baseline for assessing future construction activities. Due to the limit of time and human resources, however, a comprehensive database has not been developed yet.

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