Augmenting Command & Control (C2) Capabilities with Confidently Gathered and Rapidly Distributed Information Through Imagery and Wireless Networking

1 Introduction

For a quick and effective responding anti-terrorist system, a networked information infrastructure using up-to-date technology is an indispensable component. This infrastructure interconnects the command and control (C2) center to various sensors and responders. It collects, processes and distributes multimedia information. It operates fast and reliably. Specifically, multimedia sensors and information networks are of paramount importance.

First responders, like local law enforcement and emergency medical teams, enable command and control (C2) to function. By verbally relaying information to the incident commander, strategies, operations and tactics to rescue and mitigate can be developed and implemented. In dynamic situations, where information comes at different times and sources, verbal reports and orders can be easily subjected to misinterpretation. Imagery like photos, video and computer graphics however, convey information more effectively and efficiently. Proposed is work to explore and formulate the use of imagery to augment C2 performance and capabilities. The foreseen hardware/software deliverable processes raw digital video of scenes acquired from multiple live cameras. It would then automatically create the imagery C2 needs to effectively and efficiently distribute to end-users like law enforcement, rescue units, public health officials, structural engineers, media, decision-makers, investigators and hospitals. Such work buttresses one of the National Bioterrorism Civilian Medical Response Center's (NBCMRC) objectives, namely to leverage networked acquisition of information from multiple sources and internet technologies to mitigate biochemical attacks. Photography and videography taken from the ground and/or aerially provide a myriad of views. The net effect is that such camera distribution, if networked and processed properly, can stream the needed imagery on-line. Such work would then value add NBCMRC's proposed telemedicine and epidemiological engine prototypes.

Visual information poses more stringent requirement for the underlying communication network to have multimedia accommodation. Current public telephony networks can provide a convenient and inexpensive service to meet this requirement. However, its reliability, security and survivability during terror attacks is not always satisfactory. A dedicated subnet can balance these constraints. The wireless and fiber-optical networking technology today enable easy deployment of such a subset with broad bandwidth to transmit multimedia sources. It is also easy to merge this subset into the world-wide Internet for wider spread of the information.

2 Rationale for Imagery

Figure 1 depicts schematically the information gathering and distribution process. Like filters that condition raw sensor data, first responders collect reports from eyewitnesses and victims and pass pertinent information to the incident commander. C2 analyzes the information and then distributes important orders to key teams. Reports and orders are predominantly verbal.

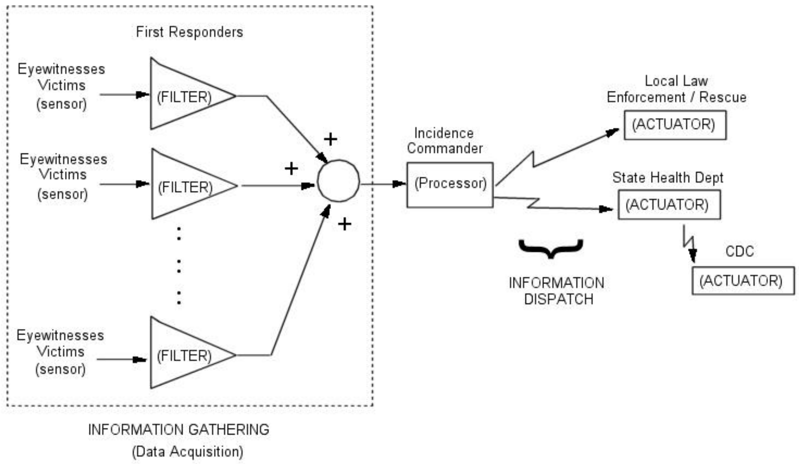

Figure 1: Information from first responders to key teams flows through the incident commander much like a classic sensor-processor-actuator loop

People are visual creatures, not often thinking in terms of data or even knowledge. For example, the incident commander must often draw mental pictures of a given situation, depending upon the observations of others and then convey tactical outlines to key operation individuals. A picture's "thousand word worth" would suggest imagery as the communication medium to effectively and efficiently gather and distribute information. Ironically, this is not the case. Rather, reports and orders are communicated verbally oftentimes demanding time-consuming verification and clarification. As imagery hardware has matured, so must the tactical, operational and strategic usage of visual information adapt to its improved capabilities.

2.1 Scalable, Horizontal and Vertical Information Flow

Used correctly, imagery can help exploit the power of scalability and both horizontal and vertical information flow. Such characteristics speed decision cycles and facilitate execution at lower levels.

Once a photo and/or video is acquired, it can be scaled to individual end-users. Areas highlighting ingress and egress pathways can be dispatched to ambulances. The same photo could be cropped to detail site damage, providing structural engineers physical clues to building integrity. Image magnification can focus on victim afflictions to assist hospitals and public health officials ascertain the level of medical need.

The same image can be distributed concurrently to operational teams. Such horizontal flow of information could for example provide all ambulances the same up-to-date information on obstacle-free convoy routes. Imagery also can flow information vertically, helping commanders visually describe the situation to higher headquarters. For example, intelligence analysts and public health officials will want to see imagery of certain areas over time to forecast situation evolution.

The net effect is that C2, which functions on three levels, namely strategic, operational and tactical, can be all enhanced by imagery's scalable and information flow characteristics:

- Strategic: imagery helps the commander communicate situational awareness and tasking requirements to senior level decision-makers
- Operational: imagery supports the commander by providing information in an easy to use format for myriad of applications, both internal and external to the command
- Tactical: imagery facilitate situational awareness and enforce protection.

Wireless digital video cameras, rather than first responders, can remain in biohazardous areas to provide real-time on-site information. Additional cameras canvassed along site perimeters and aerial footage provide multiple views. All this visual information (VI) is only useful when it is shared, used and understood. Often, VI is more important to the commanders' audience than to the commander himself, for example in briefing rescuers and enhancing public support. VI is boundless where creative approaches, like 3D reconstruction, image mosaicing and omni-directional cameras can enhance the value of visual information for response efforts and augment C3 capabilities.

3 Technical Approach

Raw visual information can make C2 vulnerable to information overload. It must be processed to prevent inaccurate communication. For example, aerial photos and thermal images are often difficult to interpret by the untrained eye. As such, hardware and software systems that can process raw video or photos into easily understood information, like computer-generated 3D reconstructed models, is fundamental. Stationary cameras, like those mounted in buildings for security, often have a limited field-of-view. However, if networked, images from multiple cameras can be mosaiced into a complete picture of the scene. Additionally, catadioptrics (lenses focused on spherical mirrors) can be employed to gather larger fields-of-view.

3.1 Mosaicing

Stitching several images together to can yield a single larger image. This machine vision technique is called mosaicing, and is often used to generate a panoramic image. The motivation for panoramas is that a single camera has a limted 50^o field-of-view slice of a scene. Multiple cameras or a moving camera can capture more scene slices. Stitched together with image processing, the entire view of scene can be created. The technique identifies visual features common between any two or more images to piece together the mosaic. For example in Figure refmosaicIsmailHaritaoglu, four images (top) were acquired by a moving camera and used to construct the larger mosaic (bottom). Common features like the poster boards and file cabinet result in pixel clusters characterized by similar colors and intensities. Algorithmically, these characteristics are identified to automatically create the large mosaic.

Using basic photogrammetry, overlapping features are not needed to create mosaics. Camera position and orientation knowledge can be leveraged to stitch disparate views. Networked cameras that, in additional to images, could provide transmit their location information to the mosaicing algorithm. This would be

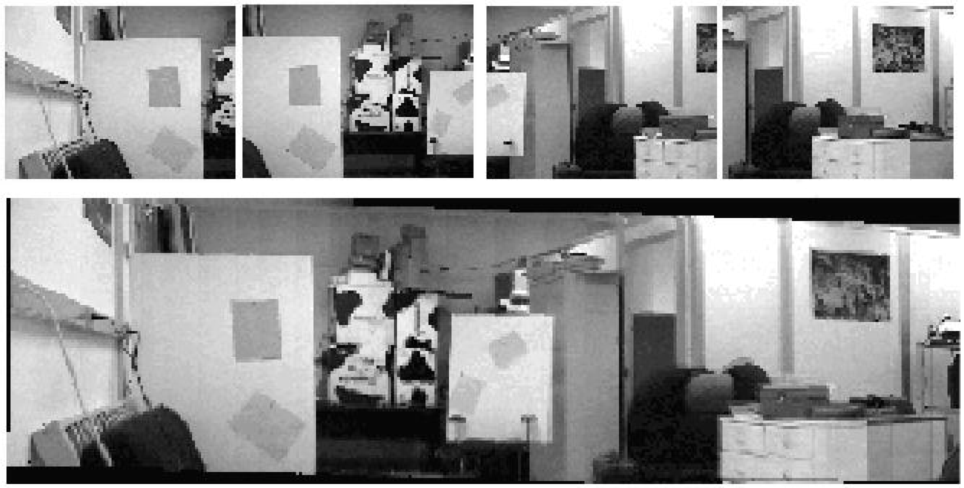

Figure 2: Four images (top) stitched automatically creating the larger mosaic (bottom)

appropriate since images of a disaster site would most probably be from cameras distributed along perimeters and even flown above.

3.2 Omnicams

Fish-eye lenses like those mounted in front doors provide a wide, albeit distorted, field-of-view. Commerical products, like Figure 3, combine hemispherical mirrors with conventional cameras to mimic the fish-eye effect and capture 180^o views of scenes. Image processing is used to un-warp the distorted image into a set of conventional 2D images. For example, eighteen images showing 10^o slices of the scene can be automatically generated. Such an *omnicam*, also known as a catadioptric system, replaces the need to have many cameras placed throughout the scene.

As such, omnicams can generated raw image slices. An incident commander can add textual information like cardinal points, stairway and exit locations which is then distributed to appropriate response teams.

3.3 3D Reconstruction

Once acquired, the viewer is limited to whatever details are visible in the two-dimensional (2D) photo or video. Beyond magnification and cropping, the viewer cannot interact with the image much. Figure 4 depicts photos of a potential terrorist target, namely 30th Street Station in Philadelphia. Such photos, like the two aerial views, would be typical of those captured during the an incident. The raw aerial photos show the station and surrounding architecture but beyond simple zooms and cropping, little information can be gathered or conveyed.

3D reconstruction (3DR) is the machine vision technique of creating a computer-generated graphical model from 2D images. Once created, the incident commander can rotate, translate and zoom the model to identify

Figure 3: A hemispherical mirror mounted in front of a camera lens (left) can capture 180^o fields-of-view (right circular image). Un-warping the image provides a set of conventional 2-dimensional images

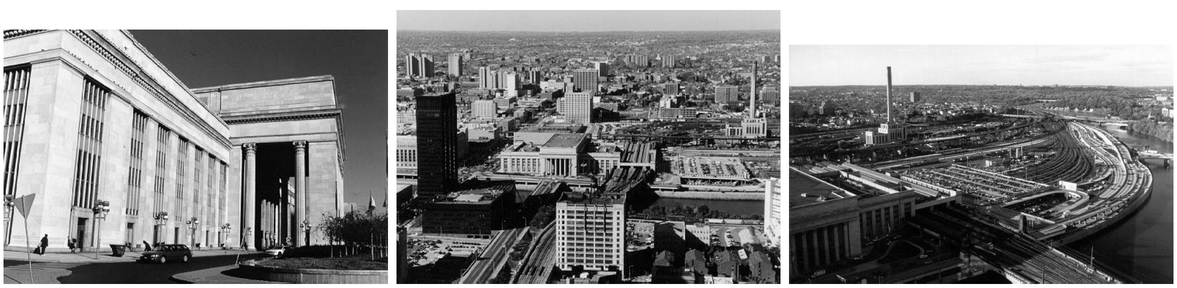

Figure 4: Three photos of 30th Street Station in Philadelphia taken from the ground (left) and aerially (left two). Beyond magnification and/or cropping, the viewer has limited interaction with the imagery.

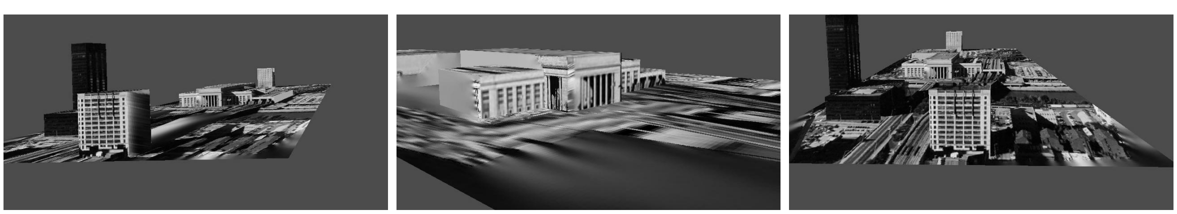

Figure 5: Three screenshots of 3D model of 30th Street Station that has been panned and zoomed

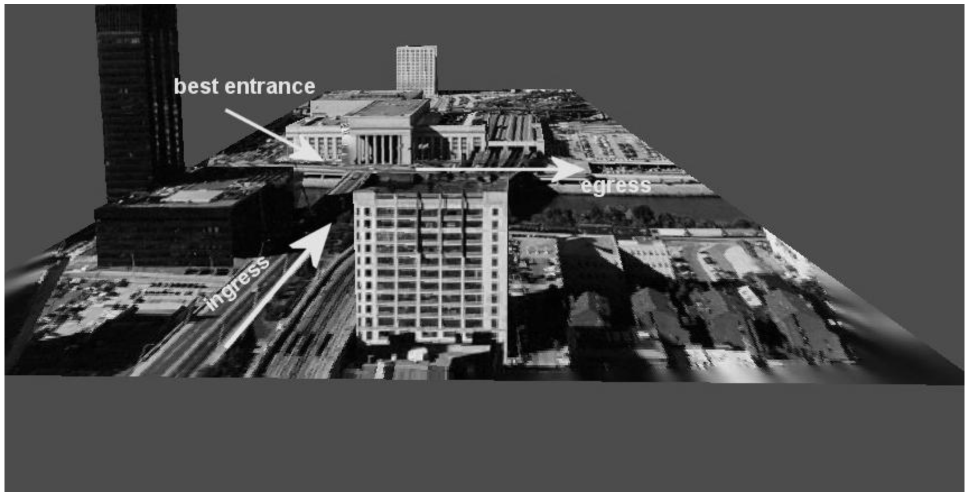

Figure 6: Rather than raw photos, a screenshot of 3D model with text enables C2 to more effectively convey pathways to response teams

and indicate to key information. Figure 5 depicts three screenshots of the 3D model reconstructed from the photos in Figure 4. This 3D model can be easily manipulated in a standard web browser like Netscape or Internet Explorer.

C2 could then highlight areas on screenshots to convey infomation to response teams. For example, ingress and egress routes can be ascertained after manipulating the model as shown in Figure 6. Rather than verbal reports and orders, such 3DR imagery would enhance and augment C2 capability, more effectively and efficiently communicating information.

3.4 Networking

The information network should explore the current public systems, like telephony, cellular system and internet to connect the terminals together and with rest of the world. Jointly considering the bandwidth, reliability, security, flexibility and cost, the wireless technology is of special interest.

3.5 Wireless

Wireless can provide a seamless coverage. It also offers mobility. These makes it an ideal technology for collecting data from various sensors and distributing information to responders. Cellular telephony has already setup a wide coverage and services. The third generation (3G) cellular system to be deployed is capable of providing high-speed data services. Exploring these resources is important to easily reach the broadly distributed sensors and responders.

With in mind the underground part the railway system, it is also necessary to explore the current radio (walki-talki) system. Because it has dedicated channels and readily installed antennas underground, it extends the coverage of communications and survives the traffic jam that will surely happen during any emergency.

Wireless local loop (WLL) is wireless networking technology developed recently and deployed extremely fast. It can build an ad-hoc network among mobile terminals in minutes. Its range is usually within a mile and working in free spectral band. Therefore, it is very suitable for an internetwork among local sensors and responders. Equipped with the up-to-date secure protocol, it is also highly immune of interference. WLL technology has also standardized the internet access.

4 Conclusion

Imagery is an effective and efficient means to gather and distribute information, expecially in dynamic situations like a bioterrorist threat. Wireless networking is rapid and reliable method to distribute imagery. As such technologies have matured, so must the tactical, operational and strategic usage of visual/multimedia information and wireless networks adapt to its improved capabilities. Proposed is to explore and formulate such usage to augment C2 performance. The envisioned work will be towards a hardware/software deliverable that would that raw information, process it and enable commanders to distribute it to key response teams. Such work would buttress NBCMRC telemedicine and epidemiological engine prototypes with imagery that is scalable, flows vertically and horizontally and unambiguous.