

# Advanced Visualization Platform for Surgical Operating Room Coordination: Distributed Video Board System

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One of the major challenges for day-of-surgery operating room coordination is accurate and timely situation awareness. Distributed and secure real-time status information is key to addressing these challenges. This article reports on the design and implementation of a passive status monitoring system in a 19-room surgical suite of a major academic medical center. Key design requirements considered included integrated real-time operating room status display, access control, security, and network impact. The system used live operating room video images and patient vital signs obtained through monitors

to automatically update events and operating room status. Images were presented on a “need-to-know” basis, and access was controlled by identification badge authorization. The system delivered reliable real-time operating room images and status with acceptable network impact. Operating room status was visualized at 4 separate locations and was used continuously by clinicians and operating room service providers to coordinate operating room activities.

**Keywords:** visualization; workflow; coordination

Smooth, efficient patient flow relies on accurate, real-time situation awareness owing to frequent and often unpredictable changes in workflow.<sup>1,2</sup> To provide real-time information on events and changes, most solutions require a labor-intensive process to input and update clinical information systems. Sensor-based passive technology is one way to reduce requirements of active data input and address reliability issues in maintaining situation awareness throughout dynamic work processes by eliminating active human input.<sup>3-5</sup> To achieve timely and reliable information access by care providers, distributed access and a scalable information delivery platform is needed. Patient privacy issues have also been shown to affect the adoption of video technologies in hospitals and must be considered in systems design.<sup>6-9</sup>

In this article, we describe the rationale and design of an automated system for visualizing the perioperative process based on collected real-time sensory data: video from within operating rooms and patient vital signs. The system, called Video Board System (VBS), provides real-time status information about operating rooms (OR), including major event landmarks (patient entrance to and exit from the OR) and rich contextual information about OR status to different decision makers. In addition to meeting above design objectives, the system also addressed information security, video-image quality, image update frequency, and impact on data distribution network.

## Methods

### Setting

We implemented the VBS in a 600-bed academic medical center’s general surgical suite with 19 ORs. Installation was approved by the center’s administration.

### Defining System Requirements

We considered several key objectives for a visualization system:

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1. It should provide real-time OR situation awareness, including live OR images and patient in and out times for all OR in one glance.
2. To observe privacy requirements, including those in the Health Insurance Portability and Accountability Act of 1996, the information should be delivered securely and viewed only by authorized users on a “need-to-know” basis.
3. The user interface must be simple and easy to use by all users. Fourth, the system should automatically gather, process, and distribute the information to eliminate burdens to OR staff and associated data accuracy variabilities.
4. The system should have a predictable impact on data distribution network that is within the design specification of most network infrastructures. Delivery of many channels of real-time video to multiple viewers can overwhelm the data distribution network.

### Key Objectives

The initial design called for a visualization system that gathered real-time visual information from all ORs and distributed it to 4 remote viewing locations. Two types of data sources were considered as desirable candidates: OR surveillance video images and patient vital signs. Both could be acquired automatically. The key design objectives were further refined once these 2 data sources had been selected.

1. Security: to consider patient confidentiality, OR staff’s “need-to-know,” and potential medicolegal exposure.
2. Reliability: to deliver variable quality images to different people within appropriate time frames.
3. Ease of use: to eliminate user-training requirements through an intuitive user interface.
4. Access control: to identify user roles for determining needs-to-know and to satisfy audit requirements.
5. Quality of service: to deliver images reliably for a range of image sizes and qualities.
6. Network distribution impact: design for scalable and predictable network impact through the use of multiple image resolution qualities.
7. Mobility: to support expansion of mobile wireless access.
8. Open and flexible architecture: to support expandable modular architecture from a variety of technology suppliers.

The following platforms were reviewed to determine their suitability as an information delivery platform for the VBS design (Table 1).

1. *Analog Video Distribution System*: Standard closed circuit security television system for OR video acquisition, mixing, and distribution to multiple remote viewing stations (RVSs).
2. *End-to-End Digital System*: Internet protocol (IP) camera network. Each RVS retrieves streamed OR video directly from IP cameras in each OR.
3. *Hybrid System*: Many analog camera systems feed video to a central location where a multi-channel video encoder is used to stream the OR video over IP network to RVSs.

The first 2 platforms did not adequately address the 3 major technical objectives of (1) providing access control for variable resolution image data depending on the user’s operational needs (housekeepers may be satisfied with low resolution images to assess OR occupancy, whereas OR charge nurses require higher image detail to determine the progression of a procedure), (2) the need for modest bandwidth requirements to sustain reliable data distribution with acceptable network impact, and (3) integrate the existing video-based distribution system with live patient vital signs-based status information in real-time with a user-friendly display.

Based on the review, we decided upon a new, tightly integrated, image-based hybrid VBS, which consists of analog cameras that send video through closed-circuit cables to a video server. The video server digitally encodes video frames into static images (JPEG) at a determined frame-rate, then redistributes it through the secured hospital IP network (intranet) along with estimated patient in-and-out status calculated from real-time patient vital signs equipment.<sup>10</sup> Hospital badge ID swiping units are used to identify the authorized users, and the image resolution is adjusted based on the user’s operational role. By using variable image quality views (ie, the amount of image data being sent), optimal usage of network bandwidth may be achieved. The next sections describe the VBS architecture.

### VBS Architecture and Major System Modules

The key design concept was based on “many-to-one-to-many” (MOM) architecture.<sup>11</sup> A variety of input sources in ORs (MANY) provide information to a hub (ONE), where information is classified and redirected to desired secure locations (MANY) on a need-to-know basis. The MOM architecture addresses the previously stated key objective and provides system flexibility and functionality. The

**Table 1.** Technology Suitability Summary With Respect to Key Design Objectives

Platform	Description	Classification	Pros	Cons
Analog	Closed circuit system	Many to one to many	Analog closed circuit system can support multi-OR video mixing and display in limited locations with high reliability and reasonable security	Does not support user access logging. Cannot adjust the image quality based on the role of user. Does not support secured mobile access. Cannot display OR status/events information such as vital signs without significant addition to the infrastructure.
Digital	IP camera network	Many to many	Each remote viewing station receives OR streaming video directly from the IP camera in the OR; security could be enhanced by IP-VPN; supports wireless access	Very difficult to stream 19 OR video feeds to each remote viewing station simultaneously with predictable network impact. Difficult to change the streaming resolution on the fly based on the user role. Overall system reliability will be low.
Hybrid	Analog cameras with video over IP distribution	Many to one to many	Reliable video capture and expandable video streaming network	Very difficult to stream 19 OR video feeds to each remote viewing station simultaneously with predictable network impact. Difficult to change the streaming resolution on the fly based on the user role. New interface development necessary to integrate video OR events such as vital signs. Limited reliability of overall system.

OR = operating room; IP-VPN = internet protocol virtual private network.

following are the major modules in the VBS based on MOM architecture.

### 1. Video Acquisition

A video network was installed as part of the telecommunication infrastructure for the OR suite. Three ceiling camera mounting points were installed in each OR to enable selection of view angles for best coverage of activities in the OR that may vary as a result of block time assignment (Figure 1A). Some services have specific concerns for patient privacy (eg, obstetrics/gynecology and plastic). In-room audio-visual switch boxes provided OR staff the option to turn cameras on or off and also allowed easy system testing and troubleshooting. Dedicated RG59 video cables connected OR video sources to a centralized video hub at a control center (average 300 feet away from the OR).

### 2. Video Processing

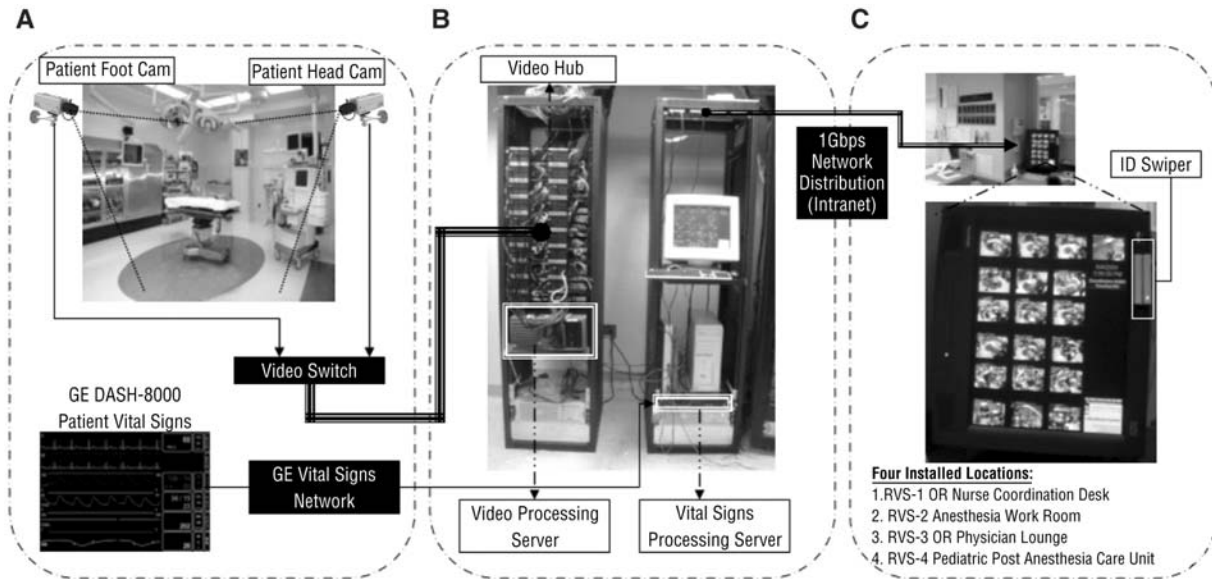
At the control center, real-time video from all ORs was simultaneously digitized in the JPEG format at the original resolution of  $352 \times 240$  pixels (95 KB average image size) and processed into 4 different image resolution formats (Figure 2). The 4 resolutions were (1)

edge view, black and white outline image ( $128 \times 96$  pixels, 14 KB), (2) low-quality color image ( $64 \times 48$  pixels, 5 KB), (3) medium-quality color image ( $128 \times 96$  pixels, 15 KB); and (4) high-quality color image ( $256 \times 192$  pixels, 45 KB). A random access memory disk technique was used to speed up the image processing and distribution. Patient and staff privacy was ensured at nearly all 4 levels of image quality, as facial recognition of patients or staff was not possible.

### 3. Video Board System Visualization, Authentication, and Secured Intranet Distribution

A secured intranet (dedicated network) was used to distribute processed OR images to 4 remote viewing stations. Each remote viewing station consisted of a computer with a 19-inch flat panel monitor with an attached hospital ID badge reader to provide access control. Remote viewing stations were strategically located in four locations: the OR control desk, anesthesia staff lounge, physician staff lounge, and an ambulatory care unit. Physical access to these locations was restricted to OR staff.

The default RVS image was set to edge view to prevent unintentional viewing by passersby and



**Figure 1.** Video board system (VBS) functional design. (A) Video and patient vital sign acquisition. (B) Video and patient vital sign processing and distribution. (C) Remote viewing stations were installed at 4 locations: the operating room (OR) nurse coordination desk, the anesthesia work room, the OR physician lounge, and the pediatric postanesthesia care unit.

served as an indication that OR images were available for viewing. If no image was available, an “image unavailable” message appeared instead. The 3 qualities of color images required authentication by swiping the ID badge. Image quality was determined by user operational role. Operating room charge nurses and attending anesthesiologists were authorized with high-quality views and other OR staff with medium-quality views. Non-OR staff with valid hospital ID badges were authorized with low-quality views. All authenticated views timed out to the default after a 2-minute delay, but authorized users could revert to the default view by swiping their badges a second time.

#### 4. Real-time Vital Signs Processing and OR Events Abstraction

Patient in-and-out status for all ORs was obtained through a real-time algorithm.<sup>10</sup> Operating room patient monitors (GE/Marquette Solar 8000 and DASH 3000, GE Healthcare, Waukesha, Wis) were networked to a biomedical engineering network. Real-time data from monitors were sampled at a rate of 6 seconds. Operating room occupancy was accurately identified 96% of the time. Identified patient in times were accurate within 4.9 minutes (confidence interval [CI], 4.2-5.7) and out times within 2.8 minutes (CI, 2.3-3.5).<sup>10</sup>

The VBS integrates on a single display for all ORs both real-time patient in-and-out status with real-time OR images for the OR staff (Figure 2). Without any interaction with an RVS, OR staff can see when an OR was occupied shown by the patient-in time. The heart indicator shows that an OR has a patient in. The elapsed time since the patient entered the OR is visualized by green circular dots next to the heart indicator (1 full dot equals 1 full hour). If an OR is empty, the last patient-out time is also displayed.

## Evaluation Results and Discussion

### 1. Data Traffic Impact and Server Utilization

To assess data traffic and video server utilization, we disconnected all RVSs from the video server and then reconnected them one by one. This was repeated for each level of image quality to measure the incremental RVS network load at each level. Video server network interface card traffic was continuously captured and summarized (Figure 3).

Remote viewing stations were shown to have minimal impact on the distribution network or on the video server (Figure 3). The VBS delivered reliable real-time OR images with low variability network impact of

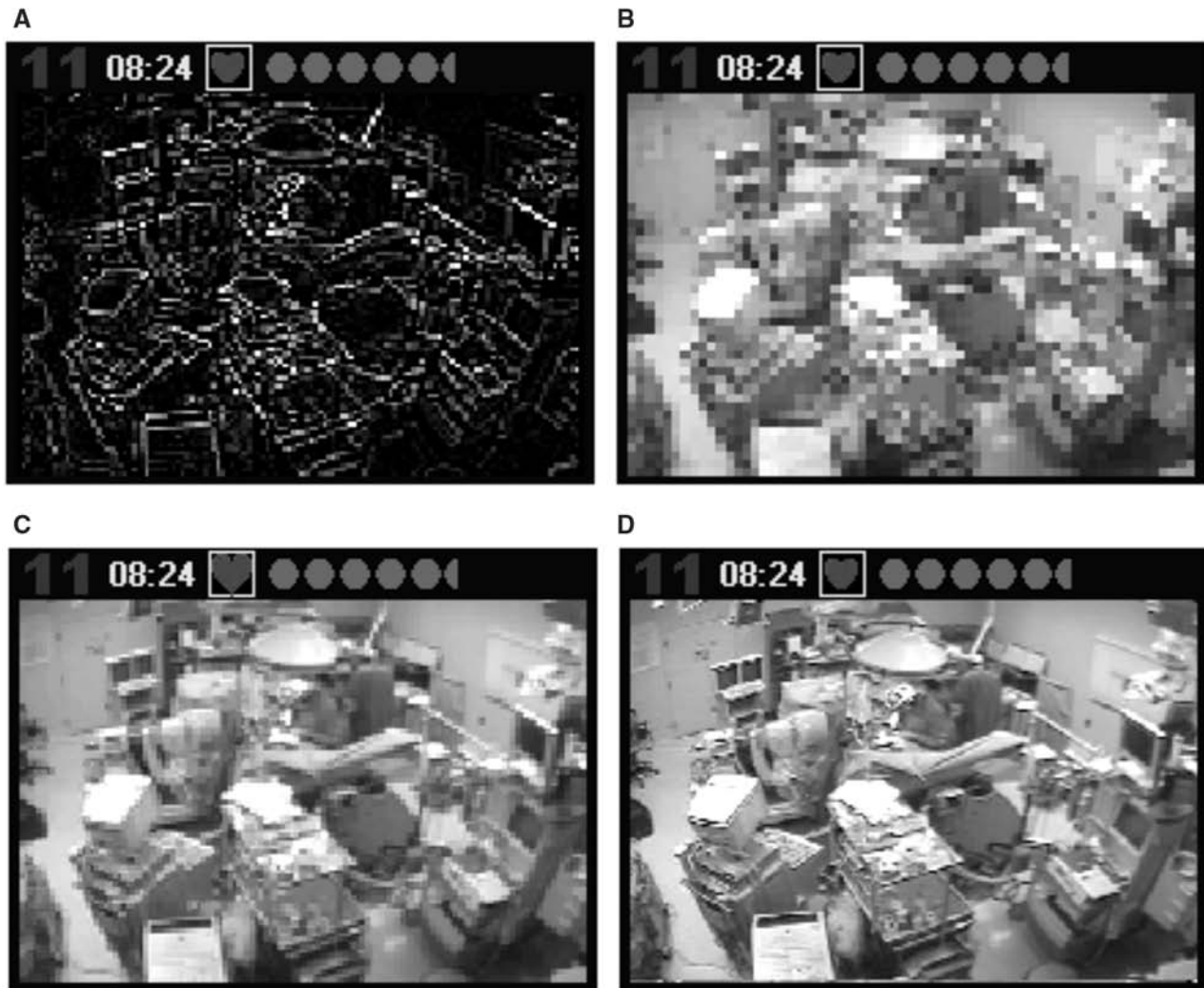


Figure 2. (A) Edge view outline image. (B) Low-quality color image. (C) Medium-quality color image. (D) High-quality color image.

3.67 megabytes per second (MBps) to 3.70 MBps for additional RVS at default view quality. The incremental load on the video server central processing unit remained low at 1% to 2% utilization increase for each additional RVS from the basis of 20%. Traffic increased linearly with additional RVSs along the 4 image quality modes (Figure 3). One may predict, from the data in Figure 3, for additional RVSs with a given image quality. Although data traffic changes depend on the level of the image quality selected, the default view should constitute 95% or more of all viewing activity, with only a tiny fraction ( $\leq 5\%$ ) for views at the other 3 quality levels. The network impact of each RVS network impact was thus estimated to be  $3.8 \text{ MBps} = 3.7 \text{ MBps at edge view} \times 95\% + [12 \text{ MBps (high)} + 4 \text{ MBps (medium)} + 2 \text{ MBps (low)}] / 3 \times 5$ , and overall network impact is 15.2 MBps (4 RVS  $\times$  3.8 MBps).

Because we used a switched 1 gigabytes per second (GBps) network as our information distribution platform, the impact to the VBS network was less than 2%. The reader may notice that the image size of the default view is larger than the low-quality view (14 KB versus 5 KB). The default view accounts for most of VBS usage, so reduction of network impact could be achieved by additional compression of the default view. For example, the image could be further reduced to 2.8 KB per image by setting JPEG compression at 80%.

## 2. Video Board System Image Capture

For all 19 ORs, 36 JPEG images per second (1.9 images per second per OR) were digitized and processed by the video server (Figure 1B). Each RVS

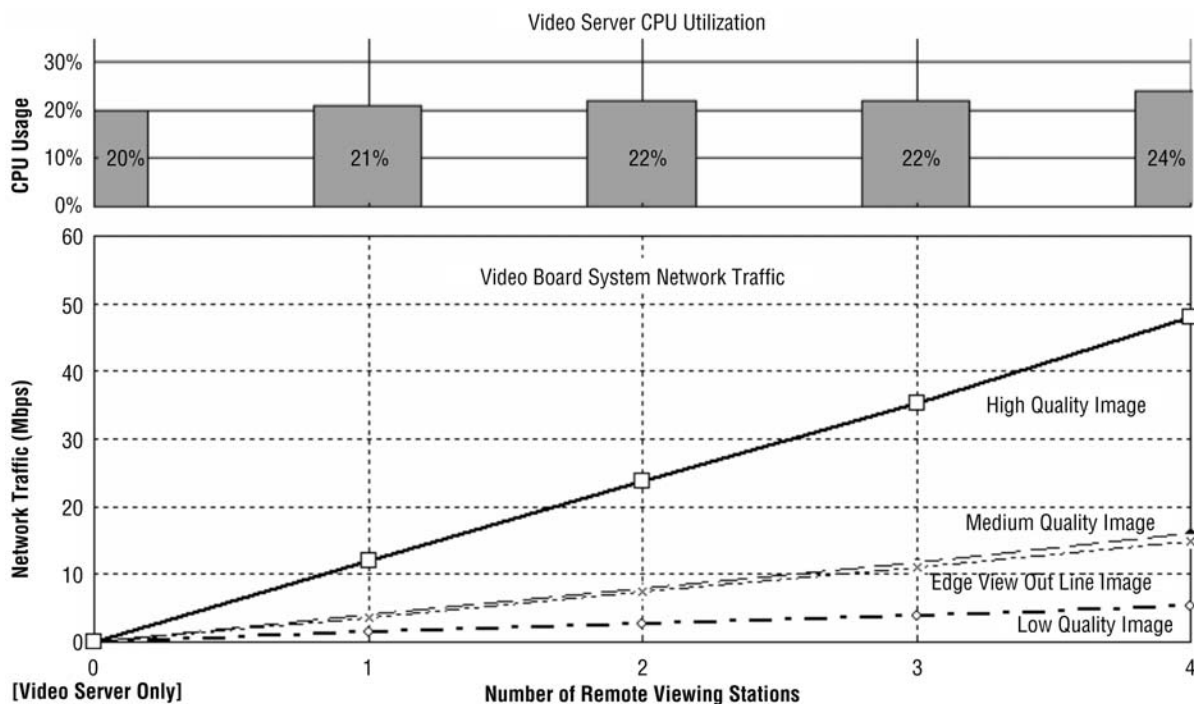


Figure 3. Video board system network impact and server central processing unit utilization.

is capable of receiving 19 simultaneous OR video images at the rate of 28.5 images per second (1.5 image per second per OR).

### 3. Video Board System Reliability, Cost, and Future System Expansion

The VBS has been in operational use for more than 1 year and continues to serve the daily needs of the OR staff.<sup>12</sup> Practical issues have been reported, such as users turning off the OR cameras for a specific case and forgetting to turn the camera back on later. One of the badge readers was not reliable and was replaced. Finally, a timeserver was added to eliminate computer system time drifting.

The cost of in-OR cameras was \$350 each, 1 VBS server was \$4000, 4 RVS were \$1500 each, 1 gigabyte network switch was \$3000, and system installation and cabling was \$15 000. The total estimated cost for VBS was \$35 000.

Future expansions may include additional image compression techniques to further reduce network impact, more sophisticated image-processing algorithms to detect procedure milestones (such as draping), and

mobile access. Additional RVS are planned at more units (eg, postanesthesia care units).

### Conclusion

This article described key design requirements and technical evaluation of a visualization system for improved situation awareness and coordination effectiveness in perioperative work processes. Visual information systems such as VBS can adequately address patient privacy requirements, operational needs of the OR staff, and the limitations of network infrastructure. Furthermore, because VBS gathers information passively and automatically, reliability of real-time information gathering is ensured without added burden to OR staff. Further studies of staff usage, user adoption, and reporting reliability of OR status will contribute to added understanding of VBS effectiveness and benefits to perioperative processes and workflow.

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