Time-Lapse Digital Photography Applied to Project Management

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Abstract: A discussion about movies used to monitor activities on a construction site is presented. A new concept in time-lapse photography is introduced, where the user records pictures of a construction site shot at an optimal frame rate and is able to play back time-lapse movies at lower frame rates, this way adjusting the running time and detail of the playback movie. A software package is built in the Windows visual environment, capable of generating a time-lapse movie of a desired frame rate from a regular digital movie shot at the construction site. The selection of the most appropriate frame rate to handle different managerial issues such as analyzing claims, investigating accidents, and monitoring progress is discussed. Solutions are sought to the problem of storing the vast amount of digital information generated by movies, using commercially available storage devices.

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Introduction

As important as planning in the project management process is controlling progress. As a project progresses, the site management team makes and keeps long reports related to the occurrences on a daily basis. As the words are open to interpretation, pictures are also taken and added to these reports. Given the length of court proceedings in solving disputes, it looks like more pictures would be more desirable. The ideal would be a movie, i.e., a thorough recording of the entire process. Watching a playback would enable one to understand much better the entire process on a day-by-day basis, and consequently to easily handle many managerial issues. For example

- The performance of equipment could be observed.
- The impact of adverse weather could be seen.
- Material delivery could be monitored.
- Accidents could be investigated.
- Expected durations could be compared with actual durations.
- Crews could be reviewed.
- Site productivity could be assessed.

A major problem with recording lengthy construction operations in real time is that the time required to view the film or video is equal to the time required to perform the original operation (Everett et al. 1998). To avoid this major inconvenience, a time-lapse technique can be used, transforming months of construction work into minutes of playback.

This paper presents the fundaments of the time-lapse digital photography technique used in the development of PHOTO-NET (Abeid 2000), a system that integrates time-lapse photography with a dynamic scheduling and progress control tool. Among other features, PHOTO-NET includes a system composed of software and hardware capable of shooting, storing, and playing back a time-lapse movie at a frame rate that is ideal for handling any of the managerial issues mentioned earlier. The paper describes this system, and discusses at length the selection of the most appropriate frame rate for filming construction operations and the technical hurdles faced in storing the vast amount of digital information on commercially available storage devices.

Time-lapse Photography Technique

The visual perception of the human being is comfortable when watching a movie within a 20–30 frame per second (fps) range. This means that there is no difference in perception if a movie is made with 30 or more than 30 fps. The National Standard Television Committee has established 30 fps as a standard frame rate in the United States. If a movie is made using a frame rate of 30 fps, all of the details of the filmed operation can easily be observed during playback. There are, however, two major problems associated with this frame rate—namely, it takes an equal amount of time to play back the movie as shooting it, and the film occupies a large amount of space on electronic storage devices such as hard disks.

The time-lapse technique reduces the frame rate when recording, but uses 30 fps when playing back; in this way, it is possible to see the movie in much less time than the time spent filming the real event. Thus, if a 6-h-long event is recorded at a rate of 5 fps, it is possible to play back the movie in 1 h at the standard frame rate of 30 fps; the shortening in the viewing time is obtained at the expense of missing some of the detail in the filmed operation. The storage space for the time-lapse film is also reduced.

Any construction management system that makes use of movies shot on a construction site needs to surmount two major problems. The first problem involves the appropriate frame rate that allows the efficient handling of any of the many construction

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management issues (e.g., delays, accidents, claims, etc.) associated with construction projects. The second problem is how to fit all of this digital information on a commercially available hard disk.

Selection of Optimal Frame Rate

The question that arises when applying time-lapse photography to a certain phenomenon is the selection of the most appropriate frame rate. The classical example of time-lapse photography, the blossoming flower, generates false expectations about the quality of a time-lapse movie. This is because the blossoming flower is filmed in laboratory conditions against a uniform background and the flower blossoms in an almost continuous path, so that the time-lapse movie is smooth and stable—as if it were filmed in the standard frame rate.

The described effect is not achieved when a movie of a construction operation shot in time-lapse mode is played back. There is always a busy background, shadows that change at different times of the day, people walking, equipment moving, and so on. In this kind of environment, the time-lapse movie loses its smoothness when it is filmed with a frame rate that does not agree with the perception capabilities of the human brain.

As the movie will not be smooth when shot at construction site conditions, one could be tempted to use as low a frame rate as 1 frame per minute (fpm), for example; in this way, a four-month-long construction project could be played back in as little as 23 min. This alternative is, however, not acceptable, because the idea is to have an intelligible report about field operations and a 1-min lapse is too long for this purpose. For example, the duration of an accident that occurred when a crane used on the Interstate-55 reconstruction project tipped and fell into the Chicago River, killing its operator, was only a few seconds; a movie would not have registered the accident, had one used a 1-min lapse (Abeid 2000).

Everett et al. (1998) applied time-lapse photography to construction management, while Crissman and Lalumiere (1998) used it to observe ice boom progress. They worked with analog movies, but they were constrained in their research by the predetermined frame rates that their time-lapse videocassette recorder (VCR) allowed; they used one frame every 8 s, which corresponds to 7.5 fpm. When working with digital time-lapse movies, such as the process described in this paper, the interval time can be determined nowadays without video recorder constraints, but other constraints such as available hard disk space and operational delays caused by the management of multiple picture files have to be considered.

To find what the most appropriate frame rate would be in a construction environment, a film was made in late 1998 of a small bridge under construction over the Kankakee River in La Crosse, Ind. The construction was filmed during one whole week using a regular video camcorder installed on a tripod placed on the roof of the contractor's trailer. A standard frame rate of 30 fps was used. The film was digitized in the standard frame rate using a system composed of a VCR and a microcomputer running a software package called Media 100.

A program called *Time-Lapse Builder* that is described later in this paper was developed to read a digital standard movie and produce another in time-lapse mode. *Time-Lapse Builder* was developed to easily produce several versions of the same movie in different frame rates, with the intention being to find out the optimal frame rate for filming construction operations. Using *Time-Lapse Builder*, a set of clips in different frame rates were generated from a 10-min digital clip of the La Crosse construction shot at the standard frame rate of 30 fps. Table 1 shows the time-lapse versions generated.

Table 1. Time-lapsed Digital Clips

Frequency	Frame rate (fpm)	Number of frames in 10-min clip
One frame every 1 s	60	600
One frame every 2 s	30	300
One frame every 3 s	20	200
One frame every 4 s	15	150
One frame every 5 s	12	120
One frame every 6 s	10	100
One frame every 7.5 s	8	80
One frame every 9 s	6	60

Note: 10-min clip filmed at standard frame rate contains 18,000 frames.

Fig. 1 presents the frames of an 8-s clip extracted from the 10-min clip. The pictures show a worker placing a form panel at four different frame rates. At 60 fpm, it is possible to see the worker coming, carrying the panel, and placing it in its position. At 30 and 15 fpm, it is still possible to understand that the panel was brought and placed in its position by a worker. In the 6 fpm clip, the only thing that is possible to see is that a worker has placed a panel. At 3 fpm, the panel would simply appear in the movie and there would be no sign of the worker.

If one wants to use the movie to check the predicted man-hours for the activity ''Placing form panels,'' it would be possible to do so only with frame rates over 6 fpm. If the worker in that scene had fallen down and hurt him/herself with the panel, the accident would be clearly seen only when using frame rates over 15 fpm.

A rate of 60 fpm seems to be a frame rate that records all of the details, but it has the inconvenience of a long playback time. With a movie filmed at 60 fpm, it would take more than 27 h to play back a four-month-long construction operation.

The solution is to record at a frame rate of 60 fpm and to play back time-lapse films at lower frame rates as deemed necessary, which is possible by skipping pictures (Fig. 2). Since the playback is always conducted at the standard frame rate of 30 fps, playing back time-lapse movies at lower frame rates has the effect of speeding up the playback time. If a situation such as an accident has to be investigated in detail, one can watch the whole set of frames at 60 fpm in order to capture the minutest details, whereas if the reason for the analysis is a claim investigation, one can use a lower frame rate. In other words, the program developed in this research enables the analyst to choose any time-lapse frame rate desired lower than the one used to produce the movie and, in this way, adjust the run time of and the detail involved in the playback.

Resolving Storage Problems

Not only is playback time a matter of concern in lengthy processes such as a construction project, but so is the vast amount of storage space required to record digital pictures. Computers treat pictures as a composition of small squares called pixels (picture elements). A pixel is an element of a matrix that emerges from a grid into which a picture can be divided. In fact, the picture in the computer environment is a three-dimensional matrix, where the first and second dimensions are the coordinates of the pixels and the third is their color. A pixel is represented by 7 bytes, two of

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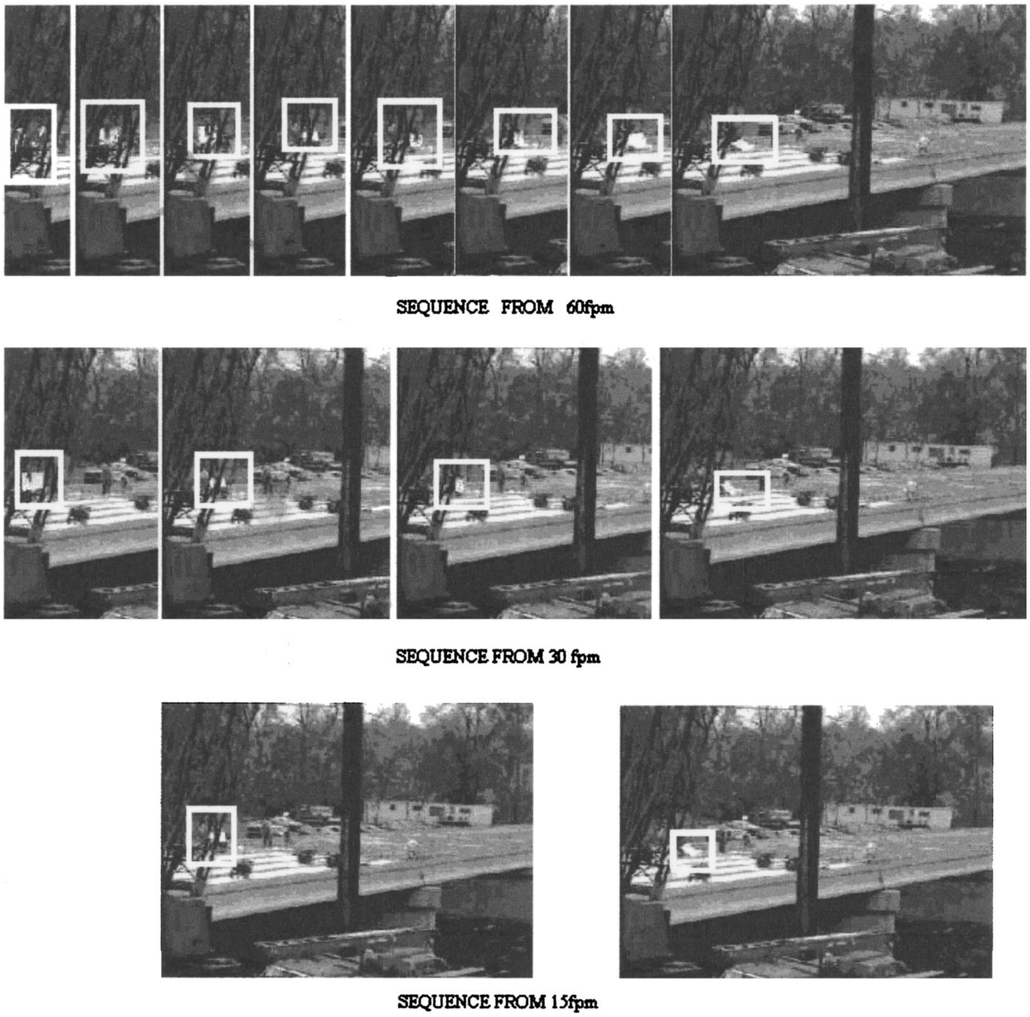

Fig. 1. Sequences at four different frame rates

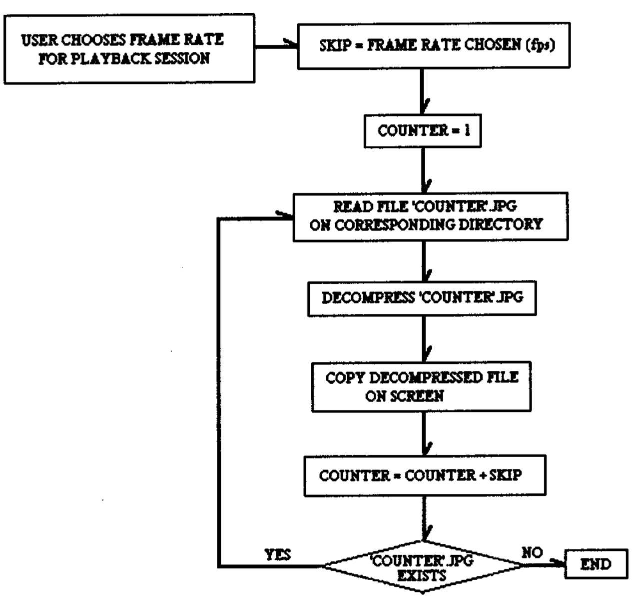

Fig. 2. Procedure for playback at frame rate other than recording frame rate

which are used for each of the two coordinates, and the remaining three are for the pixel's red/green/blue that represents a color by a number. The amount of hard disk space necessary to store a typical 1.024×768 pixel picture at 7 bytes/pixel is 5.5 megabytes (MB). A 10 gigabytes (GB) hard disk would be able to store 1,816 pictures of 5.5 MB each, which means only 1 min of a movie shot at a standard 30 fps (Abeid 2000).

To avoid this major inconvenience, three measures can be taken. First, one can film the event in time-lapse photography, as described earlier—in which case, a 1-min-long movie would actually represent 240.8 min (4.013 h) of the actual operation if, for example, a frame rate of 7.5 fpm (one frame every 8 s) were used.

The second measure is to reduce the size of the frame. A frame of 360×240 pixels, for example, would need 605 kilobytes (kB) of hard disk space, as opposed to the 5.5 MB for the 1.024×768 pixel frame. If a frame of 360×240 pixels were used in addition to a time-lapse procedure at, for example, 60 fpm, then 17.5 GB would be required to store an entire 8-h working day. This is still too much space if one realizes that a nine-month construction project, for instance, would require approximately 3.5 terabytes of disk space. The storage capability of hard disks has been increasing rapidly, but it is approaching the technical limitations of the current standard issued by the American National Standards Institute, which governs data transfer to and from most of the hard drives. The standard uses a 28-bit addressing

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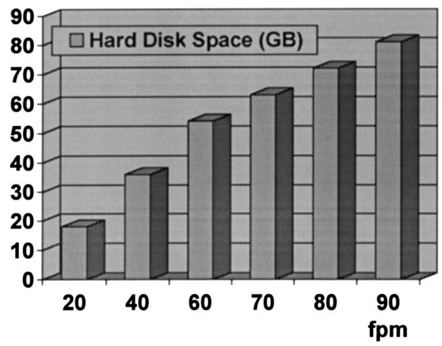

Fig. 3. Hard disk space necessary versus frame rate for nine-month-long film

system that cannot recognize more than 137.4 GB of information. There are currently new standards being developed for 48-bit addressing systems that would allow bigger capacity hard disks. Other concerns include the areal density of the disk, which is the quantity of data a disk can store per square millimeter. The current technology would have a limitation of approximately 500 GB. Considering these technical problems, there appear to be real expectations for 400-GB hard disks becoming available in just two years from now (Captain 2001). Other storage devices can also be considered, but at a comparatively much higher price, putting at risk the feasibility of the system.

The third measure is to compress the picture. Compressing a picture is an operation that reduces the size of the file by systematically reducing the information on it. Pictures are composed of shapes such as the sky, the soil, and objects. A clear sky, for example, is a set of pixels roughly of the same color. What the compressing engine does is map the boundaries of the area where the pixels have almost the same value, and store only the coordinates of the boundaries and the predominant pixel value within the boundaries. In this way, the compressed picture can be reduced to a smaller file. The more a picture is compressed, the lower is the quality of the picture when it is decompressed. So, if the quality of the decompressed picture is not of paramount importance, the picture can be reduced by as much as 80–90%.

Several different compressing engines are available on the market. The Joint Photograph Experts Group (JPEG) system was used in this research. The JPEG system was chosen because the Windows system has a class to compress pictures using it. The JPEG class allows the user to specify the rate of compression. Experiments were conducted by varying the compression rate between 60 and 80%. It was found that if a single picture is being analyzed, the difference in quality can be of significance, but when an animation is run, the difference becomes negligible. As a result, an 80% rate of compression (i.e., reducing the size of the picture to 20% of its original size) was adopted.

By compressing a picture of 360×240 pixels by 80%, files of 5–8 kB are obtained. A 46-GB hard disk could store around 5.7 million pictures, which means around 198 working days of 8 h each (nine months), if a frame rate of 60 fpm were used, if the picture size were reduced to 360×240 pixels, and if each picture were compressed by 80%.

The chart presented in Fig. 3 shows the amount of hard disk space necessary to store a nine-month-long (six days a week, 8 h a day) construction film in different frame rates, after compressing the 360×240 pixel frames to 20% in JPEG format. The amount of hard disk space necessary to store a film made with the standard frame rate of 30 fps (i.e., 1,800 fpm) would be around 1,600 GB under these conditions. Given the level of today's hard disk technology, it is impossible to store such a film on a commercially available hard disk. That is why the analysis presented in Fig. 3 includes but does not exceed a frame rate of 90 fpm.

Experiments with *Time-Lapse Builder* have shown that a large number of files can overwhelm the file management process in the Windows operating system (frames are stored as files in *Time-Lapse Builder*). To overcome such problems, the film has to be stored in a series of smaller folders that *Time-Lapse Builder* creates automatically. This problem again may overwhelm the system if the large number of pictures involved requires the formation of a very large number of folders. Experiments conducted with *Time-Lapse Builder* show that using a frame rate of 60 fpm appears to minimize these problems, while at the same time providing the necessary detail even to investigate accidents. It is true that particularly the last two measures (i.e., reducing the size of the picture, and compressing the picture) affect negatively the resolution of the pictures handled. There is indeed a trade-off between losing resolution and having an operational and feasible system. The experiments conducted with *Time-Lapse Builder* appear to indicate that the effect of these two measures on picture resolution is negligible if the system is used for purposes such as delay analysis and claims management. The pictures would not provide enough detail, however, to conduct theft investigations, which require a clear picture of individuals' faces.

The field of view is an issue that is also of importance in generating time-lapse movies on construction sites. For example, microissues such as individual crew performance and productivity, accident investigation, and security would require a narrow field of view to give sufficient detail, whereas macroissues such as weather conditions, deliveries, and activity progress would require a wide field of view—possibly of a very large portion of the site, if not the entire site. There is no optimal field of view that can cover all of the purposes, but a strategic location for the camera coupled with the right kind of lens could alleviate this problem to a great extent. In the experiment conducted on the bridge construction over the Kankakee River in La Crosse, a wide field of view was adopted by picking a high location for the camera (tripod on roof of trailer) and a wide-angle lens was used that could capture the entire section of the construction site under consideration.

Time-Lapse Builder

Time-Lapse Builder is a program built in Delphi Version 4. Delphi provides a very powerful visual component called Media Control Interface that is a high-level command interface for controlling media files built into the Windows operating system (Osier et al. 1997). By incorporating this component in a program, one can run and control a digital movie in AVI (audio video interleaved) format (a format developed by Microsoft to play videos in the Windows environment).

Time-Lapse Builder performs the following operations:

- It runs an AVI file shot at a standard frame rate of 30 fps (in this case, the digital movie made at the construction site) in a predetermined window, by using the Media Control Interface.
- It freezes the window at the interval time specified by the user (the frame rate).
- It creates a Bitmap class in order to copy the frozen window in a buffer under a bitmap format.
- It creates a JPEG class to compress the frame stored in that buffer and generates a .JPG file.

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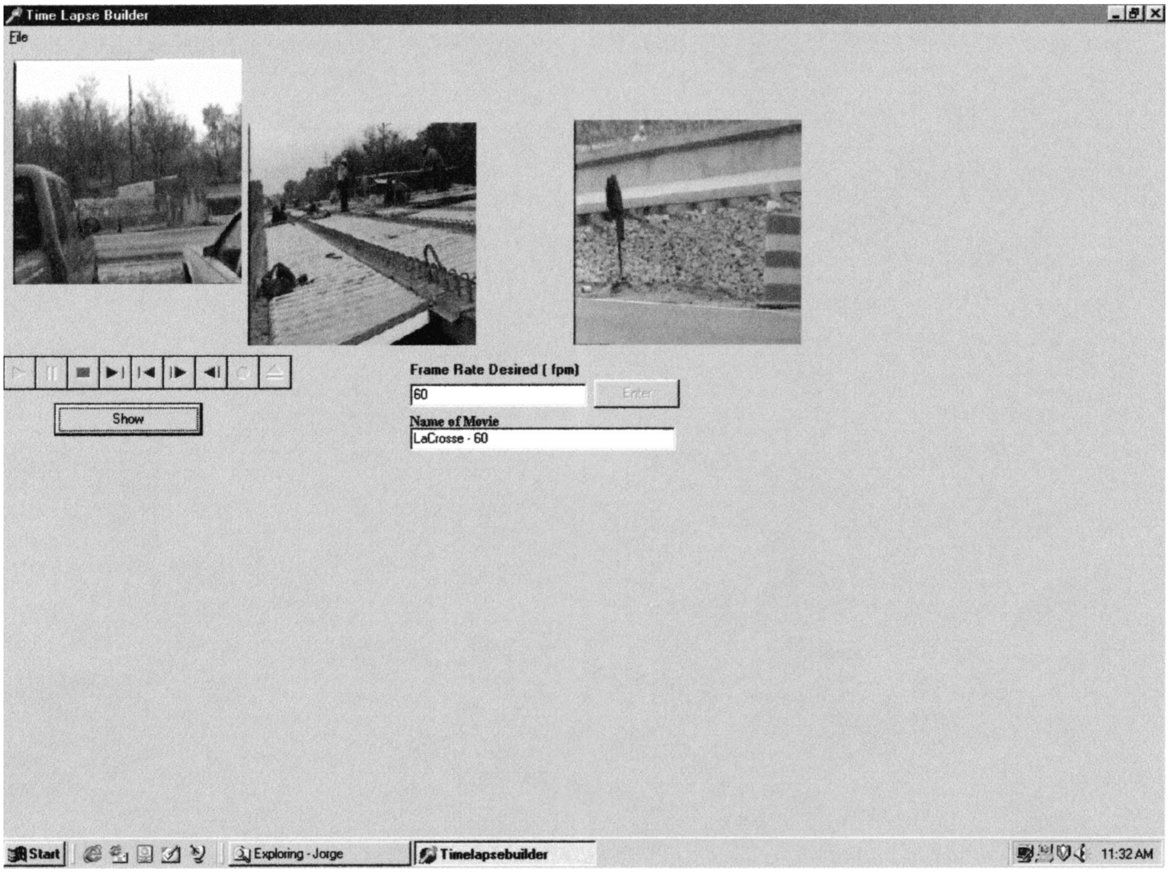

Fig. 4. *Time-Lapse Builder* playing back time-lapse movie

- It stores the .JPG file on hard disk, and disposes of the Bitmap and JPEG classes.

At the end of the operation, the hard disk contains a set of frames that include the film in a time-lapse version at the frame rate specified by the user.

A user who runs *Time-Lapse Builder* gets a screen such as the one in Fig. 4 minus the three film boxes. The user has to specify in the corresponding edit boxes the frame rate desired in frames per minute and the name of the folder where the program will store the frames. When the user clicks the ''Enter'' button, the software creates the folder and activates the options on the ''File'' menu.

Clicking on File triggers a Windows browsing engine that allows the user to find the AVI file previously stored on the hard disk and load it into the program. After that, the user can watch the movie in the leftmost movie box using the control bar on the left side of the screen. At the same time, the user watches in the adjacent movie box frozen frames as they are captured from the AVI film one by one at the frequency specified earlier by the user.

After the program finishes the time-lapsing operation, the user can watch the time-lapse version of the movie by clicking on the ''Show'' button, in which case the rightmost window shows the time-lapse film, while the leftmost window reproduces the last frame of the AVI movie and the window in the middle shows the last frame frozen by the program.

The user can generate as many time-lapse movies as necessary, depending on the purpose for which he/she is using the movie. The investigation of an accident can be conducted by using the original frame rate of 60 fpm. The length of time that it will take to play back the event is inconsequential, since the accident probably occurred over a short period of time; but all of the necessary detail will be captured in the playback. The proof of a delay in arbitration hearings may justify the use of a frame rate that is as low as 6 fpm, depending on the nature of the operation in question; arbitrators and the parties involved are interested in speedy proceedings and have no patience for irrelevant information. Productivity measurement of crews or equipment may require frame rates between 60 and 6 fpm, depending on the intensity of the operation and the type of crew or equipment involved.

Case Study

The concepts and the software (*Time-Lapse Builder*) presented in this paper were used in developing PHOTO-NET, a system where a digital time-lapse movie made at the construction site can be played back in synchrony with an animated schedule representing the as-built performance of construction activities alongside as-planned charts of these activities. The system builds a database composed of pictures (obtained through time-lapse digital photography) and data about project performance. It then combines this information to generate a screen where an analyst can observe a dynamic animation of the work schedule alongside the movie of the respective activities made using time-lapse photography (Abeid 2000).

The first version of PHOTO-NET was tested in 1999 on Unit 5 of the highway reconstruction project of Interstate 55 in Chicago. The construction field considered consisted of a portion of Unit 5 covering Piers 28–32. The camera used in this experiment was a color videocamera with an 8.46 mm (1/3 in.) charged-coupled

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device 512×429 pixels, 1/60 s autoshutter, a digital backlight compensation system, and 12 VDC (volts direct current). It was a camera used in surveillance systems. The lens was an autoiris with a fixed focal length of 4 mm and an angle of view of 87.3°. The camera was inserted into a special case to protect it against the weather, birds, and likewise. It was mounted on a 104-cm (34 ft) pole that was erected next to the construction site in order to have a wide field of view that would cover the entire construction area under consideration. The camera was tethered to a frame grabber capable of generating .bmp files from the analog pictures taken by the camera, and was connected to a microcomputer. Given the hardware limitations in this particular project, the frame grabber was set up to freeze pictures at a frame rate of 4.6 fpm, which was considered to be optimal.

The second generation of PHOTO-NET is now under development and takes advantage of new technologies, including the results of the experiments conducted with *Time-Lapse Builder*. It uses the conclusions of and the accumulated learning in these experiments when dealing with different applications (claims, delays, accidents, etc.) by generating time-lapse movies at different frame rates while using the same source film.

It was found that the concept used in the development of PHOTO-NET could be of great value to all parties involved in the construction process by enhancing clarity and eliminating ambiguity, and hence preventing the occurrence of disputes.

Conclusion

This paper reports the outcome of a study about frame rates of time-lapse digital movies. It then presents a software package specially designed to produce time-lapse movies at any desired frame rate from a regular movie of a construction site.

The software called *Time-Lapse Builder* was originally developed to generate a series of clips in different frame rates using the same movie in order to investigate the most appropriate frame rate that allows minimum hard disk storage space but adequate resolution for accident investigation. It appears that the most appropriate frame rate for recording construction operations is 60 fpm. At 60 fpm, it is possible to conduct a detailed analysis of an accident that takes only a few seconds to unfold, and it is possible to store the movie of a nine-month-long construction operation on a large but commercially available hard disk by reducing the size of the frame to 360×240 pixels and by compressing the files by 80% in JPEG format. But there is no optimal frame rate for all possible applications. For example, delay investigations may only require a frame rate that is as low as 6 fpm, whereas productivity analysis may require frame rates between 60 and 6 fpm, depending on the intensity of the operation and the type of crew or equipment involved.

It was found that *Time-Lapse Builder* was of great help in generating movies at the desired frame rate when investigating the best frame rate for a specific application. The second generation of PHOTO-NET uses the results of the experiments conducted with *Time-Lapse Builder* to deal with different frame rates using the same source film—in this way, adjusting the playback process for applications such as simple progress control, claims analysis, accident investigations, or demonstrations at courts or hearings.

Time-lapse photography used with the appropriate frame rate for the purpose can improve the parties' understanding of what really happened on the construction site, and consequently can reduce the likelihood of accidents, claims, and disputes.

References

Abeid, J. N. (2000). "PHOTO-NET: An integrated system for controlling the progress of construction activities." PhD dissertation, Illinois Institute of Technology, Chicago.

Captain, S. (2001). "Hard drives 100GB & larger." *PC World*, 19(9), 30.

Crissman, R. D., and Lalumiere, L. (1998). "Internet video monitoring of ice boom performance." *J. Hydraul. Eng.*, 124(5), 451–465.

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.

Osier, D., Grobman, S., and Batson, S. (1997). *Teach yourself Delphi 3*, Sams, Indianapolis.

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