

OBSERVATION ERROR OF TIME-LAPSED PHOTOS IN CONSTRUCTION OPERATION MONITORING

Jiwon Choi¹ and Julian Kang²

¹ Graduate student, Department of Civil Engineering, Texas A&M University, College Station, Texas, U.S.A.

² Assistant Professor, Department of Construction Science, Texas A&M University, College Station, Texas, U.S.A.

ABSTRACT : A web-based camera (webcam) is expected to enhance construction operation monitoring. However, webcams are often installed outside a building because their mobility is limited by cable wiring, which makes it difficult to monitor construction operations inside the building. If a webcam is integrated with emerging wireless communication technologies, construction professionals may be able to monitor interior construction operations using webcams without getting network cables wired on a congested and dynamic construction job site. However, one may concern that wireless communication may not be fast enough to transport all webcam images seamlessly. This paper presents an investigation as to the observation error of webcam images when a limited amount of images are delivered.

Key words : webcam, construction operation monitoring, time-lapse photography

1. INTRODUCTION

A web-based camera (referred to as webcam) is one of the new tools used to monitor construction operations on a jobsite. The webcam is expected to enhance site monitoring, which may result in better project control [1]. In most cases, webcams are located outside a building, thus occasionally the view of the camera is blocked as the project develops [2]. In addition, webcams are usually connected to web servers through cables which limit their mobility. Considering that more than 50% of construction operations are implemented inside a building and interior activities are dynamic, current webcams can hardly monitor interior construction operations. Limited mobility, therefore, makes it difficult to use wired webcams for monitoring interior construction operations.

Recently some wireless technologies, such as IEEE 802.11b and CDPD (Cellular Digital Packet Data), were available in the construction industry. These technologies could be used to transmit webcam images wirelessly. For examples, the IEEE 802.11b technology can transmit images to the server at a speed of 11 megabytes per second. However, a webcam using the IEEE 802.11b technology must be located within a specified distance from an access point connected to a host computer through a wire. Wiring to an access point may still be cumbersome. A webcam with the CDPD technology can be used on any site where cellular phone service is available. No previous network setup and special education for site personnel are necessary.

The CDPD technology based wireless webcam (referred to as a cellular-webcam) is expected to help professionals enhance their ability to monitor interior construction operations or operations in an area congested by many obstacles. The CDPD technology is believed to provide a raw data rate of up to 19.2Kbps [3]. The actual data rate is in the range of 10 to 15Kbps, because some of this capacity is used for error correction and system overhead. It transmits a 450Kb (medium quality one mega pixel) photograph within

30 to 45 seconds. Is it possible for construction professionals to use this speed for monitoring construction operations? What interval of time-lapse photos would satisfy construction professionals' expectations? The investigation of an appropriate interval of time-lapse photos to monitor construction operations may answer these questions.

The primary goal of this investigation is to determine the longest time interval for time-lapse photos that would enable professionals to interpret construction operations and productivity correctly.

2. RECORDING CONSTRUCTION SITES

Through experience gained and experimentation performed in the 90's, Everett et al. [2] found that time-lapse 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. It could be used to provide project managers with a live image of remote projects, as well.

2.1 Recording Methods

There are two major methods of recording construction activities using either time-lapse or real-time recordings. Although the real-time recording of a project provides a thorough recording of the entire process, the major disadvantage is that the time required to view the film or video is equal to the time required to perform the original operation [4]. On the other hand, time-lapse recording has the advantage of greatly reducing the amount of time spent viewing, while allowing viewers the opportunity to accurately interpret various construction operations [2]. Consequently, time-lapse recording techniques have been used in many cases for recording construction activities.

2.2 Wireless Technology

Occasionally, there are still sites where cabling is not possible or phone lines are not available [1]. In those cases,

using wireless cameras should be considered. In addition, there is frequently a problem with recording interior work after a building's envelope has been installed [2]. Since most webcams currently being used on sites are wired webcams and most interior work moves quickly from place to place, wiring through ceilings, walls, and from floor to floor proves difficult.

Regarding an IEEE 802.11b network, several wireless webcams are already available on the market today. It is relatively inexpensive and has a high-speed data transfer rate (up to 11 Megabytes, depending on the distance from an access point) [5]. On the other hand, there are some disadvantages such as a limited operations range and the necessity of setting up a wireless network on site.

CDPD technology is similar to using a cell phone camera that takes photos at regular intervals and sends those photos continuously to a web server. This camera is also currently available on the market. There are two major advantages to using this technology. First, there is no limited range to monitoring construction sites with this camera. Secondly, there is no need to establish a wireless network on site. These two merits should offer construction professionals substantial flexibility in recording and monitoring activities. However, there is a bandwidth issue to be solved. Because CDPD technology offers only a raw bit rate of 19.2 Kbps (CDPD Technology Overview 2001), the quality of image must be lowered or the time-lapse interval lengthened for greater image clarity.

3 METHODOLOGY

Brickwork on three different construction sites were videotaped. Nine different intervals for time-lapse photography (excluding one-second interval) were chosen. Each worker in a photograph was examined and graded according to predefined guidelines. The grade of a worker at every second in one-second interval photo set was compared to the grade of the same worker in other interval photo sets. 9 observation error rates per worker were obtained from the comparison of grades. Finally the observation error rate lines of workers were drawn and analyzed.

3.1 Videotaping Construction Sites

Three residential construction sites in the Bryan/College Station, Texas were selected. Outer-wall brickwork was chosen because the operation was relatively simple and the workflow was easy to understand. A digital video camera, a desktop computer and the Adobe Premiere 6.0 video editing program was used to make the time-lapse photos. One-second interval time-lapse photo set, which has a total of 3600 photos, was created as a control template for this research.

3.2 Intervals for Time-Lapse Photograph

In order to compare the differences in monitoring construction operations at different intervals, potential intervals that construction professionals may want to use in monitoring their projects were considered. Nine intervals: 3, 5, 10, 30, 40, 60, 180, 300, and 600-second were selected and divided into three groups: short, mid, and long. The short interval group consisted of 3, 5 and 10-second; the mid

interval group consisted of 30, 40, and 60-second; the long interval group consisted of 3, 5, and 10-minute.

3.3 Analyzing Time-Lapse Photos

To classify each worker, a symbol was assigned to each worker. The symbol was an alphanumeric designation indicating a site and a role in the brickwork. Three residential construction sites were classified as A, B, and C and workers on them classified as bricklayers (initialed as "B") or helpers (initialed as "H"). For instance, worker A-B2 is the second bricklayer at site-A and C-H1 is the first helper at site-C. Worker activity in each time-lapse photo was examined and classified into three categories: effective work, contributory work, and ineffective work according to pre-defined guidelines [6]. The guidelines were as follows:

Effective work:

- The actual process of adding to the unit being constructed.
 1. Measuring, laying out bricks.
 2. Carrying or holding bricks or mortar.
 3. Setting up or dismantling a scaffold

Contributory work:

- Work not directly adding to, but (through associated processes) essential to finishing the unit.
 4. Discussing the work
 5. Giving or receiving instruction
 6. Reading plans.

Ineffective work:

- Doing nothing or doing something that is in no way necessary to complete the end product.
 7. Talking while not actively working.
 8. Walking around empty-handed.
 9. Unable to find the worker in the frame.

3.4 Observation and Grading

In each photo, there were generally three or four workers visible and each worker was examined individually. If a worker was defined as doing effective work in the photo, the worker would be assigned a grade of two for that time-frame. For contributory work, the grade would be one. For ineffective work, the worker would be graded zero. Additionally, if a rework occurred, the worker involved in the rework (including demolition) would be assigned a grade of three.

In order to perform the observation, it was necessary to make nine interval photo sets out of one-second interval photo set. In order to make nine different interval photo sets, specific photographs (including the 1st photograph) from one-second interval photo set were collected. For instance, in order to make 5-second interval photo set, the 1st, the 6th, the 11th... and the 3596th photographs (a total of 720 photographs) were collected from one-second interval photo set.

The numbers of photos in each interval photo set were as follows.

- 1-second interval photo set (3,600 photos)
- 3-second interval photo set (1,200 photos)
- 5-second interval photo set (720 photos)
- 10-second interval photo set (360 photos)
- 30-second interval photo set (120 photos)

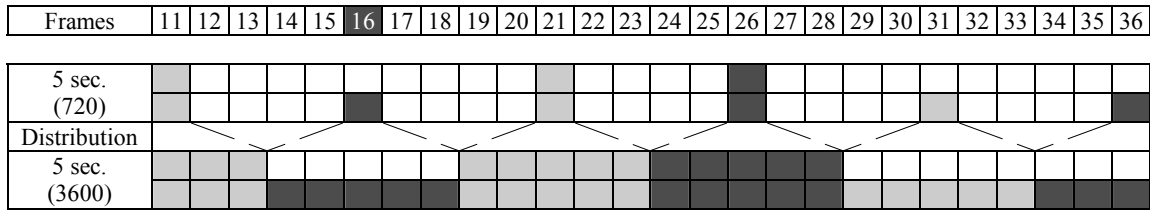


Fig. 1. Distributing grades

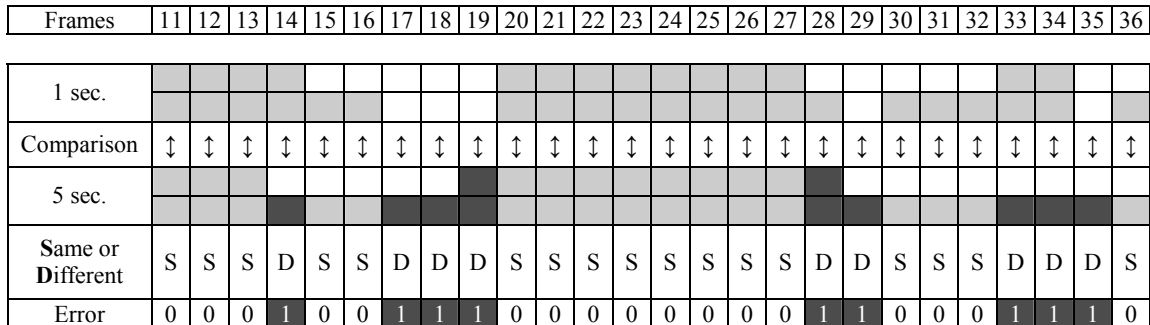


Fig. 2. Finding observation error

Table 1. Sample observation error rates table

Items	3 sec.	5 sec.	10 sec.	30 sec.	40 sec.	60 sec	3 min.	5 min.	10 min.
Worker	10.00%	34.62%	25.00%	35.00%	40.00%	50.00%	55.00%	50.00%	60.00%
-	- %	- %	- %	- %	- %	- %	- %	- %	- %
-	- %	- %	- %	- %	- %	- %	- %	- %	- %

- 40-second interval photo set (90 photos)
- 60-second interval photo set (60 photos)
- 180-second interval photo set (20 photos)
- 300-second interval photo set (12 photos)
- 600-second interval photo set (6 photos)

Observation was implemented by observing and grading all workers in every photo of ten different interval photo sets. All 10 different interval photo sets of all sites observed in order from the 10-minute interval photo set to the 1-second interval photo set. By observing in descending order from the 10-minute interval photo set, the observer could be unbiased in grading because the observer does not know what happened in previous frames. However, if the observer grades in ascending order from the 1-second interval photo set, he/she may be biased in grading the next interval photo set because the observer would already know what had happened and he/she would grade based on knowledge rather than inspection.

3.5 Observation Errors

Observation error was defined as difference between evaluation of the activities of a worker on a jobsite at the 1-second interval photo set and other interval photo sets. The basic method for obtaining observation error is comparing each frame grade of a worker in the 1-second interval photo set with the same frame grade of the worker in different interval photo set.

However, the numbers of grades for a worker in other

interval photo sets are less than 3600. For example, the 5-second interval photo set has 720 grades specifically at the 1, 6, 11, ... 3586, 3591, and 3596 frames. To compare this with the one-second interval photo set, 3600 grades should be inferred from 720 grades. A grade in the 5-second interval photo set should cover five frames, assuming that once the worker is assigned a certain grade at a frame, the grade will remain the same before and after two frames. Figure 1 shows a grade of "1" at the 16th frame in the 5-second interval photo set, and this grade will be distributed to five frames-- the 14th to the 18th frames. In this manner, all interval photo sets contained 3600 grades.

The next step compared all 3600 frames of the one second interval photo set with other interval photo sets one by one; if both grades were the same at a frame then the frame was marked 0, and if both grades were different at a frame, marked 1. The sum of marked numbers (errors) divided by 3600 frames represented the observation error rate of the worker. The same routine was continued with other workers. Figure 2 shows the observation errors at the 5-second interval. After that one observation error rates table per jobsite was made.

Table 1 shows a sample observation error rates table for a site. From the figure 3, for instance, suppose the error rate of the worker at 5-second interval is 34.62%, which is 9 errors divided by total 26 frames. This error rate is highlighted on the sample observation error rates table below. The others are arbitrary error rates.

Table 2. Observation error rates of site-A

Items	3 sec.	5 sec.	10 sec.	30 sec.	40 sec.	60 sec	3 min.	5 min.	10 min.
A-B1	6.92%	11.67%	13.36%	22.11%	28.61%	30.72%	40.44%	59.36%	71.42%
A-B2	11.06%	22.72%	19.17%	25.61%	28.69%	37.44%	44.31%	57.28%	69.47%
A-H1	3.86%	7.19%	8.92%	15.50%	21.67%	22.75%	28.31%	53.61%	58.92%

Table 3. Observation error rates of site-B

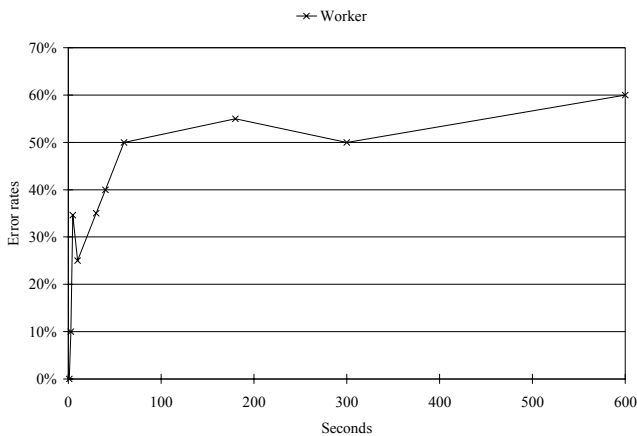
Items	3 sec.	5 sec.	10 sec.	30 sec.	40 sec.	60 sec	3 min.	5 min.	10 min.
D-B1	12.75%	14.58%	18.14%	22.36%	26.69%	30.61%	34.72%	39.72%	40.39%
D-B2	9.33%	9.86%	14.81%	15.92%	12.86%	14.78%	28.47%	10.17%	11.08%
D-H1	12.81%	14.81%	21.78%	29.11%	30.64%	33.03%	32.78%	44.92%	51.44%

Table 4. Observation error rates of site-C

Items	3 sec.	5 sec.	10 sec.	30 sec.	40 sec.	60 sec	3 min.	5 min.	10 min.
E-B1	10.42%	11.47%	13.08%	17.00%	18.78%	18.75%	32.50%	47.03%	49.67%
E-B2	5.36%	6.58%	12.14%	16.19%	12.69%	30.17%	27.97%	44.81%	35.97%
E-H1	6.83%	12.08%	16.28%	19.92%	31.33%	25.22%	30.50%	39.64%	20.81%
E-H2	7.78%	10.92%	10.89%	31.06%	29.86%	29.81%	36.39%	40.61%	43.17%

3.6 Developing Graphs

According to the observation error rates on an error rates table, the graphs of observation error rates were drawn. The graphs showed observation error rates from 0 % to 100 % on the Y-axis and time-frames from 0 second to 600 seconds on the X-axis. Each worker had his/her own error-rate line. One line contained 10 error-rates, each of which corresponds to certain intervals. Figure 3 shows a sample graph of observation error rates of the worker on the table 1.

**Fig. 3.** Sample graph of observation error rates

4. RESULTS

Error-rates of observing outer-wall brickworks were obtained, with the error-rates increasing as the time interval lengthened. Therefore, the hypothesis that the error in interpreting construction operations using a time-lapse photo would be affected by the interval of the time-lapse photo was supported by the results. Observation error rates were obtained from sites A, B, and C

4.1 Error Rates

As specified in the methodology, all 10 different interval photo sets of each site were observed by the researcher in order from the 10-minute interval photo set to the 1-second interval photo set. Finally, observation error rates were obtained.

On the Site-A, there were three workers, two bricklayers and one helper. Table 2 shows observation error rates of each worker in each time interval.

On the Site-B, among several workers, two bricklayers and one helper were observed. Table 3 shows observation error rates of each worker in each time interval.

On the Site-C, among several workers, two bricklayers and two helpers were observed. Table 4 shows observation error rates of each worker in each time interval.

5. DISCUSSION & ANALYSIS

With the obtained error-rates, graphs of broken lines showing errors along the time-frames were drawn. The trend of the error-rate-lines was examined to determine whether or not the lines decrease or increase markedly at a certain interval, form any specific curve, fluctuate more as the interval increases, etc. The graph was subdivided by observation types, sites, and worker activity types. The average observation error-rate of each site at each interval and the average of each worker activity type was obtained, compared and interpreted.

5.1 Analysis by Sites

The average observation error rate of each of the three sites was calculated and drawn. Up to the 180-second interval, all three sites showed similar trends. The average observation error rates increased rapidly until the 60-second interval, and then the error rates increased slowly or remained the same according to sites. Figure 4 shows average observation error rate graphs of all sites.

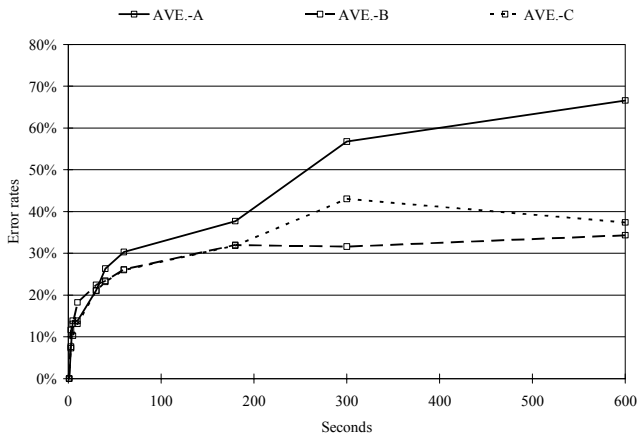


Fig. 4. Graphs of average observation error rates of all sites

5.2 Analysis by Activities

The average observation error rates of the two activities (bricklaying and helping) were calculated and drawn. Although observation error rates of certain intervals were different between the two activities, the overall trends of the two activities were fairly identical. The average observation error rate of bricklayers increased rapidly until the 60-second interval while the average observation error rate of helper increased rapidly until the 40-second interval; then they increased slowly until the 600-second interval. Figure 5 shows average observation error rate graphs of bricklayers and helpers.

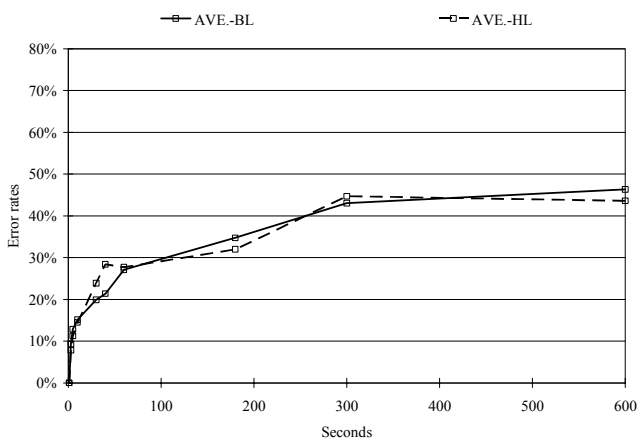


Fig. 5. Graphs of average observation error rates of bricklayers and helpers

5.3 Summary

The observation error rates of all workers from all three sites were analyzed. An error rate trend was obtained from Figure 10. In order to identify the trend line, an average observation error rate of all workers at each interval was calculated and drawn. The average observation error rate increased rapidly until the 10-second interval, and then increased a bit slower until the 60-second interval. After that the average observation error rate increased slowly, maintained, or even decreased. Figure 6 shows average observation error rate graphs of all workers.

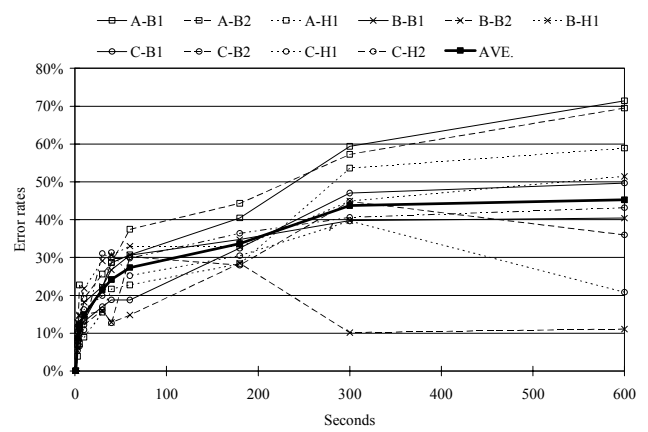


Fig. 6. Graphs of observation error rates of all workers

5.4 Discussion for Better Analysis

Although there were three categories: effective, contributory, and ineffective work, it was challenging to judge what type of work a worker was performing because the behavior of the worker was vague. This problem happened more frequently as the time interval lengthened, but it also happened when examining one-second interval photographs.

The reasons for this problem at a long interval and a short interval were different. At a long interval, there simply was no clue what the worker was doing. At a short interval, there were a number of reasons. First, relatively low-resolution photographs made it difficult to judge the nature of operation. Secondly, a worker in a distance was hard to see; and thirdly, although there were guidelines for defining worker activity, human behavior is so diverse that more detailed classification was needed to avoid ambiguity. Additionally, the analysis of all workers by examining all photographs was a repetitive and tedious task. Thus the examiner was easily distracted and could conceivably have lost his/her judgment.

In order to prevent this problem, increasing resolution of photographs, creating more detailed guidelines to classify worker activities, and taking a good rest during the examination of photographs may be important for effective research. Additionally, observing and grading by multiple people instead of one person could prevent errors from happening.

6. CONCLUSIONS & FUTURE RESEARCH

This research 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? Before initiating the research, a goal was set: to determine the longest time interval of time-lapse photos that enable homebuilders to interpret construction operations. To achieve this goal, time-lapse photographs, using various time intervals, of brickwork were produced. Interpreting these photographs, observation error rates were collected and analyzed. Finally, the error rate graphs were generated and analyzed. The trend of error rate graphs were examined and interpreted to determine the maximum time interval for brickwork.

Overall trends of observation error rates were identified. The observation error rates of most workers increased rapidly until the 60-second interval; after that, they increased slowly. Thus, it may be possible to use a 60-second or less interval photo set for interpreting construction operations and productivity, because the observation error rate slopes from 1-second interval to 60-second interval remain constant. This constant error rate slope will provide predictable error when professionals interpret construction operations or perform worker productivity studies. With a 60-second interval, we could expect an average of 28% error rate in interpreting a construction operation.

In our investigation, only brickworks at residential homebuilding sites were selected and monitored. If other work settings (for example, commercial building sites) are selected and analyzed, will the maximum interval remain the same as that for residential brickwork?

Because the analysis of all photographs was conducted by one person, the results could be different due to the examiner's different experience or interpretation of operations. Thus, despite the use of predefined classifying guidelines to judge worker activities, the result could differ from that of other people. Therefore, analysis of the same or similar photographs by other people and comparing the results would be worth conducting.

APPENDIX

Davies, S. G. (1998). "CCTV: a new battleground for privacy." *Surveillance, closed circuit television and social control*, edited by C. Norris, J. Moran, & G. Armstrong, Ashgate, Aldershot, Hants, England, 243-254

Deng, Z. M., Li, H., Tam, C. M., Shen, Q. P., and Love, P. E. D. (2001). "An application of the Internet-based project management system [Electronic version]." *Automation in Construction*, 10, 239-246.

Gilbreth, F. B. (1909). *Bricklaying system*. The Myron C. Clack Publishing Co., London

Gilbreth, F. B., and Gilbreth, L. M. (1973). *Applied motion study*. Easton Hive Publishing Company.

Kumar, R. (2002). "Aerial video surveillance and exploitation." *Video-based surveillance systems computer vision and distributed processing*, edited by P. Remagnino, G. A. Jones, N. Paragios, & C. S. Regazzoni, Kluwer Academic, Norwell, MA, 29-38

Lyon, D. (2001). *Surveillance society monitoring everyday life*. Open University Press., Buckingham, England.

Moran, J. (1998). "A brief chronology of photographic and video surveillance." *Surveillance, closed circuit television and social control*, edited by C. Norris, J. Moran, & G. Armstrong, Ashgate, Aldershot, Hants, England, 277-287

Norris, C., and Armstrong, G. (1998). "Introduction: power and vision." *Surveillance, closed circuit television and social control*, edited by C. Norris, J. Moran, & G. Armstrong, Ashgate, Aldershot, Hants, England, 3-18

Norris, C., Moran, J., and Armstrong, G. (1998). "Algorithmic surveillance: the future of automated visual surveillance." *Surveillance, closed circuit television and social control*, edited by C. Norris, J. Moran, & G. Armstrong, Ashgate, Aldershot, Hants, England, 3-18

Stafford-Fraser, Q. (1995) "The Trojan Room Coffee Pot.", (cam.ac.uk), Available: <http://www.cl.cam.ac.uk/coffee/qsf/coffee.html> (Accessed: 7 March 2003).

Staples, W. G. (2000). *Everyday surveillance vigilance and visibility in postmodern life*. Lanham, MD: Rowman & Littlefield.

Soldatini, F., Mähönen, P., Saarinen, M., and Regazzoni, C. S. (2000). "Network management within an architecture for distributed hierarchical digital surveillance systems." *Multimedia video-based surveillance systems requirements, issues and solutions*, edited by G. L. Foresti, P. Mähönen, & C. S. Regazzoni, Kluwer Academic, Norwell, MA, 143-157

Timothy, D. J., and Groves, D. L. (2001). "Research note: webcam images as potential data sources for tourism research" *Tourism Geographies*, 3(4), 394-404.

What is a Network Camera. (2002) (axis.com), Available: http://www.axis.com/documentation/whitepaper/video/what_is_network_camera.pdf (Accessed: 17 May 2003).

REFERENCES

[1] McCormack, C. (2002) "Simplify your life. Visit your construction sites online.", (oxblue.com), Available: http://www.oxblue.com/resources/Article_SimplifyYourLife_2002a.pdf (Accessed: 5 June 2003).

[2] Everett, J. G., Halkali, H., and Schlaff, T. G. (1998). "Time-lapse video applications for construction project management." *J. Constr. Eng. Manage.*, 124(3), 204-209.

[3] CDPD Technology Overview. (2001) (novatelwireless.com), Available: <http://www.novatelwireless.com/support/CDPD%20Tech.html> (Accessed: 2 May 2003).

[4] Abeid, J., and Arditi, D. (2002). "Time-lapse digital photography applied to project management." *J. Constr. Eng. Manage.*, 128(6), 530-535.

[5] Wireless 2.4GHz Internet Camera. (2002) (d-link.com), Available: <http://www.d-link.com/products/?model=DCS-1000W> (Accessed: 2 May 2003).

[6] Oglesby, C. H., Parker, H. W., and Howell, G. A. (1989). *Productivity improvement in construction*. McGraw-Hill Inc., New York, N.Y.