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Technology Gaps in First Responder Cameras

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DISCLAIMER

Certain products, technologies, and corporations are mentioned in this report to describe aspects of the ways that cameras are used at present or may be used in the future. The mention of such entities should not be construed as any endorsement, approval, recommendation, prediction of success, or that they are in any way superior to or more noteworthy than similar entities that were not mentioned.

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TECHNOLOGY GAPS IN FIRST RESPONDER CAMERAS

Margaret H. Pinson[1]

This report identifies camera technology gaps that impact first responders. These technology gaps were identified by interviewing first responders about images, video, and camera systems in general. This is a working document that is intended to foster discussion around research and product innovation.

Keywords: bodycams, camera, firefighters, first responders, image quality, in-car cameras, law enforcement, public safety, telemedicine, video quality, video surveillance

1. INTRODUCTION

In 2015, the Public Safety Communications Research (PSCR) program began interviewing first responders about quality problems they experience with images, video, and camera systems in general. We spoke with more than 100 people from different public safety agencies around the U.S. The interviews spanned federal, state, and local agencies; law enforcement, fire, and emergency medicine; rural and urban communities; disparate climates; and department sizes from small to very large. We also spoke with district attorneys' offices, manufacturers, instructors, researchers, and public safety organizations. Due to privacy concerns, the people and organizations are not identified in this report.

We also performed a limited literature and product search. Initially, we focused on publications written by first responders or recommended to us during interviews. Later, we performed a literature search to better understand two problems that had been identified by first responders: obscurants and color (see Sections 2.1 and 2.2). A contractor engaged by PSCR assisted in this endeavor.

This report draws some preliminary conclusions from what we heard about camera technology gaps. It is intended to stimulate discussion about new technologies that will better serve first responder needs. This report does not include in-depth analyses of first responder tasks, nor does it analyze the importance of the technology gaps. Those topics are beyond the scope of this document.

First responder camera problems reported to us can be traced to three general issues. First, the camera was designed for a different task than the first responder's use and so produces suboptimal information. For example, video surveillance systems are designed to provide live security; these systems are not designed to capture imagery that meets the needs of law enforcement and the courts. The consequence is inefficiency—extra steps, complicated procedures, training requirements, frustration, and other operational constraints. Second, the camera lacks automated support for first responder tasks. For example, law enforcement officers

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want each photograph to be associated with a case number. The consequence of the lack of automated support is labor intensive procedures that are prone to error and consume valuable time. Third, the camera produces surplus data (i.e., video recordings) that increase costs and complicate logistics. Practitioners tell us that 95% of their video recordings are never watched. Some departments may not deploy in-car cameras and body cameras because they simply cannot absorb the high costs of retention and distribution of the collected video. All three issues stem from one fundamental problem: the reuse of camera components that were designed for a different purpose.

This report is divided into two parts. The report body lists camera technology gaps. The appendixes identify desirable camera attributes and describe how first responders use cameras. These appendixes quote specific problems that were mentioned during our interviews. The appendixes provide context—the first responder mindset.

2. TECHNOLOGY GAPS

We began each interview with a brief description of our project. This communication consisted of approximately the following:

> "Our research focuses on image quality and video quality for public safety applications. We want to understand how first responders use images, videos, and camera systems in general; and we want to understand the quality problems that you are having. Our goal is to encourage new camera technologies that better serve first responder needs."

We encouraged people to talk about any problem, without limiting the discussion. First responders described tasks involving images or video (see Appendix A), camera attributes that they found desirable (see Appendix B), and problems they encounter. Some of the problems encountered by first responders were defects in the image or video itself. Others were quality of experience (QoE) issues involving user interfaces, software, hardware, storage, processing, and transmission.

Federal laws, state laws, and department policies impact how first responders use images and videos. First responders occasionally described a policy or law to help us understand their needs or the tasks they perform. The tasks and needs of first responders were retained; but the opinions on policy and law were eliminated. This report does not provide legal advice or draw legal conclusions.

The identified technology gaps are divided among five tables. Table 1 lists specific features that first responders identified as technology gaps. Two of these specific features are analyzed in greater detail: color constancy (Section 2.1 and Table 2) and obscurants (Section 2.2 and Table 3). Section 2.3 presents the big picture of new product designs and work flows. Table 4 lists new product innovations requested by first responders. Table 5 contains complex technology gaps that we inferred by analyzing feedback in the context of current camera technology and research into new image and video processing techniques.

We chose color constancy and obscurants for additional analysis, because resolving these technology gaps seemed to have the best potential to help all first responders. Consider the entire market for cameras. The first responder market is small, and thus has relatively little influence. Video surveillance is larger market. The consumer market is huge, and their preferred type of camera is the phone.

First responders are most likely to benefit from camera improvements that are interesting to these larger markets and become a household item. Where possible, first responders choose the same cameras for their job that they would choose for their personal lives. Application-specific systems, like bodycams, rely upon components developed for larger markets: the lens, image processing electronics, video compression algorithms, etc. A breakthrough in how cameras detect and understand color would benefit phone cameras, and a breakthrough in eliminating obscurants would benefit the surveillance industry. Thus, these technologies might be deployed on a wide enough scale for prices to drop sufficiently to be within the budget of a typical first responder department (i.e., 25 people or less).

Each of the following five tables is ordered alphabetically and contains the same columns. Column “technology gap” names the technology gap. Column “explanation” briefly describes the technology gap. Column “example problems” lists situations where this technology gap impacts first responders. These examples are either taken from the interviews or a referenced publication. Column “task” refers to Appendix A, where relevant information may be found on each task mentioned. See Appendix B, Section B.7 for information related to smart cameras and video analytics.

Table 1. Technology Gaps: Single Feature Requests. “Technology Gap” names the gap; “Explanation” is a brief description; “Example Problems” are specific to first responders; “Tasks” are discussed in Appendix A.

Technology Gap	**Explanation**	**Example Problems**	**Task**
Bodycam form factor	Where to mount the bodycam is highly problematic. No obvious solutions exist, but industry is actively seeking solutions.	Torso mount means camera points a different direction than officer Head mounts can be uncomfortable in hot weather Wires from the bodycam to battery are dangerous: they give criminals a handle to grab, manipulate the officer Bodycam at center of chest shows back of officer’s hands when a gun is drawn Bodycams come unattached when officer struggles with suspect; department accused of doing this on purpose	Protecting the practitioner
Camera detection	Large incidents are likely to include multiple first responder cameras (e.g., evidence cameras, bodycams, in-car cameras). The cameras may be from different departments. Ideally, the images and videos from each camera would automatically note the existence of all other nearby first responder camera systems, with sufficient information so that the related media could be easily located.	A local officer is performing a road-side sobriety test. A state officer drives by and records the event at another angle on that vehicle’s in-car camera.	Video surveillance evidence
Color Constancy	First responders cannot trust the colors shown in digital images and video. See Section 2.1 and Table 2	Benchmark for camera colors Comparing video from multiple cameras Person tracking Remote sensing image color correction Use of skin tones for emergency telemedicine Vehicle color identification	See Table 2
Data tampering	There is no mechanism to detect tampering in digital images and videos. A standard method is needed to verify the integrity of images and video. Related research: fragile watermarkings.	Witness submits an image of a moving car’s license plate, taken by a phone Video evidence from a first responder bodycam Video evidence from a privately owned surveillance system	Documenting a scene Video surveillance evidence Non-surveillance evidence

Technology Gap	Explanation	Example Problems	Task
Dirty lens	Dirty lenses cause low image quality. The dirty lens is difficult to notice until an image or video is viewed on a large monitor. The user must notice the dirty lens and clean it. Such manual solutions are impractical. First responders need the camera to tell them that the lens is dirty.	Law enforcement officer uses a phone frequently in dirty locations; lens is touched often; picture quality degrades Surveillance camera lens covered in dust, restaurant grease, or spider webs	Documenting a scene Video surveillance evidence
Discriminating fine shades	A realistic photo will optimize white/black contrast. This causes problems when first responders want to distinguish details among very similar shades.	Photographing blackened rubble after a fire Photographing bruises on dark skin or scratches on light skin Photographing the bottom of a lake Photographing shoe prints or tire tracks in snow, mud, or sand	Documenting a scene
DSLR training	Lack of training is a common cause for poor quality evidence photos for serious crimes (e.g., homicide). The first responder may have a digital single-lens reflex camera (DSLR) but not know how to use it properly. The need for a particular first responder to take high quality photos can be very rare. Such practitioners tend to use their DSLRs in automatic mode—or rely upon compacts. Online training would solve this problem, if it were well advertised.	Detective in a small department rarely needs high quality photos (e.g., homicide, suicide). Department has two or three detectives. Traveling for training causes a critical shortage of personnel.	Documenting a scene
Editing	Video editing changes the digital compression and thus the video content. First responders need video files that can be edited for duration while ensuring that the digital compression and video content remain unchanged (invariant). This would help forensic video analysts differentiate between real events and artifacts created by the video technology. Depends upon video file interoperability.	Surveillance video is recompressed and the file format changes upon export from original system or import to department's computers. The consequence is a reduction of quality that damages important evidence.	Documenting a scene Video surveillance evidence
Fingerprinting negative	Photographing dusted fingerprints—the dust turns the fingerprint into a "negative". Preferably, the camera should fix this.	Dusting for fingerprints	Documenting a scene

Technology Gap	**Explanation**	**Example Problems**	**Task**
Focus	Most first responders use phones and compacts. Focus errors are difficult to detect in the field. Some practitioners need to bring all surfaces of a very small object into focus. This is difficult, and inexpensive cameras don't have a "too close for autofocus" warning. Thus, it is difficult to get all surfaces in focus. Solution requires camera feedback indicating which areas of the image are out of focus and why (e.g., too close, too far away, manual focus setting).	In an evidence photo, the bone is blurred and the backdrop is in focus Building inspection photo shows irrelevant objects clearly and blurs relevant structural details When fingerprinting a decedent using photographs, it is difficult to bring all surfaces of the finger into focus	Documenting a scene
Forensic video analyst simulator	"Forensic video analysis is the scientific examination, comparison and/or evaluation of video in legal matters." [1] Few departments can afford an analyst. Without this expertise, practitioners viewing videos have difficulty differentiating between the real events and artifacts created by the video technology. First responders would benefit from software that could describe the conclusions that an analyst would reach about videos and images.	Deciding if an officer used reasonable force Deciding the size of objects that can be distinguished	Documenting a scene
Framing	A common mistake in evidence photos is to not photograph the entire piece of evidence. It would be nice if the camera indicated this mistake.	Photo shows a tooth but does not include the whole root of the tooth	Documenting a scene
Geotagging inaccuracy	Some cameras automatically geotag picture locations. This information is particularly useful when seeking missing persons, because many people automatically upload images or post images to social media. However, large errors in these coordinates complicate and slow searches. In some areas, the errors can be up to a quarter mile. Phones can report fairly accurate coordinates, because the cell towers are used to correct the coordinates. Geolocation error estimates would be helpful.	A missing hiker took a picture at the trailhead and the camera automatically uploaded it. Practitioners must visit numerous trailheads looking for one that matches the photo. Detectives seek the location depicted in a photograph obtained from social media.	Non-surveillance evidence

Technology Gap	Explanation	Example Problems	Task
Interoperable surveillance export interface	The plethora of different video surveillance systems makes it difficult for practitioners to operate the system and export video. First responders need to be able to establish a wireless connection to surveillance systems. The need is for industry wide, standard protocols that provide limited functionality for remote control. First responders would export video through a 3rd party tool instead of the surveillance system's native interface.	System exports via CD, DVD, or USB. Hardware is awkwardly located to prevent theft (e.g., attic). No one knows how to use system. Export is time consuming or fails (e.g., video accidentally erased).	Video surveillance evidence
Metadata and timestamp interoperability	Surveillance systems tend to export inaccurate metadata (e.g., date, time, physical location of cameras). Most metadata must be noted manually (e.g., system make and model, serial number, software version number). Dates and times are seldom accurate. Camera feeds are typically numbered arbitrarily (i.e., geolocation information missing).	Time noted on video conflicts with time in first responder report, causing courts to question the evidence. Investigation involves 17 video surveillance feeds, including four overlooking stairwells. The detective has difficulty figuring out which stairwell is at which corner of the building, because the stairwells all look alike.	Documenting a scene Video surveillance evidence
Night photography	First responders want citizens to have a phone app that can capture the license plate of a moving car at night.	Photo evidence from private citizens	Non-surveillance evidence
Obscurants	First responders use images and videos to perform tasks that involve viewing people, vehicles, and other targets of interest. Environmental obscurants like rain and deep shadows make this viewing task more difficult. Obscurants cause cameras to produce lower quality images and videos, due to limitations of camera technologies. See Section 2.2 and Table 3	Dust removal Haze and fog mitigation Rain removal Raindrops on windows Reflections Shadow removal Snow removal	See Table 3
Online distribution	First responders need a fast, simple, secure, trusted, and easy-to-use mechanism to exchange large data files. Many departments struggle with electronic file exchanges. Problems include firewalls, data protection, cyber security, and proprietary systems. Some departments lack computer expertise.	Law enforcement department cannot send video evidence electronically to the prosecution and defense. Video is sent on CDs and DVDs. Incompatibilities in data management systems between hospitals prevents a remote expert consultation (e.g., difficult to set up a connection, slow to transmit).	Documenting a scene Video surveillance evidence Telemedicine

Technology Gap	Explanation	Example Problems	Task
Photographing a crime scene	An important task for law enforcement is to document crime scenes through a series of evidence photos. The detectives may take 250 photos of a single room to show the entire room, each object in the room, and the relationship among all objects in the room. The crime scene is ephemeral, and all pictures must be taken before anyone knows what will be important. Thus, the goal is to characterize all aspects of the scene as carefully as possible. As an example, a tiny candy wrapper in the grass may be the key to solving a murder case. Practitioners would benefit from cameras designed to aid them in this task. A solution could take several forms. One would be a camera that provides feedback on what picture to take next. Another would be an unmanned aerial vehicle (UAV) that photographs the crime scene. Another would be an app that helps the user create a video walkthrough of the crime.	Walkthrough of a crime scene is incomplete—it doesn't show some areas that were obvious to the videographer The set of crime scene photos lack intermediate range photos that show the relationship among objects	Documenting a scene
Redaction	Redaction software exists, but none of the software are accurate enough to be trusted. Each frame must be examined for mistakes.	Removing faces from surveillance video Removing other private information (e.g., names, license plates)	Documenting a scene Video surveillance evidence
Target size	Pictures do not indicate scale unless the photographer inserts a ruler into the picture. This manual step is often overlooked. It would be very helpful if the camera performed these measurements, and stored that information as metadata.	From a photo, measure: Dimensions of a bone Length of a knife Width of tire tracks Size of a shoe print	Documenting a scene

Technology Gap	Explanation	Example Problems	Task
Telepresence	First responder adoption of real-time video systems lags the theoretical benefits of such systems. One problem is that the telepresence (sense of being there) offered by today's interactive video systems is notably worse than face-to-face interactions. Telemedicine would especially benefit from improved telepresence tools that integrated several technology innovations (e.g., improved visualization, sensor technologies, and remote instrumentation). Home-health visits would also benefit from this technology.	Remote learning for law enforcement is difficult due to the need for group interactions around physical tasks. Static camera views cause problems for telemedicine, due to the remote doctor's need to view the patient from multiple angles. [2] "Many of the home-health visits conducted today are based on the need to observe or monitor a patient's status, a function that could be accomplished through interactive video systems coupled with the appropriate instrumentation and a simple-to-use interface." [3]	Remote viewing Telemedicine
Video file interoperability	Law enforcement officers have severe interoperability problems when trying to play video files from video surveillance systems. There are more than 1,000 video file formats.	Special training and equipment needed to play video files Video can only be played on the surveillance system. Epic fail: practitioner photographs the monitor.	Documenting a scene Video surveillance evidence
Video streaming interoperability	Departments have severe interoperability problems when trying to share live video streams. The plethora of different video surveillance systems makes it difficult for practitioners to access other department cameras and privately operated cameras. The need is for industry wide, standard protocols that provide limited functionality for accessing live video streams. This interface may have reduced functionality (e.g., pan/tilt/zoom prohibited, bitrate and resolution limitations).See Appendix B Section B.4.	Multiple departments in a city can each stream video from their surveillance cameras to their phones. The proprietary systems prevent these departments from sharing video streams. 911 dispatchers want to view live video streams from cameras located near an incident. The dispatchers can only access their own department's cameras. The traffic department, school system, and many stores stream live video from their surveillance cameras, but the 911 dispatchers cannot access those cameras.	Remote viewing
Video surveillance setup advice	Most surveillance systems are set up by amateurs. They don't think to watch the system's performance at different times of day (e.g., sunrise, sunset, night). They don't consider whether or not there is adequate lighting at night over the area to be watched. One useful tool would be an algorithm that analyzes the video over a 24 hour period and reports problems that a first responder would report.	Inadequate lighting at night Oversaturation at dawn or dusk Faces cannot be distinguished due to high camera placement or distance to person (small face) Resolution or bitrate too low Retention duration of the video by the surveillance system is too short	Video surveillance evidence

Technology Gap	Explanation	Example Problems	Task
Visibility mismatch to human perception	The range of light seen by the camera does not match that perceived by the officer. The video may show more information or less information. This is very problematic for bodycams, which seem to be deployed mainly for accountability purposes. The mismatch between what the practitioner reported and what the video shows causes confusion and misunderstandings.	Video clearly shows a hose, yet officer saw a gun	Protecting the practitioner
Visualizing a crime scene	Crime scene photos are used to visualize and understand a serious crime scene. This is a complex task. In the future, a visualization system could combine hundreds of photos and multiple bodycam feeds to create a realistic model of the crime scene. Some cameras already provide information about the relative position and angle of the camera for each photograph. Lighting problems could be mitigated by combining information from multiple pictures. Related technology: Structure Sensor® at http://structure.io/ This tablet accessory allows the user to create a 3D computer model of objects.	Combine hundreds of homicide photos to create a realistic model of the room Knit multiple bodycam and in-car camera feeds together to visualize a crime scene Show where the photographer was standing, the angle of the camera, the size of the objects photographed, and identify related pictures of the same object	Documenting a scene

2.1 Color Constancy

The human visual system perceives an object's color as remaining constant (unchanged) when the object moves among different illumination conditions. This is referred to as color constancy or chromatic adaptation. Cameras produce different colors as the lighting changes in space or time. Colors produced by different cameras will not match. This is referred to as color consistency[2] [4].

First responders cannot trust the colors shown in digital images and video. Their color problems can be summarized by three law enforcement scenarios using video surveillance footage:

- A law enforcement officer is photographing a vehicle in the early morning or late afternoon. The image set includes pictures of all four sides of the vehicle. The color of the vehicle in the photos changes depending on the direction the camera faces. This happens because the color temperature of the illuminant (natural light) is different when facing toward and away from the sun. The same phenomenon may be observed by watching one day of a surveillance video camera recording a vehicle parked outdoors.
- A detective is tracking the movements of a vehicle to and from an incident, using footage collected from video surveillance systems in nearby stores. The license plate is rarely visible, and the vehicle color changes from one system to another. This complicates the detective's task of differentiating between the vehicle from the incident and other vehicles (e.g., perhaps having the same or similar make, model, and color).
- A practitioner's bodycam is filming at night in an area lit by sodium street lights and fluorescent store lights. The camera white balances for one of these lighting conditions; objects lit by the other light source look wrong (e.g., blue tinted). The color of a suspect's shirt changes from white to blue depending on where the suspect stands. This happens because the camera uses a single white balance for the entire image. By analogy, the human visual system makes multiple white balance measurements. The lightness, darkness, and color of everything you see is influenced by the surrounding context of colors, illumination, and shadow. [5]

Computer vision and video analytics struggle with these same problems. [6]

First responders verify target colors in surveillance videos using one of two mechanisms. The first is to record new footage with the surveillance system that depicts a known object. The second is image post processing (e.g., [7]–[10], EPICOLOR®). Neither solution addresses their need for efficiency and automation (see Appendix B). Post processing algorithms are particularly problematic, because law enforcement needs a viable and reliable reference to calibrate the image processing system for each piece of evidence.

Most of the technology gaps in Table 2 address color consistency and support a specific first responder task. Resolving these technology gaps will provide a near-term solution of incremental improvements to existing camera systems but cannot fix the underlying problem. Basically, each of these technology gaps identifies a specific need area that has a well-defined end goal and was identified by first responders as desirable. Table 2 omits color problems associated with

[2] Some papers use the term "color constancy" to refer to both phenomena. We will use the definitions given by Jung and Ho [4].

technologies that first responders rarely or never mentioned. Examples include correctly rendering colors of the see-through displays required for augmented reality [11], machine vision for autonomous navigation [12], cross-media color fidelity, color restoration for the film industry, and camera systems that encompass more of the visual light spectrum (e.g., wide color gamut, and high dynamic range). The latter are the focus of a fair amount of commercial development, so first responders are likely to benefit from improved commercial products regardless.

A long-term solution will require innovation: a new type of camera that captures more information. The fundamental problem is that contemporary cameras lose too much information. This is an under-constrained problem [13]. Cameras capture three color bands (RGB), and there are two unknowns (the lighting condition, and the reflectance of the materials).

Table 2. Technology Gaps: Color Constancy. "Technology Gap" names the gap; "Explanation" is a brief description; "Example Problems" are specific to first responders; "Tasks" are discussed in Appendix A.

Technology Gap	**Explanation**	**Example Problems**	**Task**
Benchmark for camera colors	First responders would benefit from a standard test that evaluates the colors produced by cameras in common illumination conditions (e.g., sodium lights, vehicle headlights, sunlight). Ideally, cameras that have reasonable color consistency would be marked, as per an Underwriters Laboratory (UL) Certification Mark.	Department is purchasing a new video surveillance system for their headquarters. They cannot easily learn about illumination conditions where the camera will produce extreme color errors (e.g., a yellow or green wash over the entire video).	Documenting a scene Protecting the practitioner Remote viewing Video surveillance evidence
Color constancy	First responders need cameras with color constancy that is good enough that color information can be trusted. The solution is a new type of camera that captures more information. Open questions include the number of color bands and optimal configuration to simplify color constancy tasks; and the tolerance (error) threshold that would balance first responder needs for color constancy with equipment costs. Related research: hyperspectral imagers and cameras for museum art preservation.	Identify suspect skin color from surveillance video Identify the color of a dog from a photograph Automatically identify vehicle color Remotely diagnose an illness based on skin tones	Documenting a scene Video surveillance evidence Non-surveillance evidence Protecting the practitioner Remote viewing Telemedicine
Person tracking color features	Matching people across multiple camera views and the varying lighting conditions For example, see [14]–[16].	A video surveillance system uses video analytics to ensure that children who enter a restroom leave with the same adult. The restroom has two entrances.	Video surveillance evidence
Remote sensing image color correction	Remote sensing images encounter atmospheric conditions that impact image colors. Color correction would aid image interpretation. For example, see Innovative Imaging & Research, http://www.i2rcorp.com/home; and KSKY Hi-Tech Corp, http://www.ksky.ca	UAV used for search and rescue or disaster response	Remote viewing
Vehicle color identification	Automatically identifying a vehicle color For example, see [17]	License plate recognition cameras could also record the vehicle color	Video surveillance evidence

2.2 Obscurants

First responders use images and videos to perform tasks that involve viewing people, vehicles, and other targets of interest. Environmental obscurants like rain and deep shadows make this viewing task more difficult. Obscurants cause cameras to produce lower quality images and videos, due to limitations of camera technologies. Basically, obscurants are more of a problem for cameras than they are for a human viewing the same targets live. Alternative mechanisms can be used to document these obscurants, such as metadata indicating rain removal or a practitioner report stating "It was raining." If time and resources permitted, these obscurants could be eliminated, for example by waiting for better weather or deploying supplementary lighting. Therefore, it is reasonable for first responders to use cameras that remove obscurants from images and videos.

The obscurant removal technology gap solutions in Table 3 are intended to be applied before the image or video is encoded for the first time. For each technology gap, we identify an algorithm that could be integral to the camera and would thus modify the original uncompressed image. The goal is an image or video that will have higher quality or improved usability after that initial compression. These are inherently lossy processes.

An alternative approach would be to develop post-processing algorithms. Such a generalized solution would fail to meet several of the attributes that first responders requested (see Appendix B), and as such would likely be less useful for first responders. For example, the software packages currently available (e.g., AMPED® software, DxO® ClearView, and dVeloper™ by Ocean System®) require a trained operator, who must choose among a large set of image processing filters. In addition, the algorithm development would be more challenging, due to the need to operate correctly on images or videos from unknown cameras.

Table 3 lists obscurants that could be removed from images and video. These technology gaps apply to both still images and video systems. In some cases, like rain removal and falling snow removal, the video algorithms offer less of a technical challenge, because the algorithm can leverage a sequence of frames to extract more information. Video algorithms offer a greater hardware challenge due to the need for real-time processing. Technology in the processor industry for visual data is progressing rapidly, so real-time video processing is not listed as a technology gap. Image algorithms typically offer the reverse situation: technically challenging algorithms that are viable even if the camera takes longer to record a photo.

Obscurant removal algorithms have not yet been integrated into most cameras that first responders typically use (e.g., in-car cameras, bodycams, compact cameras, DSLRs). Only a few video surveillance systems contain real-time obscurant removal (e.g., ProHawk® , Empower Technologies®, and LYYN®). Some algorithms have been patented but not yet commercialized (e.g., [18] and [23]). Generally speaking, there appears to be a bias among researchers to focus on rain removal. This bias does not seem to reflect first responder priorities.

Table 3. Technology Gaps: Obscurants. "Technology Gap" names the gap; "Explanation" is a brief description; "Example Problems" are specific to first responders; "Tasks" are discussed in Appendix A.

Technology Gap	**Explanation**	**Example Problems**	**Task**
Dust removal	Airborne dust reflects light and obscures targets of interest farther away. Faithfully reproducing them adds little to our understanding of the situation.	Photographing disaster scene Dust particle close to camera looks like a very large blurry circle Remote surveillance in a desert	Documenting a scene
Haze and fog mitigation	Haze and fog reduce visibility of distant targets. For example, see [18]-[19], ProHawk®, LYYN®, and DxO® ClearView.	Bodycams and in-car cameras recording during a foggy day Remote monitoring of critical infrastructure (e.g., bridges)	Documenting a scene Remote viewing
Rain removal	Rain is problematic for cameras, especially video coding. Particulates change position each video frame and reflect light. They obscure targets of interest farther away and add greatly to the coding complexity (i.e., lowers quality for a given bitrate). For example, see [20]–[25], ProHawk®, LYYN®, and Ocean System® dVeloper™.	Bodycams and in-car cameras recording during rain Photographing a homicide during a rainstorm Remote monitoring of critical infrastructure	Documenting a scene Video surveillance evidence Non-surveillance evidence Protecting the practitioner Remote viewing
Raindrops on windows	Video surveillance systems often deploy rugged cameras outside in all types of weathers. Raindrops on glass housing or lens block part of the scene beyond. Computer vision algorithms are probably more impacted than people. A solution would be a camera that could erase the visual impact of raindrops on then lens. For example, see [26].	Remote monitoring of critical infrastructure In-car camera recording during a rainstorm	Remote viewing
Reflections	Reflective surfaces like mirrors or windshields can show a face to be redacted or other details that obscure the information of interest. It can be difficult to remove the face and identifying features while retaining the information needed within the picture. Reflective surfaces cause glare, making them difficult to visualize or understand. For example, see [27].	The face of an officer taking photographs appears reflected in a car's windshield; the officers face must be redacted Broken glass reflects light and has strange shapes, making the surface of the glass difficult to visualize and understand	Documenting a scene

Technology Gap	Explanation	Example Problems	Task
Shadow removal	First responders encounter poor lighting, intermittent bright lights from emergency response vehicles, and evidence scenes where supplementary lights cannot be deployed. Shadows and uneven lighting detract from the task of displaying underlying evidence. The assumption in photography is that it is acceptable to deploy supplementary lighting to improve the picture, so the visual impact of the current light sources is irrelevant. A camera that eliminated shadows would be no different (theoretically) than setting up lights—yet faster and more efficient. The difference between this technology gap and high dynamic range (HDR) camera research is the goal of entirely removing the shadow. The residual could be a discontinuity along the shadow edge, as shown in [18].	In-car camera at night Photographing vehicle accident at night Fire marshal photographing fireground ash at night or dawn Photographing crime scene outside at night or in dim areas Bodycam footage at night lit erratically by bright lights from emergency vehicles (e.g., rotating, strobe, light bar, steady burning)	Documenting a scene Protecting the practitioner Remote viewing Video surveillance evidence
Snow removal	Falling snow is problematic for cameras, especially video coding. Particulates change position each video frame and reflect light. They obscure targets of interest farther away and add greatly to the coding complexity (i.e., lowers quality for a given bitrate). Faithfully reproducing them adds little to our understanding of the situation. For example, see [23], [28], ProHawk®, LYYN®, and Ocean System® dVeloper™.	Bodycams and in-car cameras recording during falling snow Photographing a homicide during a snowstorm Perimeter security of a 15 mile circumference site during a snowstorm Snowflakes falling on a bright day causes bright reflections toward the camera Remote monitoring of critical infrastructure	Documenting a scene Protecting the practitioner Remote viewing Video surveillance evidence Non-surveillance evidence

2.3 Product Innovation and Inferred Needs

Many of the technology gaps described above stem from a fundamental problem: the reuse of camera components that were designed for a different purpose. This section describes new product innovations that were requested by first responders (Table 4) or inferred from first responder feedback in the context of current camera technologies (Table 5).

Table 4. Technology Gaps: Product Innovation. “Technology Gap” names the gap; “Explanation” is a brief description; “Example Problems” are specific to first responders; “Tasks” are discussed in Appendix A.

Technology Gap	**Explanation**	**Example Problems**	**Task**
Basic surveillance system for law enforcement	Video surveillance systems are designed for security, not law enforcement. Video surveillance footage produces low resolution faces, mostly the top of the suspect’s head. Facial recognition algorithms work best with high quality mugshots. A basic surveillance system designed for law enforcement would photograph each person who enters the store and each vehicle that enters or leaves the store’s lot. The door camera would be at head height, to show faces. The system would use a high resolution camera (e.g., 10 mega-pixels), intelligently craft photos for identification purposes, store them at high resolution in JPEG files, and timestamp each photo with date and time synced to universal time. This system would not record video.	A typical store has two to three entrances. This system would help detectives identify suspects by providing a high quality mugshot. Storage costs would be minimized, because the data export would be a small set of photos.	Video surveillance evidence
Fight alert	A camera system could alert practitioners when it detects a fight involving weapons.	A school video surveillance system that detected a fight involving weapons could improve the police response by ≈4 min.	Remote viewing
Improved smoke detector	A fire detector in a very large building could use smoke patterns to analyze the scope of the fire and send an alert to the fire department. This would help practitioners differentiate between a small local fire and a major fire.	Fire detected in a very large building potentially threatens many lives. Department must err on the side of caution and send half of the fire trucks available. This takes resources away from other problems.	Remote viewing

Technology Gap	Explanation	Example Problems	Task
Intermediate surveillance system for law enforcement	Video surveillance systems are designed for security, not law enforcement. An intermediate system would take the basic system (see above) and add video cameras to record events. Like the basic system, the intermediate system would still photograph each person or vehicle for identification purposes. The video format would be 720p or better with a high enough bitrate that people are easily recognized. The video quality would allow a person with little technical expertise to correctly estimate sizes, times, movements, and distances. This system would be designed for law enforcement and so would solve a slew of issues like interoperability and data validation. See Table 1 for information on interoperable surveillance export interface	A surveillance system installed in a school shows a student getting beaten but not the faces of the perpetrators. Surveillance cameras around the city allow practitioners to monitor events in progress. Practitioners observe a homicide in progress but cannot zoom in enough to read the license plate.	Video surveillance evidence
Person and vehicle alert	A camera system attached to a light pole could aid with law enforcement if it combined two functions available today. First, it would keep a record of all license plates seen in the last 30 days. Second, practitioners could upload a list of faces, and have the camera send an alert when facial recognition identifies someone.	Aid in tracking a vehicle found to be of interest in an investigation long after the event occurs System alerts law enforcement when a likely match is found for a missing person System alerts law enforcement when it recognizes a person who by state law or court judgement is not allowed to be at that location	Video surveillance evidence
Person tracking	A common task for detectives is to use a store's video surveillance system footage to track a person's movements around a store. A better solution would be if the surveillance system tracked each person and stored that knowledge as metadata associated with the video file. The recognition task simplifies, because the store has known entrances and exits, each typically covered by a security camera.	Suspect scopes out a store in the morning, and returns in the afternoon to rob the place Department store has 17 cameras. A shoplifter appears on 5 of those video feeds during one store visit (e.g., entrance, shoe department)	Video surveillance evidence

Table 5. Technology Gaps: Inferred Needs. "Technology Gap" names the gap; "Explanation" is a brief description; "Example Problems" are specific to first responders; "Tasks" are discussed in Appendix A.

Technology Gap	**Explanation**	**Example Problems**	**Task**
Evidence	Law enforcement officers need to handle evidence carefully. Law enforcement would benefit from camera systems which produced videos and images that can be submitted to the courts unchanged and checked for tampering. Desirable features include: • A mechanism to check for image and video tampering • Video files that can be exported and edited without recompression or reformatting • Accurate times and dates Related research: fragile watermarking See Table 1 for information on data tampering, editing, forensic video analyst simulator, metadata and timestamp interoperability, and video file interoperability.	A video surveillance system saves video in a proprietary format. The video must be reformatted and recompressed to play on the department's computer. The dates on the surveillance footage disagree with the officer's report. Witnesses give officers footage from their phones. The officers have no way to check whether the video was doctored.	Documenting a scene Video surveillance evidence
Forensic photographer simulation	Phones are a pragmatic multipurpose tool. The image quality from phones is approaching that of compact cameras, but consumers assume lower quality. Many practitioners don't have time or interest in training with a DSLR. Such practitioners make errors that more experienced photographers wouldn't. Practitioners would benefit from a phone app that provides the expertise they lack: that of a criminal photographer. This app would also encourage acceptance of phone cameras among first responders. The app would likely need to have several modes (e.g., tire tracks, dark objects, fingerprint powder, and small objects). Also of interest: automatically associate photos with a case number; camera uploads photos automatically to the department's evidence system. See Table 1 for information on potential functions of the tool, such as angle, dirty lens, discriminating fine shades, fingerprinting negatives, focus, size, and elimination of snow, rain, and dust.	Most departments are small and rarely photograph crime scenes. The department owns high quality cameras but the practitioners do not know how to use them. The practitioner takes haphazard, random photographs. The set of images does not show the relationship between different objects in a room or their relationship to each other. Photos may not show critical information, so the practitioners must also draw diagrams and take measurements (e.g., location of a bruise or scratch, size of the knife).	Documenting a scene Video surveillance evidence

Technology Gap	Explanation	Example Problems	Task
Prototypes	Before first responders can adopt novel camera technologies, they must consider whether the technology can be deployed given the constraints that their department operates under and the needs of the courts. First responders will have difficulty holding these discussions unless practitioners can play around with the proposed technology using prototype software. This buy-in is a roadblock to some vendor product innovations, particularly solutions that must be implemented in hardware.	A phone app demonstrates a camera that removes falling snow, but can only capture short videos. First responders choose settings similar to their bodycams and film with both systems during a snowstorm. The sample footage aids in discussions on the merits and drawbacks of a bodycam that removes falling snow.	All

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APPENDIX A TASK ANALYSIS

This appendix provides a high level overview of how first responders use digital images and video. Each section summarizes a broad use case and the types of problems that first responders encounter.

The information in this section is incomplete. Our conclusions are based on the relatively small sampling of first responders interviewed. We continue to interview first responders and learn more about their needs.

Live video streaming and recorded video are often perceived as functionally similar—two sides of the same coin. Feedback from first responders indicates that these two use cases have very different requirements and problems. Therefore, we separate live video streaming from later views of the recorded video, if any.

A.1 Documenting a Scene: DSLR, Compacts and Phones

A common thread for all first responders is the need to document a scene. The goal is to inform people who were not present, perhaps decades in the future. Examples include:

- Describe an area, to organize response planning for large events
- Record ephemeral events, such as a crime scene, accident, or injury
- Depict evidence that is difficult to preserve, such as a can of beer or fresh meat
- Depict stolen goods, so they can be returned to their owners
- Show an accident to an emergency room doctor, to understand the kinetic energy
- Walk large numbers of investigators through a major crime scene while limiting the traffic
- Document interactions, to avoid allegations of misconduct

These images and videos used to document a scene are often evidence. This impacts how the media are handled. Images and videos with very low visual quality must be retained, because erasing them would raise concerns that someone erased the image in an attempt to hide evidence. Examples are a photo where a street sign reflects all light so the sign cannot be read, and a photo depicting indistinguishable shades of black due to insufficient lighting.

Phones, compact cameras, digital single-lens reflex cameras (DSLRs), bodycams, and in-car cameras are used to document scenes. Law enforcement officers and firefighters use all of these camera types, depending upon the department. Paramedics tend to use phones to take a picture and display it to the emergency room doctor. There may not be a sanctioned mechanism to transmit the image to the hospital's system.

Most first responders are satisfied with the picture quality produced by their department-issued camera. Most issues are expressed as user experience (UX) or quality of experience (QoE) problems. Examples include:

- The high cost of storing, retaining, editing, and redistributing video

- The extensive training needed to benefit from DSLR manual modes
- Personnel costs associated with video systems (e.g., camera maintenance, video storage system costs, personnel to edit video for distribution)
- Dead batteries
- How to associate photos and video segments from multiple cameras to a single event (e.g., multiple officers' bodycams, multiple in-car cameras, nearby store surveillance video, photos from each still image camera)
- Incompatibilities between data management systems used by different departments (e.g., between emergency medical providers, from law enforcement to attorneys)
- The copy from camera to storage system appears to work correctly but didn't. When evidence is needed, images are corrupt or contain only a link to the camera (long since erased).
- Picture was taken at the wrong angle (e.g., on an x-ray, one tooth overlaps another, bodycam video shows the floor, the camera pointed to one side of the event)
- Picture does not include the whole object (e.g., x-ray shows only part of the tooth's root)
- Picture does not indicate scale (e.g., a bone photo with no adjacent ruler, size of the knife is unclear)
- Walkthrough of a crime scene is incomplete—it doesn't show some areas that were obvious to the videographer
- The set of crime scene photos lack intermediate range photos that show the relationship among objects
- Photos must be manually associated with the case number. It would be better if the camera could automatically accomplish this task. An example workflow would be the officer enters case number when taking pictures, and the camera copies images to the appropriate file on the department's evidence system. This workflow is particularly appealing for phones.

Some physical environments make it difficult for the first responder to get the photograph they need. This is typically not described as an image quality problem. The perception is that the camera performed correctly, but the environment is difficult for photography. Difficult environments include:

- Rain falling—blurry images, distortions caused by raindrops on the lens
- Snow falling—light reflects off the snow flakes
- Dust in the air—light reflects off the dust, a particle very close to the lens can appear as a very large blurry circle
- Fog
- Smoke—all you see is the smoke, unless a thermal imaging camera is used
- Sand, mud, and snow are difficult to photograph (e.g., photographing footprints or tire tracks). Sand is the worst as it holds little detail; snow photos are often all white if a flash is used.
- Glass and broken bottles (e.g., photographs taken straight on reflect light; photographs taken at an angle are difficult to understand and visualize).
- Hot days with high humidity—lenses fog when entering or leaving air-conditioned vehicles

- Cigarette butts. Close shots are blurry, and far shots omit details (e.g., object cannot be identified, cigarette brand indistinguishable)
- Cold temperatures—the photographer’s breath forms a cloud in front of the camera
- Night—especially when photographing very large outdoor scenes
- Dimly lit environments with no electricity and where separate lights on tripods cannot be deployed, because evidence on the ground cannot be disturbed (e.g., fire investigation)
- Sunrise, sunset, and oncoming headlights—due to the wide dynamic range of light
- Blackened rubble from a fire—the goal is to distinguish among blackened objects
- Very short focal distance, such as fingerprinting by photographing a finger—inexpensive cameras don’t have a “too close for autofocus” warning; and it is difficult to get all surfaces in focus
- Photographing the back side of a car door handle—use mirrors, but the image flips
- Photographing dusted fingerprints—the dust turns the fingerprint into a “negative”
- Highly reflective surfaces (e.g., street signs) appear white and cannot be read at night if photographed with a flash
- Reflections—reflective surfaces like mirrors or windshields can show the face of the law enforcement officer who took the picture. Sometimes, the identity of that officer is not supposed to be released, and it can be difficult to remove the face and identifying features while retaining the information needed within the picture.

Innovative solutions using current technology include:

- Wildlife cameras used to capture license plates at remote locations (e.g., a trailhead parking lot).
- 360 degree cameras for use in surveillance of outdoor areas, to ensure visibility in all directions.
- Replacing one roaming pan-tilt-zoom (PTZ) camera with four fixed surveillance cameras, for approximately the same equipment cost (ignoring storage).
- Bodycam used also as a still image camera.
- Bodycam video can be used to supplement crime scene photographs. As EMS responds to a victim, they will spread equipment around the site. Bodycam video will show what the site looked like before EMS modified the scene. For example, whether the blood pool had a distinct edge before EMS pulled the victim through the blood pool and distorted its edges.
- Phone issued to each first responder. The image quality today is impressive even in low light; only the flash response is disappointing. One department that did this reported that roughly 85% of photos are taken by officers with their department phones and that the phones are used for multiple purposes.
- GoPro® camera used to record a firefighter’s viewpoint for training purposes only.

Of the different types of cameras used by first responders to document situations, only bodycams were associated with enough quality complaints to be considered separately.

A.2 Remote Viewing: Real-time Video Streaming

Real-time video streaming is used to observe a remote location or to enable two-way communication (i.e., videoconferencing). Delay is a critical problem for two-way communication but less important otherwise (e.g., remote viewing of in-car cameras or bodycams).

Videoconferencing is mostly used by emergency medical response personnel. Example uses include:

- Consultation with remote experts (e.g., stroke, infant resuscitation)
- Language translation, including sign language for the deaf and hard of hearing

Quality problems unique to videoconferencing include:

- Inability to distinguish between hands / arms and the background.
- Subject is poorly lit
- Poor clarity
- Insufficient frame rate
- Inappropriate content in the background (e.g., a naked person walks past)
- Personnel prioritize local issues over remote emergency situations. Emergency medical personnel cannot rely upon remote experts.

The video relay service (VRS) uses videoconferencing to translate between sign language and voice communication. Sign language translators indicate that the video transmission bandwidth is too low for clear communication. For VRS, these quality problems lead to miscommunications and misunderstanding.

One-way live video streaming is mostly used by law enforcement. Example uses include:

- Site monitoring
- Criminal trespass
- Traffic monitoring
- Crowd monitoring for large events
- Monitoring the progression of wilderness fires
- Remote control of UAV and UGV
- UAV used to remotely search mountainous terrain for lost hikers
- Monitoring critical infrastructure (e.g., bridges)
- Remote attendance of live training events

First responders are responsible for specifying systems for their own use and are able to procure systems that satisfy their needs. The following quality problems were reported:

- Insufficient zoom capability. An example is witnessing a live shooting but being unable to zoom close enough to get the vehicle’s license plate.
- Noisy or grainy images from older cameras
- Inadequate cyber security (hackers attack these systems)

- Remote attendance of live training events is usually ineffective for first responder purposes, perhaps because the training tends to be very hands-on
- Incompatibility between different systems that offer real-time video streaming (e.g., two different departments)
- Micromanagement—managers who want to be able to watch real-time video streaming from any officer at any time
- Loss of situational awareness. This increases the chances of the practitioner getting shot and killed. For example, getting absorbed in a phone, or an officer doing their own license plate number searches instead of calling dispatch.
- Regulations restricting UAV deployment

The first responders we interviewed rarely expressed interest in UAV (tethered or untethered), UGV, and tactical cameras (e.g., pole-mounted cameras, videoscopes, throwable camera balls, and under door cameras). It is not clear whether this indifference vis-à-vis UAV, UGV, and tactical cameras is caused by underutilization, technology gaps, an intrinsic attribute of these cameras, or operational constraints (as per the concerns expressed around telemedicine in Section A.5).

We observed substantial delays when first responders demonstrated system interactions, such as requesting a new video surveillance stream or moving the surveillance camera position. However, the first responders did not object to the delays. All of the environmental issues reported in Section A.1 apply to one-way live video streams.

Future feature requests focused on video analytics embedded into a surveillance camera that would minimize the information transmitted and allow first responders to formulate better responses. Examples include.

- A smoke detector detects smoke and then sends video to the fire department indicating whether the fire in a 20 story hotel is major (e.g., showing many people running around on multiple floors) or small (e.g., shows only smoke coming from one door).
- A school's video surveillance system detects a hallway fight and then sends video to law enforcement. Officers can use that video to determine whether the hallway fight is simply roughhousing or involves a weapon.
- Voice aggression detectors that trigger remote personnel notice
- Boundary warnings

Some of these technologies are available today, but were not deployed by the requesting agency. Whenever possible, it is desirable to embed as much of the video processing as possible into the device on the edge (i.e., the camera). This reduces bandwidth requirements and provides some safety from denial of service attacks—for example, the camera system can continue to operate in isolation. Video analytics are particularly of interest, as this minimizes the volume of information to be sent.

A.3 Video Surveillance Evidence: Privately Operated Video Surveillance Recordings

Most of the video surveillance recordings used by law enforcement agencies are created by people who are not themselves first responders and, consequently, have no understanding of first responder needs. Some first responders use video surveillance either minimally (to protect their own office) or extensively (in a wide network of cameras around their city). These recordings may be used soon after events (as part of an immediate response) or much later (as evidence).

The most commonly mentioned quality problem is interoperability. The problems can be best understood by stepping through the process a hypothetical officer takes to retrieve video from one store's surveillance system.

- Surveillance system users don't understand that the quality cannot be increased beyond the initial recording.
- Each video surveillance system has a unique user interface. The personnel on duty do not know how to use the system, so a manager from another store may have to drive several hours to operate the system. If the officer arrives after hours, a different officer must return later.
- The manager may not know how to fully operate the system. Perhaps the person who knew the system left years ago. The only alternative may be to take a picture of the image on the surveillance system screen.
- The system may have been set up with a short retention period. If detectives are busy with a higher priority case, the video evidence may be deleted before detectives have time to collect video from the system.
- To protect the surveillance system from criminals, the hard drive may have been concealed in an awkward location, like in an attic or behind a hot water heater. Physically locating and accessing the hard drive to export video may be a major endeavor.
- There is a wide variety of different surveillance systems, which export video using a multitude of proprietary codecs. Sometimes the media export includes the drivers needed to play the video. Unfortunately, those drivers are often missing. Each person who wants to play that video export (i.e., the original evidence) must find a compatible computer and a compatible driver.
- The quality of video seen by the surveillance system users for live monitoring is different than the quality of video saved by the system. The saved video is often of much lower quality than the live video streams.
- Many surveillance systems use a different video file format for internal storage than for exported video. This involves a format conversion, which by its nature lowers the quality of the video. Sometimes, this quality drop is substantial.
- The quality of a video playing (in motion) is different than the quality of video paused (i.e., one still frame). Pausing the exported video involves another drop in quality, and often it is that final frame that must be used for facial recognition of a subject.
- Most business-owned video surveillance cameras are placed differently than what first responders need. Most business surveillance systems are designed by the store owner to accommodate their main purpose: discovering if employees are stealing from the till. There is usually a good camera view of the employee and till, that can be used to identify

already known employees. This view usually shows the tops of heads and may not show any information about a robber who enters the store.

- The most important view for first responders is recognizable faces of everyone who enters or leaves the store. If a camera is positioned for this purpose, the camera view is often too wide (i.e., too few pixels on each face) or too high (i.e., only shows the tops of heads).
- Storage space is a problem for all surveillance systems. Many store owners make logical choices to minimize resolution and compression rate. Unfortunately, the store owner's choice makes the resulting video less useful for first responders.
- Many business surveillance systems are old, and their quality has degraded. Camera lenses get dirty and aren't cleaned. Spiders build webs around the cameras. Even with fully digital systems, the sun can burn images into the camera.
- Many systems operate in black-and-white or infrared mode at night. Others have color errors in response to artificial lights, including streetlights. Some surveillance systems inaccurately represent colors at all times of day (e.g., the color of a car across a 50 yard parking lot). Regardless of the specific cause, valuable color information is very often lost.
- Many store surveillance systems provide video footage that has only been viewed during daytime operational hours. They may have very poor performance at dawn, dusk, and night due to the unusual lighting conditions. At night, there may not be enough store lighting for the system to differentiate between objects. Many surveillance systems auto-white balance incorrectly in response to direct sunlight, causing details to blend into similar shades of black. Illuminated countertops, backlit bar tops, backlit display shelves, and light tables can cause similar distortions.
- Roaming pan-tilt-zoom surveillance systems often point away from critical events.
- The cost of investigating a misdemeanor can greatly outweigh the damage resulting from the misdemeanor itself. There is a high cost associated with obtaining video surveillance footage from a business and recording that footage as evidence. Law enforcement departments likely have no mechanism to refuse to do this, even if the event is the burglary of a one dollar item. When considering cost, consider the officers' time responding to the report, returning later when someone is available who can operate the store's surveillance system, entering the video as evidence, the costs of retaining that video, and personnel costs to edit and redistribute the footage as needed.
- Although surveillance systems are improving, many stores are not motivated to replace or update their systems. Some law enforcement officers say that they have never found store surveillance footage to be helpful when solving a crime.

In short, video surveillance systems are often set up without any thought given to the information that is wanted from the footage. The wrong system is purchased, the cameras are put in the wrong places, or the wrong system settings are chosen, and so the footage cannot give the desired information—evidence of a crime.

The quality complaints for recorded surveillance video include:

- Interoperability problems (e.g., the exported video does not play, the video playback drops frames)

- The high cost of data storage
- Very low coding bitrates, chosen in response to high system or storage costs
- The hidden costs of video processing personnel, system maintenance, data storage, editing, distributing the footage upon request, and re-editing the footage when a defendant asks for extra footage
- Lack of clarity (e.g., picture is fuzzy or grainy)
- Zoom is inadequate
- Image is clipped at black or white, so that distinguishing features are missing.
- The recorded video has bad quality
- Low quality of paused frames
- The export process lowers the video quality (compared to playing the video on the system)
- Low resolution video at a very low bitrate
- Faces cannot be recognized
- Camera shows the tops of peoples' heads
- Inadequate lighting adjacent to the surveillance camera
- Dirty camera lenses (grease from restaurants, grime, cobwebs, rain, dust)
- The surveillance footage is retained for only a few days; video has been erased when an officer arrives to request it.
- No one knows how to use the system—that person left for another job
- Motion activated recordings
    - Recordings from pixel-difference-triggered systems miss critical frames when the clothing color is too similar to the background
    - Poor sensor placement for an IR triggered motion recording (e.g., hot sun damages sensor so system records everything or nothing)
    - Shadows or a cloud in front of the sun fool the system
    - Exported video provides no supporting documentation of why frames are missing
    - No timestamps

Feature requests for video surveillance recording systems:

- 30 day retention period
- Cameras placed by all entrances and exits, that show faces with enough clarity to be recognizable
- Standard access mechanism (so don't need to depend upon system owner)
- Wi-Fi capable video export (so don't need to physically access system hard drive)
- Standard video format used for all exports (perhaps 4 to 6 formats)
- Video export does not lower quality

A.4 Non-Surveillance Evidence: Other Privately Operated Images and Videos

Fire marshals and law enforcement personnel receive images and videos from outside sources. Examples include:

- CAD drawings depicting a building layout

- Geographic information system (GIS)
- Photos from Facebook® or other public websites
- Videos recorded by a witness on their phone
- Google Earth® photos of buildings

No complaints were stated around CAD and GIS. These are the shining star—the high quality that every user desires.

Google Earth building photos provide a useful "before" picture for fires but are typically not available for new neighborhoods. Google Earth building photos are also useful for finding locations shown in photos (e.g., locate the playground that these kids were fighting in, based on a distinctive background).

A.5 Telemedicine: Interactive Video Communications

Emergency medical response is a field where improved use of video technologies could yield major improvements. These benefits are balanced by concerns such as:

- Cost of the system
- Department does not understand HIPAA obligations[3]
- Interoperability problems
- Liability concerns
- Medical care does not improve
- Physicians are too busy
- Telepresence is not good enough [2]
- User interface problems

More detailed analyses may be found in NPSTC's *EMS Telemedicine Report* [29].

Telemedicine is an area where video quality compromises are particularly difficult to accept. However, it is difficult to identify technology gaps unique to the use of video technologies for telemedicine, due to these more pressing concerns.

A.6 Protecting the Practitioner: Bodycam and In-car Camera Recordings

Most in-car cameras and bodycams are deployed to protect the practitioner. Bodycams and in-car cameras record what really happened, for example showing that the practitioner acted

[3] The U.S. Department of Health and Human Services, Office for Civil Rights, provides guidance to the public on HIPAA compliance. For example, see U.S. Department of Health and Human Services, Office for Civil Rights BULLETIN: HIPAA Privacy in Emergency Situations (Nov. 2014), available at: https://www.hhs.gov/sites/default/files/ocr/privacy/hipaa/understanding/special/emergency/hipaa-privacy-emergency-situations.pdf. For information about the HIPAA Security Rule, which establishes safeguards that must be in place to ensure appropriate protection of electronic protected health information, see U.S. Department of Health and Human Services, Summary of the HIPAA Security Rule, available at: https://www.hhs.gov/hipaa/for-professionals/security/laws-regulations/index.html.

professionally. Bodycams are very valuable as training tools, because they allow practitioners to watch and learn from events (e.g., their own response, another department's response). Bodycams aid credibility by showing what the practitioner saw, heard and said. TASER® CAM recorders and gun-mounted cameras serve this same purpose. Departments told us that they rarely or never export single frames from bodycam and in-car camera footage (e.g., maybe once a year to read a license plate). Contrast this to video surveillance cameras, where frames are frequently exported (e.g., to identify a suspect). See Kampfe [31] for more information on the role of bodycams for first responder accountability.

Most cameras point in one direction, so videos typically show only part of the event. Bodycam videos often point at the ceiling, the floor, people's knees, to one side of the event, or the back of officer's hands (e.g., when a gun is drawn). Similarly, roaming pan-tilt-zoom (PTZ) surveillance systems often point away from critical events; or a bystander's phone video may only show an officer shooting but not the events leading up to that moment. This can be actively misleading when the case reaches court. This is a particular problem for bodycams, which are intended to depict what that particular first responder experienced.

First responders mentioned the following problems:

- Law enforcement officers often perform roadside sobriety tests off the side of the road for safety reasons. Performing these test between the squad car and the stopped vehicle is unsafe (e.g., the stopped vehicle backs up, a passing car collides with the squad car).The in-car camera does not film the event.
- Ambulances are spread out (i.e., parked in diverse locations). They don't report in at start and stop of day like law enforcement. So the in-car camera recording card in the system gets full and no one changes it out.
- Bodycam does not point in the direction the officer is facing. Often, the bodycam video shows the floor, the ceiling, or points to an area off to one side of the officer. Officers stand at an angle to suspects to keep their gun out of reach, which exacerbates this problem.
- Bodycam at center of chest shows the back of officer's hands when the officer's gun is drawn.
- The camera is large and bulky
- The bodycam has a cord connecting it to the battery pack, which is typically attached to the officer's belt. This attachment cord gives criminals a handle to grab and manipulate the officer—which is dangerous.
- Bodycams come unattached when the officer is physically struggling with a subject.
- The range of light seen by the bodycam does not match that perceived by the officer. The video may show more information or less information.
- Battery life is a consideration for these mobile devices, as is storage space. A logical choice is to lower the resolution and coding bit-rate, to extend storage space.
- Bodycam footage raises a multitude of privacy concerns (e.g., peeping toms, criminals using the footage to plan future crimes, disgruntled ex-spouses).
- Bodycam footage does not show what the officer perceived with his other senses (e.g., a gun in the suspect's pocket during a pat-down).

- Department can afford the initial equipment purchase but not the ongoing expenses (e.g., repair, maintenance, inventory, training, indexing, audit trail, retention, redaction, and redistribution).
- Bodycams and in-car cameras produce an overwhelming amount of video. The logistics of how to retain the video and who handles the video are unhappy surprises for agencies that adopt these technologies.
- In-car camera quality is poor when headlights are off. Nighttime can be an issue for both bodycams and in-car cameras.
- Bodycam system and in-car system may not necessarily be purchased from the same vendor, which means the systems don't integrate. This causes major problems. It doubles data and the complexities of handling data. If remote viewing is available (i.e., in real time), then video from both systems likely will not play in the same viewer. This is very frustrating for practitioners.
- Good video without good audio is fairly useless. In-car camera and bodycam video is good, but audio provides context. This doesn't cover a full complaint, but good audio helps ascertain who is the aggressor and how practitioners communicated. Audio (good audio) is very important.
- Practitioners would appreciate more rugged bodycams and in-car cameras. For example, an in-car camera that can bounce in a trunk for a year without the hard drive failing.
- In-car camera wireless options are less useful in rural areas (i.e., wireless access may be rarely available).
- If timecodes differ between the bodycam and in-car video, the court says "what are you trying to hide" and this causes problems. Practitioners must also integrate these videos with all other data (e.g., officer name). Proprietary systems prevent this integration.
- Manual switches to turn on and off a bodycam result in user error. A practitioner in a life threatening situation will not remember to turn on the bodycam.

Information missing from the bodycam or in-car camera video can sometimes be inferred from the audio track, if it is present, because audio is recorded from every direction. However, audio is often not recorded by bodycams.

Overall, bodycams received very mixed reviews. Some departments believe bodycams are a necessary tool (e.g., to support practitioner testimony), while other departments described bodycams as an immature technology that was not ready for prime time.

APPENDIX B DESIRABLE ATTRIBUTES

First responders' opinions of image quality, video quality, and camera systems are impacted by their tasks and the environments in which they are performed. First responders multitask in a complex, time sensitive, and potentially hostile environment. They must continue operations no matter the weather, lighting conditions, or unavailability of infrastructure.

The National Public Safety Telecommunications Council (NPSTC) concluded that "A 'one size fits all' video program is unlikely to meet the needs of most EMS organizations." [29] The same can be said for all first responder camera system needs. We received conflicting feedback from first responders because different departments perform diverse tasks in unique environments.

This appendix describes camera characteristics and video technologies that most first responders we interviewed describe as desirable. The goal is to help the reader understand the first responder perspective and the types of solutions that are likely to have favorable impact. Unless otherwise specified, these characteristics were requested consistently throughout our interviews.

B.1 Efficient

The camera system needs to do its job quickly and efficiently, so the first responder can move quickly to the next task. Quality problems cause inefficiency in ways that are difficult to measure. Examples include:

- A specialized doctor is available for remote consultation but does not receive the patient's images or videos in time to provide feedback before time critical medical decisions must be made.
- Officers wait hours at a store for the arrival of an employee who can operate the store's video surveillance system.
- A video surveillance system allows an officer to view a shooting in real time but cannot zoom closely enough for the officer to read the suspect's license plate.
- Officers take 250 to 500 photos of a single room during felony investigations, to make sure they get all needed pictures.
- A detective watches nine hours of video to make sure no one entered or exited a building.
- Evidence photos are lost through user error (e.g., corrupted files, file shortcuts retained but actual files lost, records lost during system upgrade, surveillance video exports a proprietary codec but not the requested video).

The desire for efficiency is a common thread of first responder feedback on images, video, and camera systems.

Inefficiency seems to be the root cause underlying first responders' hesitation to use cameras in situations that require time critical responses. Consider a fire department responding to a fire in a typical two story family dwelling (2.5 floors and a basement). Streaming bodycam video to the incident commander is impractical. There may be 25 firefighters in the building, so logistics is a problem. These logistics include coordinating hardware on 25 firefighters, room in the firetruck for monitors, and figuring out the location of each imaging stream. Video won't help with the critical Z-axis problem (i.e., identifying which floor a firefighter is on). Connectivity and bandwidth would also need to be considered. Instead of live video streaming during an incident, firefighters report that they recorded video during the incident for training purposes (e.g., a bodycam on one firefighter, an in-car camera in the firetruck pointed at the building), or use a hand-held thermal imaging camera to find victims and hot spots.

B.2 Thrift

First responders must divide limited budgets among competing priorities. Camera systems will never rank among the top ten most critical expenditures. Most first responder agencies choose inexpensive camera systems that were designed for entertainment purposes. First responders tell us that many forensic photographers do not have access to a high quality camera. For financial reasons, they use a 10 year old camera or an iPhone®. Specialized camera solutions only seem to be deployed by a wide variety of agencies if the functionality is simple, well defined, and implemented within a single device. Examples are the hand-held license plate reader and the hand-held thermal imaging camera.

Naturally, the definition of "inexpensive" varies. Larger departments have enough funding to deploy complex camera infrastructures. For example, New York and Chicago integrate live video streams into their 911 call response centers and can play live video feeds from tens of thousands of cameras. However, this is rare today. First responders tell us that 80% of police departments in the U.S. have 25 people or less; and 70% of police departments in Colorado have 10 people or less. Many departments choose the same camera systems preferred by typical families for personal use (e.g., a phone, a compact on sale at the local camera store).

B.3 Automatic

Few first responders have the time and interest to obtain specialized training about camera technologies. Complicated interfaces and complex procedures are a roadblock to deploying video technologies.

Most first responders need cameras that yield optimal performance without manual intervention. For photography, first responders prefer smartphones, compact cameras, and hybrid point-and-shoot / digital single-lens reflex cameras (DSLRs). Most first responders who have DSLRs operate them in automatic mode roughly 80% of the time. First responders who have the training to use DSLRs in manual mode are typically on specialized taskforces.

The same issue applies to video surveillance (both real-time and recorded) and video records that must be exchanged between agencies. All law enforcement agencies consulted complained about the labor intensive process needed to export video from business and privately owned video surveillance systems.

B.4 Interoperable

All image and video storage, transmission, import, and export systems need to be interoperable. Officers want to be able to walk up to any video surveillance system, enter the store owner's password, and export video immediately. They want a consistent user experience (e.g., program interface, exported file format), so that the officer is only trained on one system. Hospitals want to be able to easily send video and images directly to any other medical center. Fully proprietary systems add inefficiency and risk lives. Examples include waiting hours for a civilian expert who can export surveillance video, and deciding on a medical treatment course without feedback from a critical specialist because the system set-up procedure is too slow.

Few agencies reported using live video surveillance, but the few that did reported issues obtaining access to live video feeds. For example, one city's toll facility, port, transportation department, law enforcement department, airport, and public school system may each be able to stream live video feeds from their own surveillance cameras to their department's computers. However, access to other departments' live video feeds may be prevented by multiple issues, such as proprietary systems, permission to access, spectrum utilization, governance structure, firewalls, or the lack of a common network. The typical solution was to commission a unique solution, like the National Capital Region Network (NCRnet) which connects 21 jurisdictions in Maryland, Northern Virginia and the District of Columbia (DC). See Contestabile [30] for more information on interoperability problems and solutions.

First responders want all camera systems to have standard interfaces that allow disparate systems to share video and image. This is not an objection to proprietary systems—first responders appreciate the extra functionality provided by well-designed proprietary systems. Rather, every camera system should include a standard mechanism that allows recorded video, recorded images, or live video streams to be exported and imported. That interface does not need to be fully flexible. For example, live video streams might be restricted to a small set of configurations (e.g., one image resolution, several bit-rates, pan / tilt / zoom prohibited).

B.5 Clear and Focused

"Clarity" is the word most commonly used by first responders to describe what they want from the images and videos themselves. Clarity is a gestalt evaluation of all aspects of visual quality, including camera optics, resolution, frame rate, compression artifacts, and display.

Typically, everything in the photo needs to be clearly in focus (e.g., as opposed to motion blur or soft edges). Between shooting a photo and using a photo, there is a delay and often a change in personnel. Thus, the photo needs to accommodate unknown needs—and potentially show details that the photographer thought unimportant.

Example problems include:

- When fingerprinting a decedent using photography, it can be difficult to bring all surfaces of the finger into focus.
- When photographing bones as evidence, sometimes the camera focuses on the backdrop (which has no value) and the bone is blurred.

- When a face is pulled from a store's surveillance video, the face is badly blurred (e.g., you would not be able to recognize your own grandmother).
- When a fire marshal takes photos during a building inspection, the camera focuses on irrelevant objects and blurs the relevant structural details.
- A witness in a moving car gets a picture of the suspect's moving car, but the license plate cannot be read due to motion blur. This scenario is particularly likely at night.

Sometimes it is desirable for a specific area of an image to be in focus while the remainder of the image is blurred. Current camera systems are appropriate for that situation.

B.6 Minimal Data Storage

Outside the law enforcement community, the conventional wisdom is that data storage costs are declining. Law enforcement officers disagree. Their digital storage costs are rising rapidly, due to the proliferation of video recordings and the desire to increase retention durations. Logistically, this cost includes surveillance video, photos of crime scenes (≈500 photos for a typical homicide or suicide), in-car camera footage, and bodycam footage. Unusable videos and images cannot be deleted ahead of the retention schedule. This would raise concerns that the department is trying to hide something.

Financial impact is an important factor when departments decide whether to deploy camera systems such as bodycams and in-car cameras. The main concern is not the initial purchase but rather the ongoing costs (e.g., repair, maintenance, inventory, training, indexing, audit trail, retention, redaction, and redistribution). Kampfe [31] provides an analysis of these financial issues.

Our interviews included departments that do not to deploy either bodycams or in-car cameras. During those interviews, financial impact was typically the first issue raised. One such law enforcement department had operated in-car cameras in the past that were later removed. Discontinuing the use of the in-car camera system did not hinder operations. The in-car camera system was slightly useful for DUI arrests (failed sobriety tests), but a good narrative was just as effective and could be corroborated with a breathalyzer.

Some departments interviewed used systems that make intelligent choices on what to record and when (e.g., squad car automatically activates a video recording when the light bar and siren are activated, or when the officer microphone is manually activated). Other departments discontinued in-car cameras when officers began wearing bodycams, since both systems recorded similar views. Both solutions minimize costs by reducing the amount of data stored.

Some first responders expressed interest in video analytics that will help practitioners cope with these vast quantities of video data by identifying what segments to watch. This is a difficult proposition today, because video surveillance systems are not designed for that task. Most video surveillance cameras record low quality video that challenges video analytics and facial recognition algorithms.

Data storage is an area where departments are impacted differently. Some departments told us that they have no problems with data storage costs. This is partially a result of the different policies that impact different jurisdictions within the U.S.

B.7 Smart Cameras

The first responders we interviewed rarely used systems with real-time video. Examples of real-time video use include UAV, unmanned ground vehicles (UGV), virtual boundary checks, ad hoc deployment of video streaming to allow remote experts to coordinate disaster response, tactical camera balls, or live video streaming to a 911 call center from cameras around the city. A few departments had decided not to deploy real-time video systems or owned an old system that was no longer operational (e.g., due to funding or changes in communication systems). The only widely deployed real-time video system was video surveillance used to monitor critical infrastructure or to provide security within and around the first responder facility itself.

Naturally there were a few exceptions, such as departments in very large cities (e.g., the top 50 largest cities in the U.S.). Some of these departments are using their own funds to develop complex video systems that address their unique needs. One example is 911 call centers that can monitor live video streams from cameras throughout the city. Another example is interconnection among multiple types of systems (e.g., 911 call center video, booking photos, license plates). Those departments are very interested in video analytics, for example to alert officers about suspicious events.

By contrast, first responders were very likely to express interest in smart cameras that do not have network access. Smart cameras make intelligent decisions and respond to their environment in complex ways. Most departments seem perfectly fine sending an officer to download information from a camera system as needed. Examples of camera technologies that first responders rely upon today are:

- Hand-held license plate readers
- Video surveillance systems that only record when motion is detected
- Wildlife cameras

Wildlife cameras are an inexpensive and fairly reliable mechanism to record the license plates of cars entering parking lots for wilderness trailheads. Their deployment dramatically increases the success rate at closing cases involving theft from cars at such trailheads. Those thefts mostly occur during daylight, so poor nighttime performance is not a problem.

Detectives appreciated video surveillance systems with high quality motion detection triggers. They can rely upon the system’s judgement that no one entered or left the building during the intervening time. Significantly less storage is needed to store the evidence, because long periods when nothing happens are omitted.

Strong interest was expressed in other smart cameras that would either function without connectivity or with minimal connectivity (e.g., only the ability to send alerts, tweets, or text messages). An example request is a light pole camera that would have two functions. The first is to keep a record of all license plates seen in the last 30 days, to aid in tracking a vehicle found to be of interest in an investigation long after the event occurs. The second is to allow officers to upload a list of faces, and the camera sends an alert when facial recognition identifies someone (e.g., a missing person, a person who by state law or court judgement is not allowed to be at this location).

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This report identifies camera technology gaps that impact first responders. These technology gaps were identified by interviewing first responders about images, video, and camera systems in general. This is a working document that is intended to foster discussion around research and product innovation.

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