Observation Error of Time-Lapsed Photos in Construction Operation Monitoring

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Abstract

A web-based camera (webcam) is expected to enhance construction site monitoring, which may result in better project control. However, in most cases, webcams are located on the outside of a building because their mobility is limited by cable wiring, thus occasionally the view of the camera is blocked as the project develops. If a webcam is integrated with emerging wireless network technologies such as IEEE 802 or Cellular Digital Packet Data (CDPD), construction professionals may be able to utilize the webcam to monitor interior construction operations without worrying about getting the network cables wired on the congested and dynamic construction job site. Especially, the CDPD technology should enable the webcam to transmit captured photos from any construction site as far as the cellular phone service is available. However, with the speed of CDPD (19.2 Kilobits per second), it would take as long as 6 minutes to send one Mega pixel digital image. One may ask if construction professionals could figure out operations implemented at the job site by observing a 6 minute interval time-lapsed photo set. How many mistakes should we anticipate when interpreting the time-lapsed photo set with this time interval? To what extent can the frame rate of the webcam be lowered for monitoring construction operations at the job site? To answer these questions, we then produced time-lapsed photos of brickwork at three different construction sites with various time intervals and investigated error rates in identifying construction crew’s productivity using these time-lapsed photos. This paper presents a preliminary result of our investigation.

Introduction

A web-based camera (referred to as a webcam) is one of the new tools proposed to monitor construction operations on a remote jobsite. Although many construction professionals may expect that webcams installed on the remote job site would enable them to monitor construction operations without visiting the job site, dynamic nature of the construction project often makes it hard to install webcams at a right spot to capture the right image they want to see. As the construction progresses
dynamically, the location of the webcam may need to be changed frequently in order to capture the best image of the construction operations. However, frequent cable wiring for moving webcams from one spot to another, especially inside the congested building, may be bothersome and apt to hinder construction operations. It may be the reason why most webcams have been installed only outside the building being constructed. When the webcam is installed outside the building, it may not be able to capture the image of the operations implemented inside the building because the view of the internal operations is often blocked by exterior walls. Considering the amount of activities executed inside the building, webcams installed outside the building may never be able to supply what construction professionals want. In order to best utilize the webcam to monitor construction operations, we may need to be able to install the webcam wherever we want and change its location as often as we want.

Wireless technologies such as IEEE 802.11 and CDPD (Cellular Digital Packet Data) may resolve wiring problems in installing webcams inside a building. If these wireless technologies were employed for the webcam to transmit images wirelessly, webcams could be mounted more easily even inside the building without wrestling with network wires. IEEE 802.11 is a technology that can transmit images at speeds up to 54 Megabits per second, which is fast enough to deliver even motion images in real time. However, a webcam armed with IEEE 802 technology should be located within a specified distance from an access point. Wires connecting access points and a host computer could still obstruct effective operations at the job site. A webcam armed with the CDPD technology, on the other hand, can be used on any site as far as a cellular phone service is available. No cable wiring is necessary at all to utilize the CDPD technology at the job site. At a glance, the CDPD technology seems to better fit construction projects. However, the CDPD technology transmits a raw data only as fast as 19.2 Kilobits per second (CDPD Technology Overview 2001). Error correction mechanism and system overhead lower the speed down to somewhere between 10 and 15 Kilobits per second. Theoretically, with this speed, it would take about 6 minutes to transmit one image of 450 Kilobytes (=3600 Kilobits, rough size of one Mega pixel image). One may then doubt whether time-lapsed images transmitted every 6 minutes would deliver enough information for construction professionals to understand the situation going on at the job site without visiting the remote job site. If it is not fast enough, what interval of time-lapse photos would satisfy construction professionals’ expectations?

Abeid and Arditi (2002) have investigated the appropriate time-lapse interval for handling construction management issues such as delays, accidents, and claims. For investigation, they produced time-lapsed photo sets of a small bridge construction with various intervals. After they reviewed construction operations using these time-lapsed photo sets, they concluded that placing form-panels could be best monitored with less than a 10-second interval. They also concluded that they needed at least a 4-second interval time-lapsed photo set to interpret accidents taking place on a job site. Overall, one-second interval between frames was recommended for multipurpose use.
Obviously, the current CDPD technology doesn’t seem to match the time-interval of the time-lapsed photo recommended by Abeid and Arditi. It is reasonable, therefore, to expect that the time-lapsed photo set transmitted by the CDPD technology may not facilitate construction professionals to monitor construction operations on the job site effectively. It could be easily expected that construction professionals should make more mistakes in interpreting the job site situation using longer interval time-lapsed photos. Then, how many mistakes would we make in interpreting the time-lapsed photos when the photos are transmitted by utilizing the CDPD technology? To what extent could the frame rate of a webcam be lowered and still be able to monitor construction operations with a certain level of confidence? Investigation of the relationship between the probability of misinterpreting the job site situation and the time interval of the time-lapsed photo set may enable us to better utilize a cellular-phone-enabled (CDPD-based) webcam to monitor construction operations on a remote job site.

The presented paper reports a preliminary result of our on-going investigation to identify the relationship between the time interval of the time-lapsed photo set and the amount of errors one could make in interpreting the job site situation.

**Recording Construction Operations**

Since early 1900’s, construction professionals have been using construction photographs or movies for documentation and analysis of construction activities (Everett, Halkali, and Schlaff 1998). Time-lapsed film and time-lapsed video have both been used for productivity analysis and for the improvement of construction operations (Oglesby, Parker, and Howell 1989). The motion study of bricklayers by Gilbreth (1909) demonstrated a good example of utilizing motion pictures for studying worker activities. Gilbreth photographed the progress of work on the Augustus Lowell Laboratory of Electrical Engineering for the Massachusetts Institute of Technology in order to explain the detail work procedure of the project and improve a bricklaying process. Investigations performed in the 90’s found that time-lapsed video could be of significant benefit in documenting actual project progress, in resolving claims and disputes, for providing education, and in public relations, fund raising, and media applications (Everett et al. 1998).

The use of construction activity recordings diversified over time. As a Closed Circuit Television (referred to as CCTV) system was available in the construction industry, professionals were seeking a new way of providing project managers with a live image of remote projects. The CCTV system was originally developed to keep surveillance on people and objects. In New York City, for instance, there are more than two thousand private surveillance cameras taping citizens in public (Staples 2000). Likewise, in the UK, many cities applied the CCTV system to create safe, secure, and attractive places for consumption, entertainment, and tourism (Lyon 2001). The CCTV system was applied to a traffic surveillance system as well. Some traffic cameras can monitor the speed and detect speeding cars (Norris and Armstrong 1998). Some advanced cameras can observe even a moving object without missing it...
(Kumar 2002). The most significant changes in using the CCTV system happened when a video camera was connected to the Internet in 1991 to check the level of coffee in Trojan Room coffee pot (Stafford-Fraser 1995). The first Web-enabled camera (referred to as Webcam) was available on the market in 1996. However, it took several more years for the webcam to be utilized on a construction site due to technical problems such as difficulty of getting high-speed network connection on site. Recent application of webcams for the WorldCom Corporation headquarters construction project enables thousands of project participants to check construction progress at a regular basis (Staples 2000).

**Wireless Technology**

**IEEE 802.11 Standards.** IEEE 802.11 or Wi-Fi denotes a set of Wireless LAN standards developed by working group 11 of IEEE 802 (Wikipedia 2004). The 802.11 family currently includes three separate protocols: 802.11a, 802.11b, and 802.11g. The most widely available and implemented wireless LANs today comply with the 802.11b standard. It uses an unlicensed 2.4 GHz band and delivers a raw throughput as far as 300 feet with a speed of up to 11 Megabits per second (Geier 2002). Metal, water, and thick walls, however, absorb 802.11b signals and decrease the range drastically. The 802.11a standard uses the 5 GHz band and operates at a raw speed of 54 Megabits per second. In spite of its faster speed, 802.11a has not been widely adopted because, at 5 GHz, its signals cannot reach as far as those of 802.11b. The 802.11g standard works in the 2.4 GHz band like 802.11b, but it operates at 54 Megabits per second raw throughput like 802.11a. It is fully backwards compatible with 802.11b and uses the same frequencies. Operating in an unregulated frequency band, 802.11b and 802.11g equipment can incur interference from microwave ovens, cordless phones, and other appliances using the same 2.4 GHz range (Wikipedia 2004). Although, the IEEE 802.11b standard is relatively inexpensive and has a high-speed data transfer rate up to 11 Megabits per second, one still has to setup several access points on a construction job site in a way that the distance between a camera and the access point would be less than 300 feet. The ordinary construction site conditions may not be favorable for wiring network lines from a host computer to each access point.

**CDPD (Cellular Digital Packet Data) Technology.** CDPD technology is used by a cell phone camera that takes photos and transmits them over the wireless Internet. As long as one gets a cellular phone call on a construction site, the images of the job site taken by a camera could be transmitted to the server without getting the network lines wired on the job site. Although CDPD’s ability of transmitting images at a longer distance would avoid any network lines to be wired on a construction job site, one must deal with CDPD’s narrower bandwidth in order to employ it for transmitting images wirelessly. Because CDPD technology offers only a raw bit rate of 19.2 Kilobits per second (CDPD Technology Overview 2001), the quality of image transmitted over the cell phone line must not be as good as the one transmitted over IEEE 802.11 or it should take longer time to deliver the same quality of image.
Experiment

Videotaping Construction Sites. In order to identify the relationship between the time intervals of the time-lapsed photo set and the amount of errors one could make in interpreting the job site situation, we decided to videotape construction operations and produce time-lapsed photo sets with various time intervals using a digital video editor.

We have selected three residential construction sites in the city of Bryan/College Station, Texas and videotaped their outer-wall brickwork. Outer-wall brickwork was chosen because we could easily set up a camera without bothering the operation and the motion of the brickwork was relatively simple and easy to understand.

A digital video camera was set up at a location where the majority of bricklayers could be monitored. The distance between the workplace and the camera was at least 50 feet in order not to disturb the work. Each bricklaying work site was videotaped for one hour.

An hour-long videotaped image was then imported to a personal computer and converted into a one-second interval time-lapped image set by utilizing digital video editing software. Overall, one hour-long videotape was converted into a total of 3600 one-second interval time-lapsed photos. Then one photo out of every 3 consecutive images was selected and then combined to produce a three-second interval time-lapsed photo set. Additional eight different time-lapsed photo sets (5, 10, 30, 40, 60, 180, 300, and 600 second time-lapsed) were produced using the same method. In total, we have produced 10 different interval time-lapsed photo sets as follows:

- second interval photo set (with 3,600 photos)
- second interval photo set (with 1,200 photos)
- 5-second interval photo set (with 720 photos)
- 10-second interval photo set (with 360 photos)
- 30-second interval photo set (with 120 photos)
- 40-second interval photo set (with 90 photos)
- 60-second interval photo set (with 60 photos)
- 3-minute (180-second) interval photo set (with 20 photos)
- 5-minute (300-second) interval photo set (with 12 photos)
- 10-minute (600-second) interval photo set (with 6 photos)

Evaluating workers’ activities. A graduate student working on construction management at Texas A&M University was recruited to evaluate workers’ activities captured in the time-lapsed photo sets and classify them into three categories: effective work, contributory work, and ineffective work according to pre-defined guidelines (Oglesby et al. 1989). The guidelines we used were:

- Effective work (actual process of adding to the unit being constructed)
  - Measuring, laying out bricks
  - Carrying or holding bricks or mortar
  - Setting up or dismantling a scaffold
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- Contributory work (work not directly adding to, but essential to finishing the unit)
  - Discussing the work
  - Giving or receiving instruction
  - Reading plans
- Ineffective work (doing nothing or doing something that is in no way necessary to complete the end product)
  - Talking while not actively working
  - Walking around empty-handed
  - Unable to find the worker in the frame

Generally more than one worker were captured in one photo. We evaluated each worker’s activity individually frame by frame. If a worker was doing an effective work, he/she was given 2 points for that frame. For contributory work, 1 point was assigned. For ineffective work, no point was given. The points given to each and every photo for a specific worker was multiplied by the time interval of the photo set used. For example, if the worker in a specific photo was doing an effective work he/she was supposed to receive 2 points for that photo. If that photo, however, happened to belong to a 60 second interval photo set, 120 points (= 2 points x 60 seconds) were assigned to that worker for that time frame. Summation of points assigned to each and every time frame will be a total score of that worker. In this way, one would receive 3600 points if he/she was doing always an effective work for an hour. Since the point of each photo was multiplied by the time interval of that photo set, the total point one could receive would be always 3600 points regardless of time interval.

All 10 different interval time-lapsed photo sets of site A, B, and C were observed in order from the 10-minute interval photo set to the 1-second interval photo set. We tried to minimize the observation bias by having the student to take a descending order from the 10-minute interval photo set. If the student grades in ascending order from the 1-second interval photo set, the low interval photo set that he/she already have reviewed should impact his/her decision with a high interval photo set.

**Observation Errors.** Observation error is defined as a difference between the total point of a worker in the 1-second interval photo set and the total point of other interval photo sets.

**Results and Discussion**

For classification, bricklayers were denoted as B and helpers were denoted as H for each site. B2A, for instance, represents the second bricklayer working at site A.

**Site A.** Activities of two bricklayers and one helper were captured at site A. Figure 1 shows the observation error of site A. Although all three workers showed similar trends as shown in the figure, the error rates differed from each other. The observation error rates of B1 and H1 increased rapidly until the 40-second interval
while the observation error rates of B2 increased rapidly until the 60-second interval. After that, error rates increased slowly.

![Figure 1. Observation errors of site A](image)

**Site B.** Among several workers captured at site B, two bricklayers and one helper were evaluated. As shown in Figure 2, observation error of B2 showed different pattern than the other two workers B1 and H1. The observation error rates of both B1 and H1 increased rapidly until the 60-second interval; after that, error rates increased slowly. However, the observation error rates of B2, who worked most of the time, increased rapidly until the 10 second interval; after that, the error rates fluctuated. Especially, error rates of 10% in both 300 second and 600 second interval deserve one’s attention.

**Site C.** At site C, two bricklayers and two helpers were observed. Figure 3 shows observation error rate of site E. Observation error rates of worker B1 showed a different pattern from others, but looked normal in comparison with other site workers. It increased until the 40 second interval; then slowed down. Although the observation error rates of B2, H1, and H2 showed similar trends among themselves, they are different from other site workers. The observation error rates of B2, H1, and H2 increased rapidly until the 30 second interval then began to fluctuate.
Overall Analysis by Sites. The average observation error rate of each site regardless the type of workers was developed as shown in Figure 4. Up to the 180-second interval, all three sites showed similar pattern. All average observation error rates increased rapidly until the 60 second interval, and then the error rates increased slowly or remained the same.
Conclusions and Future Research

The presented investigation started with a single question: how much could the frame rate of a webcam be lowered and still be able to monitor construction operations at a jobsite? To seek an answer to this question, we produced time-lapsed photo sets of brickwork with various intervals. The error rate of the higher interval time-lapsed photo set was identified by comparing it with one-second interval time-lapsed photo set.

The observation error rates of most workers increased rapidly until the 60-second interval; but their increment is quite consistent. Thus, it may be possible to predict the confidence level by utilizing time-lapsed photo sets up to 60 second interval if more investigation will be implemented for various activities. Enabling construction professionals to predict the level of confidence in utilizing time-lapsed photo set may promote the use of webcam for monitoring construction operation. Considering that error rate of 60 second interval photo sets marked less then 30% for all sites, time-lapsed photo set with less than 60-second interval may be utilized for monitoring construction operations and evaluating productivity with 70% of confidence level.

In the presented paper, only brickwork at residential homebuilding sites was selected and analyzed. One may speculate whether the maximum interval would remain the same if other work settings (for example, commercial building sites) are selected and analyzed.

Since the analysis of all photographs was conducted by one person, the results could be different if it was asked to someone else due to the examiner’s different experience.
or interpretation of operations. Therefore, analysis of the same or similar photographs by other people may be needed.

References


