

THE APPLICATION OF A PANORAMA IMAGE DATABASE MANAGEMENT SYSTEMS (PIDMS) FOR INFORMATION INTEGRATION ON CONSTRUCTION SITES

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EDITOR: C. Anumba

Naai-Jung Shih, professor

Department of Architecture, National Taiwan University of Science and Technology

email: shihnj@mail.ntust.edu.tw

Jen-Ta Lai, graduate student

Department of Architecture, National Taiwan University of Science and Technology

Yau-Liang Tsai

EeRise Corp

email: yltsai@eerise.com.tw

SUMMARY: *This study developed a panorama image database management system (PIDMS) to manage construction-related records. A set of panorama cameras was used to record panorama images and videos for the inspection and management of working schedule, manpower, materials, or machinery. Users can log in as construction site managers, contractors, general users, designers, draftspersons, or system managers through a browsing interface. The system is made according to functions, such as real-time monitoring, image labelling, working drawing browsing, video indexing, and construction recording. Three levels of application were developed.*

KEYWORDS: *panoramas, construction supervision.*

1. INTRODUCTION

Most of the architectural construction projects have to prevent risks, maintain cash flow, and correlate resources. To achieve better communication between constructors, design firms, and subcontractors, the manager of a construction site has to ensure both safety and efficiency in order to meet a client's budget and schedule. Traditionally, a diagram-like schedule was used to represent construction progress and also used as a framework to relate photo images, text records, numeric data, and drawings to specific tasks for communication and inspection purposes. However, a construction project usually deals with a large amount of information whose management is very effort-consuming (Al and Salman, 1985; Atkin, 1986). To facilitate management with convincing visualization, virtual reality (VR) technologies or 3D representations are used to simulate objects and activities (Retik, 2000; Vaha et al, 1997). But for in-site monitoring, visual information from different angles still needs to be retrieved to record the as-built situation. The visual records should combine schedule data to form an integrated database.

4D technologies have applied databases and 3D modeling tools to create time-based construction descriptions as a means for facilitating inspection (Dawood et al, 2003; Haymaker and Fischer, 2001). Links have been established between databases and corresponding 3D objects at specific time periods. However, the differences between design and real construction may exist. As-built visual records are needed to chronologically note construction progress. A comparison of as-built geometries with original design models was made to show the progress of the steel structure (Shih and Wang, 2004). However, a comparison of the construction progress in as-built visual form between two schedule days in panoramas was not done before.

The monitoring of an architectural construction site not only has to check working schedule, but also needs experienced supervisors to ensure tasks are conducted according to design and specifications. Today construction sites are getting larger and larger. If neighbors are included, the region would be too large for supervisors to monitor complete surroundings. Recent technology uses video cameras to record site occurrences at certain important spots through arrays of monitor screens. Those cameras can only display specific regions of

angles, viewpoints, and spans. Even when the cameras can sweep back and forth periodically, time lag exists. Unless a large number of cameras are used, a whole-view and chronological recording cannot be achieved.

Construction practice contributes a major part of architectural education. Due to the safety problems and interruption to workers, difficulties exist in bringing large numbers of students to a real site. Former researches built 3D computer models and used animation and VR technologies to simulate assembly processes, in order to predict potential construction problems or to be used as training materials (Cambell, 2000; Retik and Shapira, 1999). However, the level of visual details was limited, due to the modeling process being effort-consuming and the number of components usually too large to be inclusive. Wilkins proposed an Internet platform to incorporate stage-wise videos and image for learning purposes (Wilkins and Barrett, 2000). Combining as-built visual information as part of a construction database management system would be an extension not only to facilitate site monitoring, but also for pedagogical purposes.

2. RESEARCH PURPOSE

The purpose of this study is to develop a panorama image database management system (PIDMS) to manage construction-related information. The study would use VR technology to build-up a panorama-based construction site monitoring system for a remote renovation site using a set of panorama camera for 30 working days. Construction-related information should be accessed on Internet and form a communication platform for involved parties.

3. PANORAMA IMAGE DATABASE MANAGEMENT SYSTEM (PIDMS)

The images in PIDMS refer to the panorama videos and each framed panorama. In order to correlate as-built images and notes, most of the PIDMS has to link text records, numeric data, and drawings to specific images for communication and inspection purposes. Time-based panoramas record object movements with spatial or non-spatial attributes noted along a time axis (see Fig. 1). The image-based records are used to monitor and compare the difference between related frames to determine changes in the contents. The panoramas and notes are parts of the database for records, case studies, and decision-making needs. The system is composed of panoramic monitoring, information transfer, image analysis, record integration, and user interface (Fig. 2).

The 360 degree panorama video is used as a fundamental reference to monitor activities, check schedules, and add construction-relate documents. The videos and images are accessed through a time-based Internet browsing interface with several advantages, including the abilities to:

- monitor and respond to construction problems in real-time;
- permit routine construction schedule checks;
- add new object information throughout the construction process;
- integrate activity-based construction information of space and schedule through a visual interface.

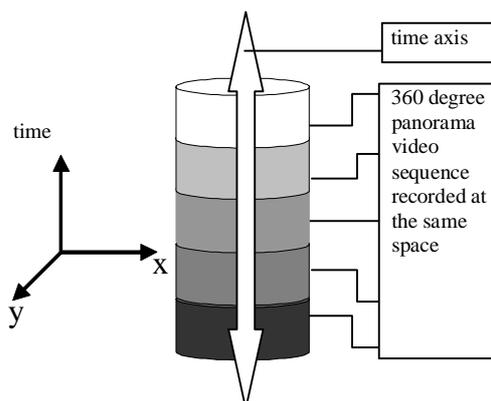


FIG. 1: Time-based panoramas recording.

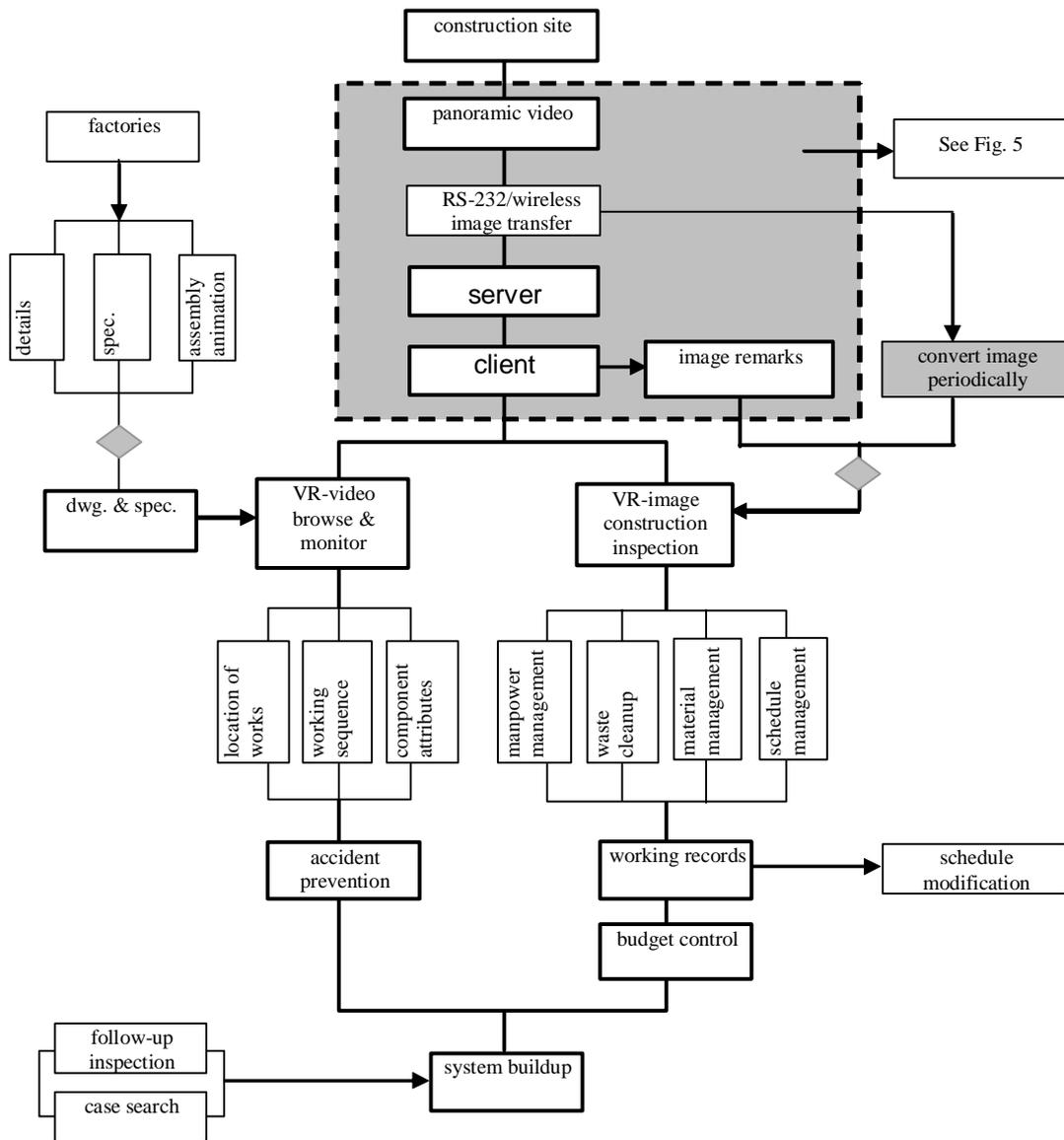


FIG. 2: System framework of panorama image database management system (PIDMS).

4.1 System setup

This study applied PanoDome (the map camera or mapcam) in supervising an interior construction site. PanoDome is a device that can be used to take 360 degree panorama videos (EeRise Corp., 2001). In conjunction with recording control software, it acts as a mapcam and can zoom in/out at a spot with the help of an additional camera (Speedom). A mapcam is named for the image covering a whole space and can be used to index the contents. The video lens of PanoDome (see Fig. 3) is attached by a CCD that can be connected to a camcorder, or any recording device. Because the video can capture up to 30 frames per second, the PanoDome records the surrounding environment continuously. It can be carried as a mobile device or installed as a fixture (see Fig. 4).

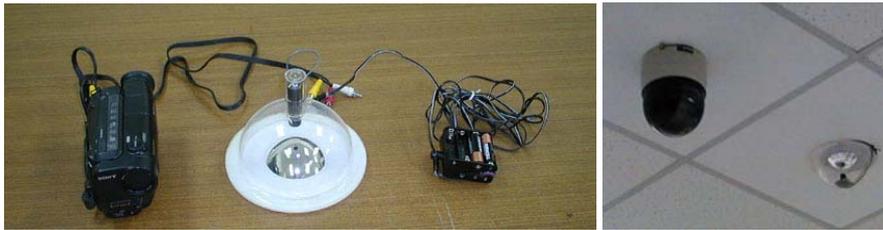


FIG. 3: Setting of a portable and fixed PanoDome monitoring system.

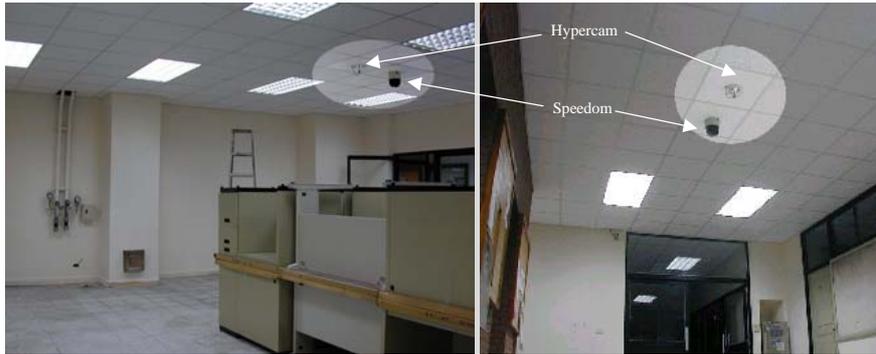


FIG. 4: PanoDome and Speedom on a ceiling in room R912 (left) and lobby (right).

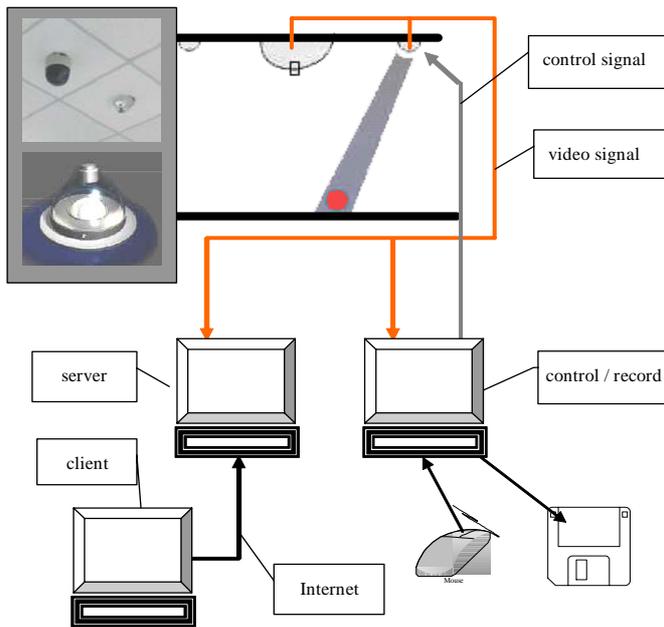


FIG. 5: Diagram of a PanoDome system.

The monitoring system is developed on a PC platform (see Fig. 5) that needs to be located near the monitoring site. An important feature of the system is the monitoring of remote sites through Internet. Remote users (such as supervisors, design firms, construction companies) can connect through Internet to retrieve images and progress records, as well as update information for follow-up inspections. A program, ViewNet, is used to log in servers to check what's happening in a distant site, including overseas. PanoDome, which provides a map of the site image, is associated with pan-tilt-zoom (PTZ) video cameras, Speedom, to retrieve clearer details. The PTZ camera is subject to the applications of motion detection and motion tracking. The system can control several

cameras at remote locations from the server site. System setting includes a RS-232 and two video (co-axial) cables to transfer video and control signals to and from the site and the server. Wireless transfer is possible. A 2.4 GHz wireless device was tried but the signal couldn't transmit through concrete walls without reduction: the maximum distance of transmission was between two stories inside a concrete building.

4.2 Panorama images

The images captured in a video clip are shaped like donuts (see Fig. 6 and Appendix A) that can be extracted one by one and simultaneously de-warped to panorama pictures. De-warped panorama pictures are converted into panorama scenes that are again connected into a video clip. A user can access files by recording date and hour. The layout of video information is divided into three regions.

- Map region (Fig. 6 top left): The picture is taken by the map camera PanoDome. The direct input video image is shown in donut shape. This part of the image is deformed and is not suitable for the observation of the environment in a normal form. However, any moving object can still be identified.
- Focused region (Fig. 6 top middle): The zoom-in picture is taken by Speedom. This region shows a closer view of a location of particular interest. The view can be either oriented by dragging a cursor alone, or by interacting with the other two regions by pointing to where the cursor is located. Speedom numbers can be increased as desired.
- De-warped region (Fig. 6 bottom): This is the region where the de-warped image of the donut-shaped video is placed. Instead of opening a fixed-sized window and permitting users to view different angles by pointing and dragging a mouse, the whole spectrum of panorama is displayed. The panorama is separated into one or two vertically overlapping 180 degree parts to reduce the window size. As with the picture before turning into a panorama scene, objects and environment within the image are deformed.



FIG. 6: A frame of panorama video clips (left), its de-warped image (bottom), and a man working (right) at renovation.

4.3 System and user interface

PIDMS interface allows users to input details, specifications, and records during construction (see Appendix B). Users can log in as construction site managers, contractors, general users, designers, draftspersons, or system managers. The system is a composite of its functions, such as real-time monitoring, image labelling, working drawing browsing, video indexing, and construction recording. The relationship between information and user privilege is shown in Fig. 7. In the synchronized application of the system, the integration of visual information makes the PIDMS a communication platform for construction-related parties. The recorded construction image facilitates the estimation of area, materials, machinery, manpower, or schedule directly or indirectly, as indexes for future project references of efficiency. The panorama images of a completed project are used to show

information on construction components through a browsing interface. The web page shows the activities that occurred in a space and is linked to other panorama images, panorama videos, images, and VR objects (Fig. 8).

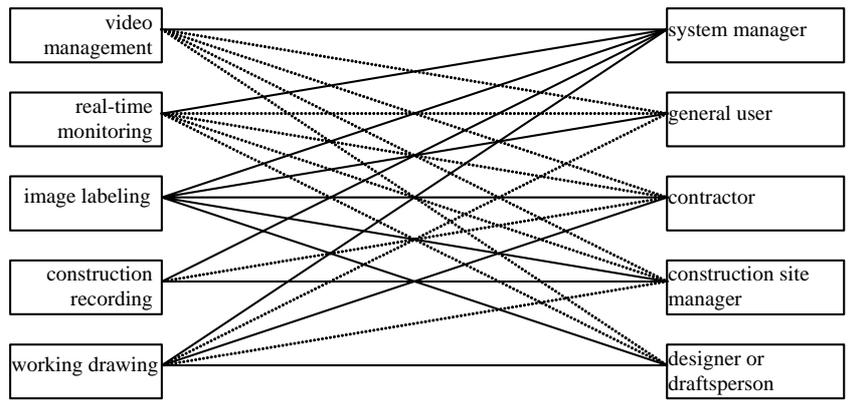


FIG. 7: The relationship between information and user privilege.

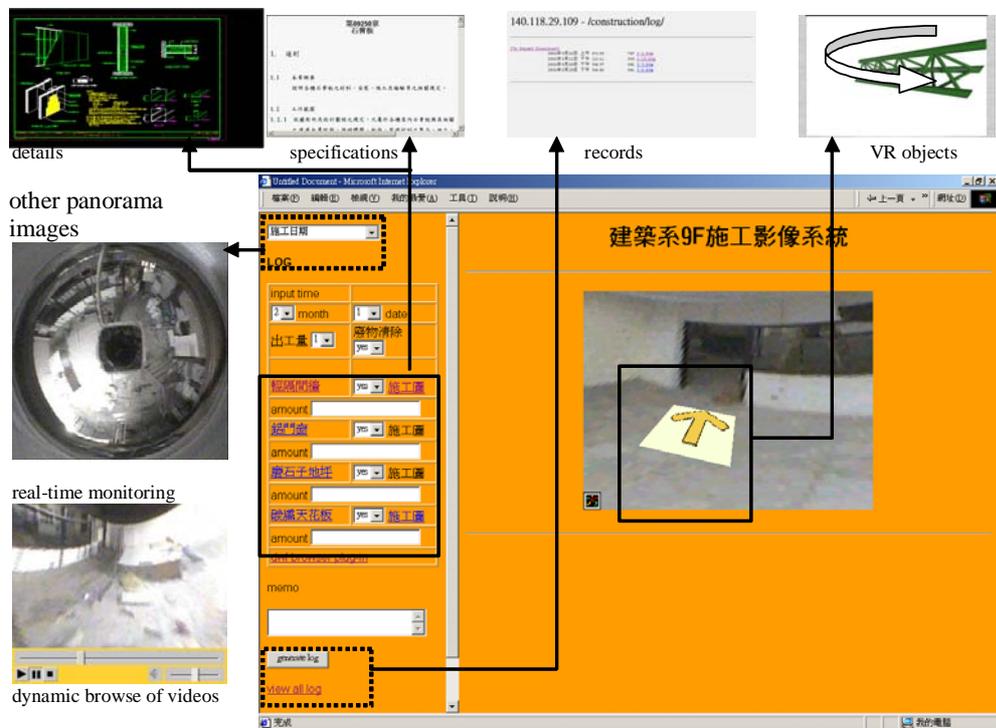


FIG. 8: Browse interface.

4. RENOVATION SCHEDULE

This experiment was tested in a remodeling project about the size of 20mx20m. The recording and monitoring starts from electric and interior partition works. Whole interior renovation took 30 days (see Appendix C). There were 19 working items running from one to seven days each. Not all items could be monitored for two reasons. First, before item 3, new fireproof coating was applied to refurbished steel beams. The paint needed to be sprayed with room openings sealed in order to control coating thickness. Due to concern that the paint might attach to camera covers, the renovation before the eleventh day was separately recorded by photos. Since this study only applied one set of PanoDome and Speedom, the monitoring couldn't reach works outside this room. As a result, 9 out of 19 items couldn't be seen from this system.

The PanoDome and Speedom were fixed separately on two pieces of 30cmx30cm plywood that was the same size as a 30cmx30cm ceiling tile module. They were installed in a room (see Fig. 4 and Appendix A). But before ceilings were installed and used for structural support, they were placed on a cable tray. Ceiling rails and tiles were installed between the 21st and 25th day of the schedule. On Feb. 24, ceiling rails were shown on images along with lighting fixtures. On Feb. 26, newly installed ceiling can be seen in the image.

4.1 Checklist

The application of the system is compared with a checklist commonly used in site supervising work. After a preliminary study, a feasible application in terms of checklist items is divided into three categories (see Table 1), such as the ones that can be visually checked at a distance, the ones needing additional measurement (tightness or level to confirm if a work is done), and the ones needing supervisors present in person. The panorama supervision is suitable for the first type of work with explicit visual checks, like the number of steel bars of a column or to determine if a task is in progress.

The original checklist (Table 1) is categorized into checking methods, inspection frequency, and emphasis for each construction stage and item. Checking methods are reserved for the items suitable for visual inspection or requiring numeric confirmation from instrumental measurement. Inspection frequency refers to two types of re-check: 1) case can be closed once correction has been made; 2) the case needs periodical inspection. Emphasis represents the types of description used to describe a situation, such as “ ” standing for text is required to indicate if items match with contract drawings or specifications; “#” standing for data are required to specify a correction or the amount of displacement or level height; or “*” standing for images required in addition to text and numeric data.

TABLE. 1: Example of items that can be checked for explicit visual confirmation.

Stages	Items	Checking methods: numeric measurement	Inspection frequency	Emphasis
Construction preparation	dimension specified by working drawings	numeric measurement	done once correction has been made	
	reference points for levels	numeric measurement	need periodical inspection	#
	floor levels	numeric measurement	need periodical inspection	#, *
	opening dimensions	numeric measurement	need periodical inspection	#, *
	...			
Under construction	secure the openings of elevators and conduits	visual inspection / confirmation	need periodical inspection	#
	prohibition of unauthorized personnel	visual inspection / confirmation	need periodical inspection	
	...			
Post-construction	if lateral supports or brackets are installed for scaffold	visual inspection / confirmation	need periodical inspection	#, *
	...			

: text description needed; #: data needed; *: images needed

There are many categories and items included in construction supervision. This study simplifies the supervision and system setup by emphasizing tasks on interior renovation and the fireproof coating of refurbished structure. Working schedule started from demolition cleanup to painting jobs. The functionality of feasible checks requiring explicit visual confirmation was extended by applying an additional PTZ camera, except when the check needs numeric measurement or verification like coating thickness or floor level.

Visual inspection in this application was originally used for items that can be explicitly specified from a distance. The function was extended when a PTZ camera was applied for a closer look at an object. The result shows it can even read small font text on a label of a can 6 meters away. Future application would incorporate the close-up function with on-site and imbedded measuring instruments to simplify some types of inspection without physical presence.

The review of time-based PanoDome and Speedom image clip (see Appendix A) shows that:

- work progress is almost 4 days ahead of schedule;
- a time lag exists between HVAC and interior finishing schedule.

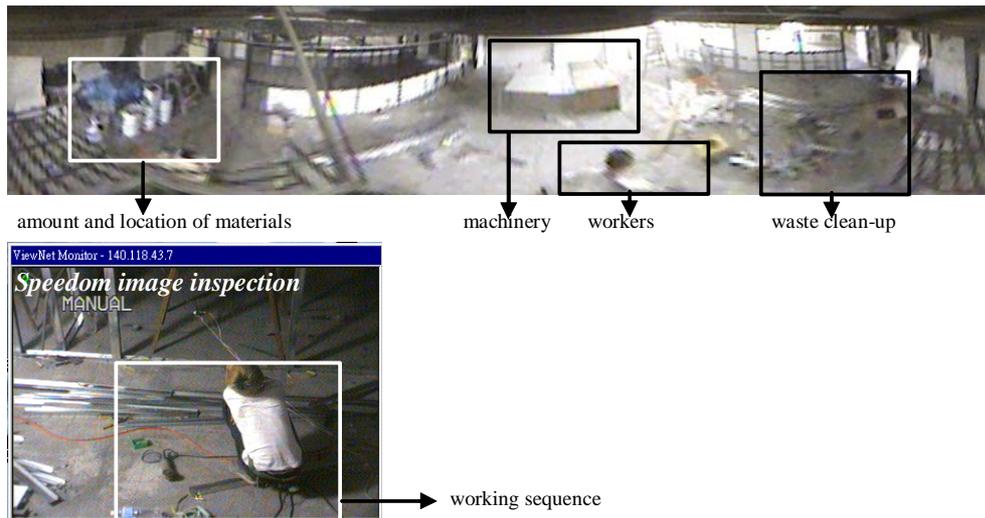


FIG. 9: Inspection of working image

5. INSPECTION AND ANALYSIS OF PANORAMA IMAGES

The system creates a project-dependent database for an in-depth exploration of the application of panorama records. This application is used to enhance or replace the functions of construction records. Based on the spatial and non-spatial attributes of the objects presented in panoramas, the visual inspection of construction items can be classified into five categories (see Fig. 9).

- Working schedule: In order to avoid unnecessary interruption to workers, the panorama video camera was installed on the bottom of the upper slab and later moved to ceiling level. The downward viewing regions include activities involving walls and floors.
- Manpower: The panorama includes all contract workers simultaneously presented at the same space. The worker count and the time of appearance can be used referentially for such considerations as budget, salary, and progress.
- Inspection and management of materials: The delivery and storage of construction materials or components are usually defined in schedule. The panorama presents real-time knowledge of the arrival time and the locations with follow-up changes. Planning ahead and constant updating of data ensures that materials match schedule needs without volume stock piling.
- Machinery management and operation procedure check: For working items and materials that need to be unloaded or assembled, machinery is monitored by the panorama system for better management and logistical operation.
- Clean-up inspection: Construction waste, for example, negatively impacts sanitary conditions at the site. Be aware of large waste and plan a path of movement that can ensure uninterrupted working circulation.

6. THREE LEVELS OF APPLICATION

PIDMS has three levels of application:

- Level I – telepresence and image recording for progress monitoring and schedule inquiry: Site supervisors used to traverse sites to check progress. PIDMS can be used to simultaneously check progress in multiple regions. The system is associated with database inquiry for working sequence and location, so a certain amount of effort can prevent potential mistakes and guide or correct workers to make the best use of manpower. The image-based inspection is suitable for collecting the number of workers, the items of materials, and the location of wastes that are feasible for visual checks.
- Level II – recording construction activities: This remote video and VR interface show users construction process (in real-time or afterward) by being placed at the center of a construction site,

and without interrupting workers. Compared to PTZ video camera, browsing in 360 degrees allows users to actively search objects in space by not defining specific angles and items.

Construction components are converted to VRML objects to enhance the sense of presence.

- Level III – information integration: In contrast to 2D drawings, telephone calls, partial regional photos, and time/location-fixed communication, users can use the visual interface to communicate, exchange information, and add new data, as a way to integrate information.
 - Contractors and factories can supply materials and manpower based on the schedule and real-time images of site. The drawings and specifications of assembly, which are part of PIDMS database, are also used for supervisor's reference.
 - Construction companies can record or modify working schedule based on the location, sequence, and amounts of components retrieved from panorama video or images, drawings, and specifications.
 - When conflicts occur between design and construction, design firms can browse uploaded images or descriptions to recall an original situation.

As construction progresses, the video and image records are added through the interface until the end of the construction, as enterprise information portal (EIP) for the project platform. This platform is used to integrate visual information as project-dependent database and for use as a communication base to serve future judgments of responsibility when disputes or accidents occur. Former projects, as references for similar cases in the future, can be integrated with other cases to form a case database to broaden the system perspective.

Before or during the construction process, suppliers (structure steels or curtain walls) can use PIDMS to update documents and drawings (plans, sections, elevations, details), or add assembly animation to help supervisors ensure an appropriate installation sequence and location of components. Information is continually integrated as construction proceeds (Fig. 11). Periodically stored images are used to check materials, machinery, and manpower and the notes made at the same time. Through the ASP program, the checked data can automatically generate records and estimations for budget, schedule, and material orders (Fig. 10).

7. CONCLUSION

This research dealt with real-time panoramic monitoring of construction sites. The panorama images and videos were used as maps for an Internet communication platform composed of daily records, such as images, texts, and numeric data serving as a panorama- or image-based information system. The PIDMS increases the efficiency and effectiveness of supervision. Future study could include video segmentation function to analyze the contents of video clips for a more direct manipulation and connection between images, 3D objects, and attributes.

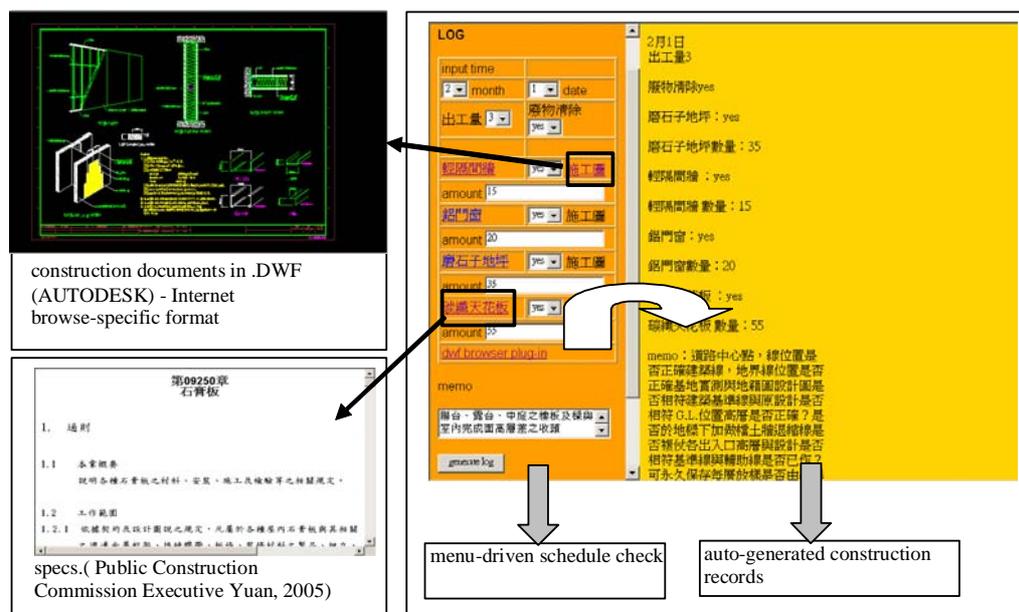


FIG. 10: Inspection interface for construction site management.

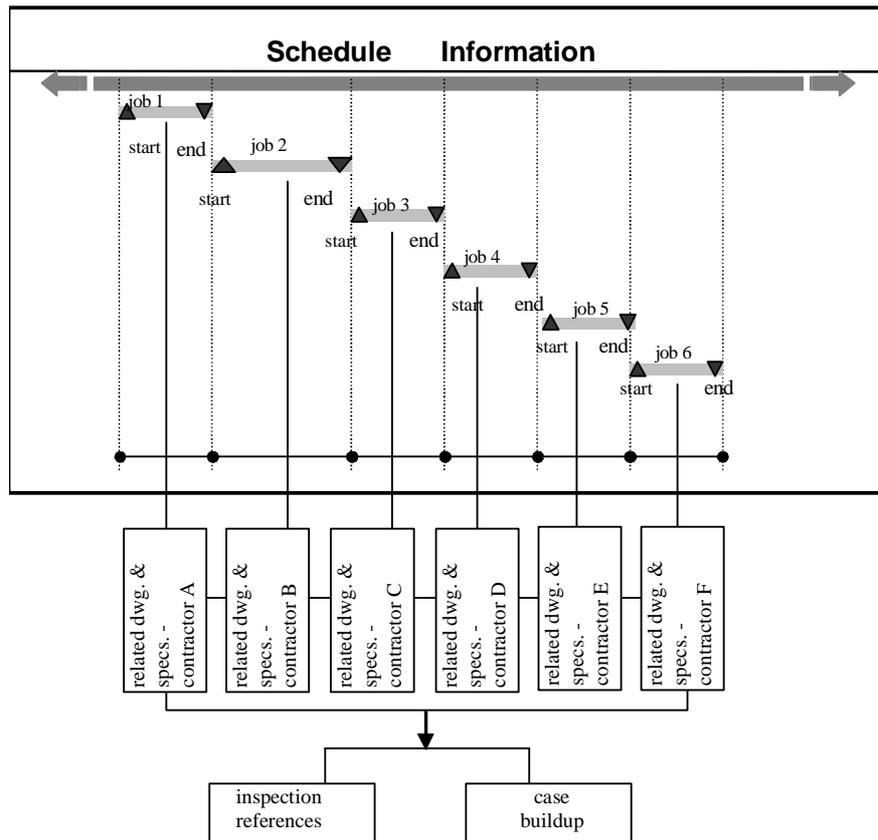


FIG. 11: Integration of construction-related information.

8. ACKNOWLEDGEMENT

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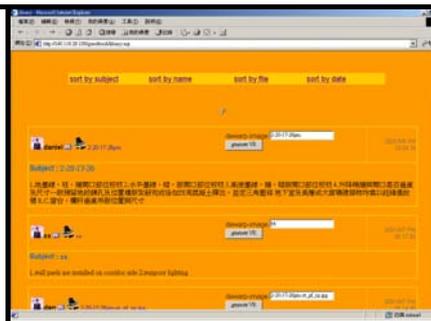
Appendix A. Time-based PanoDome and Speedom image clips

Date	Scheduled items	Real progress
Feb. 20, 13:54pm	7-15	
Feb. 22, 08:43am	7-10, 15	
Feb. 24, 15:24pm	7-10	Item 7 & 8 ahead of Feb. 25 schedule
Feb. 26, 10:11pm	4	Item 4 ahead of Mar. 2 schedule
Feb. 28, 10:49pm	4, 18	Item 18 ahead of Feb. 28 and Mar. 5 schedule, Item 6 ahead of Mar. 2-5 schedule
March 2, 8:40am	4, 6, 18	

Appendix B. PIDMS interface



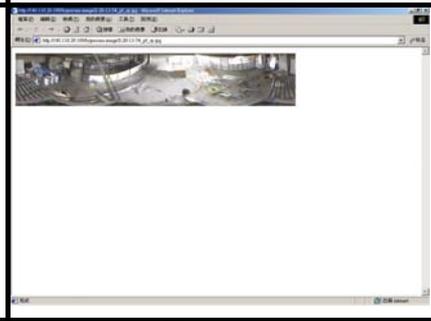
Search panorama video: Users can select and play panorama video records.



Search visual and non-visual files: Users can search uploaded files by user name, file name, and subject.



Note a frame: A frame of map image is captured for note-taking purpose.



Browse de-warp image: Images are browsed along with notes.



Image de-warp: A frame of map image is snapped and de-warped into panorama image to create a VR scene.



Upload documents: Other documents can also be uploaded and browsed. Managers can upload images.



Add image to database: Let users upload images to server database.



Static panorama images: Use ASP program to de-warp image into .ivr and html files with links being created for browsing.



Label panorama images: Users can add description to label the records. Other users see the records and search by keywords.



Browse panorama videos: Panorama videos can be browsed using iVideo plug-in.

Appendix C. Renovation schedule of the interior renovation site

tasks	units	amount	days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30			
1 Clean-up walls and slab blacken by smoke	set	1	2																																	
2 Clean-up and resurface remaining fire coating on steel beams	m	120	4																																	
3 Apply new fire-proof coating (three side coating, one hour fire rating)	m	120	5																																	
4 Install new ceiling tiles	m ²	550	5																																	
5 Replace fire damaged floor tiles	m ²	20	1																																	
6 Whole floor wax	m ²	540	3																																	
7 Install new partition dry walls (12 mm)	m ²	80	7																																	
8 Install new partition dry walls (12 mm)	m ²	58	7																																	
9 Fix existing aluminum partition frames	m ²	127	7																																	
10 Install new door frames and existing door frame inspection	set	12	7																																	
11 Newly made exterior wall window frames	set	2	2																																	
12 Install exterior wall windows	set	1	1																																	
13 Egress door inspection	set	1	1																																	
14 Broken aluminum window inspection and glass replacement in staircase	set	4	1																																	
15 Interior and exterior clean-up of wood cabinets, broken panels replacement	m ²	120	5																																	
16 Use dry wall to seal the vacancy above wood cabinet	m ²	5	1																																	
17 1:3 mortar on SRC columns	set	1	1																																	
18 Wall painting	m ²	580	6																																	
19 Site clean-up	set	1	4																																	