

# Wearable Technologies for Law Enforcement

## Multifunctional Vest System Options

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### Key Findings

- Wearable technologies with the potential to provide significant benefit to officers in the field are available today at reasonable cost.
- More-sophisticated wearable technologies are also under development and are rapidly improving.
- Increased access to portable, reliable, uninterrupted power in the field that travels with the individual officer is currently feasible and will likely be more so in the future.
- Law enforcement access in the field to broadband data and communication is likely to improve rapidly.
- There are significant and challenging policy questions associated with technologies that are becoming available to law enforcement and are being adopted and expected by the public (examples include real-time access to personal data and use of unmanned aerial vehicles).
- Bulk and appearance matter and can be critical factors in the adoption of technology.
- Law enforcement agencies should think about how to engage with manufacturers now to specify their needs and provide input on the directions that research, development, and design should take in the near future to best accommodate their unique challenges and opportunities.

This report is part of an ongoing research program, led by the RAND Corporation and sponsored by the National Institute of Justice, to identify high-priority research needs of criminal justice agencies.

Its focus on wearable technologies for law enforcement resulted from the finding that approximately one-third of the top-tier technology needs identified in workshops with criminal justice practitioners and academics could be addressed by these technologies. To identify the wearable technologies and their potential applications described in this report, the authors used the knowledge derived from the workshops, as well as ongoing contacts and conversations with law enforcement practitioners, to set the context and performance requirements for the technologies and performed a detailed review of existing commercial wearable technologies and the relevant scientific, technical, and patent literature.

Wearable technologies provide an opportunity to address several problems faced by law enforcement officers in an increasingly complex and technologically challenging environment—for example, the size and weight of equipment they must carry, the proliferation of batteries for electronic devices, the need for mounting and docking systems for body-worn cameras (BWCs), and the need for comfort and flexibility while wearing body armor underneath uniforms. Law enforcement officers can take advantage of a rapidly evolving set of wearable technologies with increasing capabilities, functionality, performance, and availability in convenient formats. Many of these are

already in use by the wider community. In addition to ubiquitous fitness monitoring devices and various modes of wearable connectivity to electronic devices, researchers and industrial workers are using wearable augmented reality and virtual reality devices to increase productivity and enable new approaches to solving problems. Several different commercial and quasicommercial efforts are also currently under way to incorporate electrical functionality directly into garments, either by constructing the garment out of electrically conducting thread or by incorporating the capability to send an electrical signal from one part of the garment to another.

This report reviews the current and projected status of wearable technologies with potential for use by law enforcement and describes three conceptual integrated vest systems that incorporate these technologies. These three systems are meant to represent what could conceivably be implemented very quickly to enhance existing capabilities, what might be done in the near term to provide additional capabilities, and what might be considered to take advantage of technologies that are still in development and could provide even greater capabilities.

As with implementation of any new technology, such barriers as cost, inertia, and uncertainty associated with benefits are likely to arise. However, experience with law enforcement's uptake of such technologies as BWCs, smartphones, and license plate readers suggests that these barriers can be overcome. It was beyond the scope of this report to develop and analyze specific scenarios for how to overcome these barriers. Moreover, the authors recognize that many law enforcement agencies have made investments in current BWCs. The purpose of the basic system described in this report is not to propose that these agencies scrap their existing systems, but rather to demonstrate that a lighter, more flexible system is feasible today, with technologies like flexible batteries and wireless charging that could be incorporated as an add-on to existing systems.

The three systems discussed in this report are

- a basic system composed of commercial or near-commercial technologies that moves equipment from

belt to vest and provides a convenient platform for BWCs, microphones, and wireless charging

- an enhanced system that incorporates wearable technologies with functionality for officer health and safety and situational awareness
- an advanced system that incorporates all of the above, integrated into an electrically conducting garment with capability to harvest and store energy from officer motion, together with increased surveillance and processing capabilities.

After describing and analyzing these, we draw some conclusions regarding their potential use by law enforcement.

## Basic System

The basic system makes use of off-the-shelf commercial or near-commercial technologies from the emerging smart clothing and e-textiles market and builds on advances in the use of electronics in entertainment and costume design, as well as the availability of miniaturized electronic components and batteries. It provides a flexible vest or shirt as a convenient platform for BWCs, microphones, and wireless charging, including light, easily embedded batteries with connectivity to the BWC and microphone. The charging technology makes use of midrange wireless transmission technology that is currently under development and in the early stages of commercial use. It would be worn over body armor and would be flexible enough so as not to be a hindrance to officer mobility.

The BWC of the basic system consists of two components: (1) a miniature chip module containing a charge-coupled device (CCD), a lens, and necessary wiring and (2) a single-chip computer processing device to collect, compress, and store real-time video for transmission as desired—e.g., to a cell phone or Bluetooth-connected device. The microphone is a lightweight, fingertip-sized device that has already been integrated into clothing; several of these can be incorporated into the basic system without noticeably increasing weight or power requirements. The basic system would incorporate small, flexible

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batteries integrated into the garment—e.g., along the rib cage. Credit-card sized batteries are now widely available and are becoming more flexible and tailored to the needs of the purchaser, partially driven by desire to serve the emerging Internet of Things market. Wireless charging components like those demonstrated at consumer electronics shows could be integrated into the basic system and linked to charging systems located in the officer's vehicle or preset at defined locations with appropriate charging ranges.

### Enhanced System

The enhanced system contains two features not found in the basic system: connectivity to a WiFi mesh network and sensors that can provide indications of officer health and safety. The WiFi mesh network would make use of evolving digital information system capabilities to provide greatly increased situational awareness for law enforcement officers in the field, especially those on foot. It could use a centralized control node located in a police station or other facility and base station nodes in appropriate fixed locations in the field. These could be established by law enforcement or other agencies or could use existing WiFi nodes, such as those established by commercial Internet providers. Officer health and safety components of the enhanced system include biometric monitoring devices and the possibility of a sensor that could detect a broken link in a conducting layer caused by a blunt force impact or a projectile and send a signal to a linked radio or other receiver.

### Advanced System

The advanced system incorporates features that are in the development stage or that are not currently widely available from commercial vendors. These include integration of biometric monitoring into the garment that makes up the vest, onboard processing, capacity for recharging batteries by harvesting energy from officer motion or the environment, and increased situational awareness provided by advanced sensing capabilities. Integration of biometric monitoring would rely on developmental capabilities to build electrical conduction directly into the garment, while onboard processing could be accomplished with the integration of existing miniaturized computing systems. Batteries would be recharged by harvesting energy from the officer's motion or from ambient environmental conditions (e.g., temperature gradients) using one or more of a variety of developmental and early commercial systems. Sensing capabilities unique to the advanced system would include real-time video analysis—e.g., for facial recognition—and digital atmosphere awareness—e.g., identification and processing of ambient cell phone signals.

### Conclusions

We conclude from our review and analysis that wearable technologies with the potential to provide significant benefit to officers in the field are available today at reasonable cost and that more sophisticated wearable technologies, such as those envisioned for the enhanced and advanced systems, are under development and are rapidly improving. Our analysis also yielded several findings with potential ramifications for the law enforcement community:

There is no reason for law enforcement to wait for wearable technologies that can provide improvements in the bulk, weight, and flexibility of carried equipment—major incremental improvements are available today using currently available commercial technology.

- The burden of officer-mounted audio and video recording devices can be greatly reduced.
- Increased access to portable, reliable, uninterrupted power in the field that travels with the individual officer is currently feasible and will likely be more so in the future.
- Law enforcement access in the field to broadband data and communication is likely to improve rapidly.
- Wearable health and safety technology is improving rapidly and represents a challenge and opportunity for law enforcement.
- There are significant and challenging policy questions associated with technologies that are becoming available to law enforcement and are being adopted and expected by the public (examples include real-time access to personal data and use of unmanned aerial vehicles).
- Bulk and appearance matter and can be critical factors in the adoption of technology by law enforcement.

Perhaps the single most important conclusion of this report is that there is no reason for law enforcement to wait for wearable technologies that can provide improvements in the bulk, weight, and flexibility of carried equipment—major incremental improvements are available today using currently available commercial technology. However, law enforcement agencies need to think about how to engage with manufacturers now to specify their needs and provide input on the directions that research, development, and design should take in the near future to best accommodate their unique challenges and opportunities. By the same token, manufacturers should reach

out to law enforcement agencies and practitioners as the technologies described in this report continue to develop, in order to secure their positions in a large and rapidly evolving market.

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## 1. INTRODUCTION

This report is part of an ongoing research program, led by the RAND Corporation and sponsored by the National Institute of Justice, with the objective of identifying high-priority research needs to provide options to criminal justice agencies (including law enforcement, courts, and corrections) that can contribute to effective and efficient performance of their missions. Its focus on wearable technologies for law enforcement is based on review and analysis of high-priority technology needs previously identified in workshops with diverse groups of law enforcement practitioners and academics, as well as other members of the criminal justice community and relevant technology developers (see, for example, Hollywood, Boon, et al., 2015; Hollywood, Woods, et al., 2015; Jackson et al., 2015; Silbergliet et al., 2015). The implementation of wearable electromagnetic devices for sensing, tracking, video recording, or biomedical monitoring would address approximately one-third of the top-tier technology needs identified in these workshops.

To identify the wearable technologies and their potential applications described in this report, the authors used the knowledge derived from the workshops referenced above, as well as ongoing contacts and conversations with law enforcement practitioners, to set the context and performance requirements for the technologies. We then performed a detailed review of existing commercial wearable technologies and the relevant scientific, technical, and patent literature to identify existing or emerging wearable technologies with the potential

to meet that context and those performance requirements. This resulted in the identification of six classes of technologies that we incorporated into an integrated system that could be worn by a law enforcement officer. In the balance of this chapter, we explain how and why such an integrated system could result in benefit for law enforcement.

## 1.1. Law Enforcement Needs and Wearable Technologies

Law enforcement officers are required to perform difficult, and increasingly complex, duties under challenging and unpredictable circumstances. As technology has changed and evolved, law enforcement has strived to adopt new technologies with the objectives of improving officer safety, increasing workflow efficiency, supporting uninterrupted communications in the field, and increasing officer accountability. In addition, as society at large has adopted new technologies (e.g., increasingly ubiquitous smartphones), law enforcement has adopted these technologies either formally, through department-issued property, or informally, as officers choose to adopt and carry new technological tools on their own.

However, one often overlooked consequence of the potential adoption of these various new technologies is the physical and logistical burden this may place on the officer. Put simply, there are only so many items a person can effectively carry. These constraints are even more important for law enforcement officers, who are in physically demanding jobs that may require rapid and efficient movement at any time.

Advances in technology have made it possible for officers to be connected to critical centralized systems, such as dispatch centers; to one another; and to an ever-increasing range of potentially valuable data and information through handheld devices, Bluetooth connections, smartphones, tablets, and other tools. The desire for increased officer accountability, together with changes in technology, has led to the rapid adoption of BWCs, recording devices, and associated tools. Technological advances have also affected functions beyond communications and information—for example, many law enforcement officers now carry “less-lethal” weapons, such as conducting electrical weapons (e.g., TASERs). Finally, in addition to department-issued equipment, officers, like ordinary citizens, have access to and routinely carry a variety of commercially available technologies that not only help them do their jobs but also help them remain connected to their families and engaged in society.

However, while improvements in technology have increased the number and variety of technologically advanced items that a typical officer may be issued or may wish to carry into the field, there has not been a corresponding decrease in the amount of existing, standard law enforcement equipment. Officers almost universally carry bulky items that include a departmental sidearm, handcuffs, a portable land mobile radio, a flashlight, and other items. Similarly, officers in many larger departments now regularly wear bulky and restrictive ballistic vests under their patrol uniforms, regardless of assignment.

At the same time that departments wish for their officers to carry additional equipment into the field and to routinely wear ballistic protection, departments are also increasingly wary of adopting an overly militaristic appearance, which may cause concern among the public. Unfortunately, the mere presence of multiple pieces of equipment and the clothing and devices commonly adopted by law enforcement to carry such equipment—including external vests and multipocket battle dress uniform-style clothing—may create an appearance that is similar to military personnel, regardless of the nature of the equipment that is actually being carried.

These changes suggest a series of questions:

- What tools and technologies should officers carry into the field to maximize their effectiveness and efficiency while meeting other common goals, such as safety and accountability?
- What is the best way to manage and minimize the physical burden placed on officers by this range of equipment?
- How can the power and connectivity demands of diverse equipment be managed most efficiently and effectively?

Wearable technologies may provide one potential solution. Wearable technologies are undergoing a rapid evolution, with an increasing range of capabilities, functionality, performance, and availability in convenient formats. Fitness monitoring devices come in a wide array of sizes and styles (Harrop, Raghu Das, and Holland, 2015; Lamkin, 2016). We can now control, read data from, or listen to our electronic devices through watches, bracelets, and glasses or even have this capability integrated into gloves, hats, jackets, and vests (Harrop, Raghu Das, and Holland, 2015). Researchers and industrial workers are using wearable augmented reality (AR) and virtual reality (VR) devices to increase productivity and enable new approaches to solving problems (Kenney, 2015). Athletes and sports teams at all levels, from unaffiliated individuals to professional leagues, are using a variety of wearable devices to monitor and evaluate

performance and endurance, both to improve training methods and to develop game strategies and tactics (Platoni, 2016).

Several different commercial and quasicommercial efforts currently under way allow the incorporation of electronic functionality into garments, either by making the garment from conducting thread or by building in the capability to conduct electricity from one part of the garment to another. These garments can, for example, continuously monitor body functions and transmit the data to a remote source, incorporate biometric sensors, provide connection to and control of electronic devices, and allow incorporation of batteries or wireless charging systems to extend the operational lifetime of electronics when a local source of electricity is unavailable (Tyler, 2016).

These advances in wearable technologies provide the opportunity to address several significant problems facing law enforcement officers:

- the size and weight of necessary equipment, much of which is carried on the belt
- the presence of multiple devices with batteries that need to be recharged
- the need for mounting and docking systems for electronic devices, such as BWCs
- the need for comfort and flexibility while wearing body armor underneath uniforms
- the need for ongoing/rapid refresh Global Positioning System (GPS) monitoring and geolocating for officer safety and situational awareness
- given the inherent physical and mental stresses of law enforcement work, the potential for improved officer health and safety through periodic or ongoing monitoring of vital statistics, such as heart rate
- the desire to avoid a militaristic appearance that may complicate community policing efforts.

In this report, we review the current and projected status of wearable technology with potential for use by law enforcement and describe three conceptual integrated vest systems (basic, enhanced, and advanced) that make use of such technology to address the problems noted above. These three systems are meant to represent what could conceivably be implemented very quickly to enhance existing capabilities, what might be done in the near term to provide additional capabilities, and what might be considered to take advantage of technologies that are still in development and could provide even greater capabilities. The basic system is composed of commercial or near-commercial technologies that move equipment from belt

to vest and provide a convenient platform for BWCs, microphones, and wireless charging. An enhanced system incorporates wearable technology with functionality for officer health and safety and situational awareness. An advanced system incorporates all of the above, integrated into an electrically conducting garment with the capability to harvest and store energy from officer motion, together with increased surveillance and processing capabilities.

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## 2. STATE OF TECHNOLOGY

This chapter reviews the current and projected status of wearable and other relevant technologies for the integrated vest systems envisioned in this report. The key components identified from the high-priority research needs as being of greatest interest and potential utility to law enforcement fall into six categories:

- BWC and microphone
- power source
- wireless charging
- data and connectivity
- vest material
- sensors.

As illustrated in Table 2.1, there are important differences between the technologies and components considered for the different systems. The basic system uses off-the-shelf components within an integrated design intended to be achievable at low cost and within a short timeline. While the other systems also use off-the-shelf components in many cases, they have different technical and implementation challenges. The enhanced system requires decisions concerning which biometrics to measure, how often to measure them, and how to access and use the data, as well as decisions associated with how to access or create a mesh network and protocols for its use. Some components for the advanced system will not be off the shelf but will instead require technical advances, and this system's implementation would likely involve issues associated with surveillance and privacy. While the focus of this report is on technology and how it may be used in an integrated vest system to address the problems described in the previous chapter, we recognize that adoption of new technologies by law enforcement is not a simple matter. Many problems will have to be faced by agencies that adopt integrated vest systems such as the ones we describe, including officer privacy, citizen privacy, data security, addi-

**Table 2.1. Components of Integrated Vest Systems**

Component	Basic	Enhanced	Advanced
<b>BWC and microphone</b>	Off-the-shelf components	Off-the-shelf components	Advanced camera and microphone system
<b>Power source</b>	Flexible lithium-ion (Li-ion) batteries	Flexible Li-ion batteries	Flexible batteries with energy harvesting
<b>Wireless charging</b>	Off-the-shelf components	Off-the-shelf components	Integration into garment
<b>Data and connectivity</b>	Existing systems	Mesh network	Mesh network with processing capability
<b>Vest material</b>	Off the shelf	Off the shelf	Fabric provides electrical connectivity
<b>Sensors</b>	None	Biometric and injury-monitoring devices	External environment with analytics and processing

tional personnel and skills required to manage and maintain the systems, cost, and cultural barriers to change. Discussion and analysis of these very real problems are, however, beyond the scope of this report.

We also recognize the fact that many law enforcement agencies have already invested in BWCs, and we are not suggesting that these agencies should abandon their current systems. The basic system we describe in Chapter 3 is not intended as a replacement for these systems but rather to demonstrate that technology exists that could provide such benefits as reduced weight and increased flexibility. Components of the basic system, such as flexible batteries and wireless charging, could, in fact, be incorporated together with existing systems.

## 2.1. Body-Worn Camera and Microphone

BWCs have become an important technology for law enforcement officers, enabling continuous incident recording and, in some cases, facial recognition. Today's commercial BWCs come in several varieties, but all require some sort of mount or attachment to the officer's apparel. Table A.1 in the appendix provides relevant information about commercial BWCs.

There is a substantial literature on BWCs. Most notably, the Police Executive Research Forum published a report (Miller, Toliver, and Police Executive Research Forum, 2014) based on interviews with more than 40 police executives with experience with BWCs and reviewed more than 20 BWC policies submitted by police agencies. The publication examines the perceived benefits of and challenges with BWCs and provides policy recommendations that reflect promising practices and

lessons learned. A more academic examination into the same topic area was published in the same year (White, 2014).

Building on the fact that there has been a substantial increase in criminal justice use, public and media attention, and commercial offerings of BWCs, the National Institute of Justice has conducted several market surveys in recent years about the use of BWCs by criminal justice agencies (NIJ, 2011, 2012, 2014; Hung, Babin, and Coberly, 2016).

Academic research in the area has also been growing in recent years, focusing, for example, on the impact of BWCs on response-to-resistance incidents and external complaints (see, e.g., Jennings, Lynch, and Fridell, 2015; Ariel, Farrar, and Sutherland, 2015). Cameras seem to reduce both of these substantially and also improve evidence collection and report writing. Jennings, Fridell, and Lynch (2014) also investigated officer perceptions of the use of BWCs in law enforcement. Their main finding was that police officers were open to and supportive of the use of BWCs, believing that BWCs could improve the behavior of both citizens and officers themselves. Officers also agreed that BWCs were unlikely to impact their willingness to respond.

The BWC in the basic system is assembled from components that can be integrated into the vest to reduce weight and increase flexibility. Key components include a charge-coupled device (CCD), a lens, and a device for processing and storing relevant data. Several commercial alternatives are available for the CCD and lens<sup>1</sup> and for processing.<sup>2</sup> Miniature microphones that could be incorporated into the vest to allow for sound

<sup>1</sup> For example, see Adafruit products available from Arduino at Adafruit, undated(a).

<sup>2</sup> For example, mini-computers are available from the Raspberry Pi Foundation (undated[a]).

identification, recording, and triangulation are also commercially available.<sup>3</sup> This combination of components could be set up for use in any of the modes that officers currently use—e.g., with continuous buffers and with programmed or manual on and off functions. Audio and video could be synchronized for evidentiary value.

## 2.2. Power Source

Key needs for law enforcement in relation to power include reliability, long duration, the ability to supply multiple devices, and, if carried by the officer, light weight and minimal bulk. All of the vest systems envisioned in this report will rely on rechargeable batteries as their power source, although the advanced system also takes advantage of energy harvesting. The choice of battery depends on a range of factors, such as cost, energy density, service life, size, flexibility, thinness, and weight. The cost, weight, and energy density constraints of this application make the type of Li-ion batteries used in most mobile devices the appropriate choice for the vest system.<sup>4</sup>

While Li-ion batteries are commercially mature, the technology continues to improve. Objectives include extending life span, improving safety,<sup>5</sup> increasing energy density, reducing size and weight, and increasing flexibility. Recent commercial and near-commercial products are highlighted, for example, in Langridge and Edwards (2017). Recent developments in flexible batteries relevant to the vest systems include screenprinted Zn-polymer batteries (Imprint Energy, undated) and a flexible Li-ceramic battery that can be cut and retains its functionality (ProLogium, 2015).

The U.S. Army has developed a vest system called Soldier-Wearable Integrated Power Equipment System (SWIPES) that incorporates batteries for charging mobile devices. SWIPES is likely to be similar in terms of its power requirements to the advanced system and is hence a useful reference (see U.S. Army Communications-Electronics Research, Development and Engineering Center, 2015, for more information). Table A.2 in the appendix provides information about the types of batteries used in SWIPES.

The advanced vest system incorporates energy harvesting to keep batteries charged. Projections for the emerging needs

of wireless sensors and network applications suggest combining energy harvesting with thin batteries (see, e.g., He, 2016), a combination that would be appropriate for the advanced system.

Specific energy-harvesting options include capturing the kinetic energy from officer motion and thermal power generation from body heat or environmental sources. In either case, the advanced vest system could route harvested power directly to devices needing charging through the electrically conducting material envisioned for this version of the vest. There are many relevant research and development efforts on such energy-harvesting technologies, including, for example, on nanotechnology-enabled energy harvesting and storage (Assist, 2012; North Carolina State University, 2016) and on converting mechanical energy from human foot traffic into electrical energy (Sensitile Systems, undated; Instep Nanopower, 2016).

## 2.3. Wireless Charging

Contact wireless protocols are already in use and popular in electronics. They allow for easy charging by simply placing the device's coil on a charging plate. In the vest systems, the lower back coils could be integrated and work in concert with a power transmission plate that could be placed somewhere in the officer's patrol car, allowing electronics to recharge any time an officer is seated in the car. The benefits from wireless charging are significant:

- no wear and tear to connectors
- no connector port providing entry for contaminants
- no small connectors to attach
- capability to charge devices continuously by building power transmitters into common objects.

The current shortcomings of these devices relate to inefficient energy use, short charging distances, the need for proper alignment, and local heating. Additionally, as with any new technology involving electromagnetic energy transmission, there may be a perceived threat of health problems. For example, although cellular phones are ubiquitous in the United States today and are routinely carried by law enforcement and the public, members of both groups have expressed concern in the past regarding the potential health impacts of regularly carrying and using such devices. Similarly, wireless charging devices may lead to challenges in their adoption in the vest systems. As with cellular devices, it is likely that some combination of data demonstrating safety, widespread adoption by the

<sup>3</sup> See, for example, iComX (Interactive Wear, 2017b).

<sup>4</sup> For details of the characteristics and operation of Li-ion batteries, see Reddy, Chapter 26, 2011.

<sup>5</sup> For example, safety can be improved through the use of nonflammable solid electrolytes with high capacity (Walter, 2017a and 2017b).

public for other purposes (e.g., performance sports apparel), and increased familiarity could allay such fears.

Wireless charging in small devices currently uses inductive or resonant magnetic coupling. The main standards in the area are Qi (short-range magnetic induction charging) and Alliance for Wireless Power (A4WP) (longer-range magnetic resonance charging):

- Qi is the existing interface standard developed by the Wireless Power Consortium for inductive electrical power transfer. Qi-standard technology is currently used by most leading mobile device manufacturers (e.g., BlackBerry, Samsung, HTC, and Nokia) and is widely in use.
- A4WP is an independently operated organization dedicated to building a global wireless charging ecosystem for consumer electronic devices. It was formed when Rezence (an interface standard initially developed by the A4WP) and Power Matters Alliance merged in 2015. A4WP has been adopted by such companies as Intel, Qualcomm, and WiTricity.

The resonant magnetic coupling of the A4WP standard appears to be most appropriate for the vest systems because of the flexibility it allows in placement of devices. Three companies currently offer relevant device options, each using a different patented technology: Energous, Ossia, and WiTricity (Mims, 2015; Ossia, 2013; WiTricity, 2016).

## 2.4. Data and Connectivity

Communications (e.g., radio and phone) and data collection, transmission, and storage (e.g., BWC video), as well as capability for data processing, are critical functions for law enforcement; accordingly, they are envisioned as critical functions for all of the vest systems. For reference, Table A.3 in the appendix provides further information about technologies relevant to such functions, which are described briefly in this section.

**Mesh networks.** In the enhanced and advanced systems, WiFi mesh networks that can connect moving nodes could be used to provide officers on foot with information about their fellow officers (i.e., location) and stream video and audio from the vest-mounted camera to nearby officers and police vehicles. This would offer a means to provide data to accelerate responsiveness, improve decisionmaking, and increase situational awareness. The mesh network hardware for the vest is already widely available, including relatively inexpensive transceivers, chipsets, and other components specifically designed for use in

a mesh network. The network itself could build on home WiFi networks that are already in use for commercial applications, or it could use the portion of the spectrum, 5.92 GHz, specified by the Federal Communications Commission (FCC) for vehicle-to-vehicle and vehicle-to-pedestrian safety systems.

**Bluetooth** allows a device to use radio waves to communicate with other devices over short distances without any wires. Law enforcement officers are already using the technology in wireless headsets and microphones. It is expected that Bluetooth will also soon be used to support sensors for biometrics and to automate camera recording with certain triggers (Basich, 2016). Furthermore, Bluetooth Low Energy technology allows devices to run for long periods of time on standard coin-cell batteries. We assume that other widely available communications technologies, such as open radio, cellular, satellite, or conventional WiFi, will be accessible by any of the vest systems.

**Nonwireless connectivity.** In addition to certain wireless protocols, it is likely that the integrated vest systems will require several methods of data connectivity to ensure constant information flow and wide-enough bandwidth for any situation. Fortunately, most of the relevant technology is mature enough that it can simply be purchased and embedded into the vest systems.

**Unification, processing, and storage.** The vest systems contain several components that send and receive information and some that also need quick processing and storage on site. System unification is the nervous system of the vest: It takes in all the information, processes it, makes decisions, and stores everything for future use or transmits it for real-time monitoring. Unification is similar to a modern computer system and will require an onboard computer and processing system (e.g., Raspberry Pi) as well as a hard drive (potentially a solid-state hard drive for light weight and fast storage).

**Control and display devices and platforms** would be used as data terminals and perhaps also as displays for other officers' cameras or for relevant video from fixed closed-circuit television cameras commonly used by law enforcement for traffic flow monitoring, security, and other purposes. The product alternatives here are plentiful: Data can be read and controlled on laptops, tablets, or mobile phones or even through accessories, such as watches, glasses, or head-up displays. Note that different systems are required to integrate control and display devices to the communications platforms.

**Integrated hearing protection** has become a major trend in law enforcement communications (Basich, 2016). In addition to over-ear muffs, there are several other options that

## The basic integrated vest or shirt system will provide information collection, energy storage, and charging technology.

incorporate hearing protection and noise cancellation technology into communications equipment. These include in-ear headsets with algorithms to protect hearing from loud noises while simultaneously giving the direction of those noises and making human voices loud enough to be understood.

**Facial recognition and emotion detection systems.** It might be technically feasible to integrate facial recognition as part of the advanced system (Whittaker, 2016; Weise, 2016; Visual Semantics, 2016). The system could be coupled to databases of warrants, revoked driver's licenses, personal protective orders, or other readily available information of use to law enforcement. Counting people is another, simpler application that would be feasible. Independent of the technical ability to perform facial recognition, there are important legal and policy issues related to privacy and appropriate use, which are outside the scope of this report but should be carefully weighed in any application.

The advanced system could also benefit from display devices with built-in capabilities to take advantage of AR (see, e.g., Six15 Technologies, undated, for smart glass products). AR applications for law enforcement could include nonobstructive overlays of critical information, such as information about individuals (driver's license and registration, criminal background check, etc.) or locations (addresses or location of call for service, prior history of calls for service at location).

**Data management.** In addition to its real-time use, sensor data from the vest systems will likely need to be stored and analyzed at a central location. Several relevant software solutions exist to fulfill the basic needs of most departments. At the same time, an increasing number of new solutions and platforms are targeted to organizations that wish to collect sensor data from specific internally managed wearable devices, control approved applications, or otherwise improve situational connectivity. A recent example of such a firm is Augmate, which focuses on

enterprise information technology solutions to help securely deploy and manage smart glasses (see, e.g., Augmate, 2017; DHS, 2016).

**Functional wearable technology software.** New software platforms offer novel ways of benefiting from the increasing connectivity of devices, as well as from data from wearables. Some of the related products are applications specifically designed around public safety and security. For example, Canadian CommandWear Systems has developed a software platform that integrates location and biometric data from devices to provide personnel tracking, two-way text communication, and video sharing to facilitate planning, mission execution, and review of operations among teams (CommandWear, 2016). The start-up HAAS Alert has a similar system for connecting people and vehicles in cities, with the goal of streamlining their disaster and emergency notification processes (DHS, 2016).

### 2.5. Vest Material

Both commercial and quasicommercial efforts are under way that allow electronic functionality to be incorporated into garments, such as the vest systems. These include using electrically conductive yarns and threads as well as conductive polymers. Garments with electronic functionality—either the capability to conduct electricity from one part to another or a fully conductive garment or thread—could:

1. *Transmit data* to an electronic device in another part of the garment or to a remote source, thus reducing the burden of data cables and connections.
2. *Monitor body functions* directly, or incorporate biometric or environmental sensors.
3. *Enable power-related solutions*, especially through eliminating the need for power cables and, hence, reducing the weight of the system, as well as through the incorporation of batteries or wireless charging solutions to extend the system's operational lifetime when a local source of electricity is unavailable.

There have been substantial developments in research and commercial efforts in recent years, especially with respect to functions 1 and 2 above. More applications are moving beyond the laboratory, with significant end-user applications beginning to appear for the medical, health and fitness, military and security, fashion, and sports markets (Tyler, 2016).

Because of these developments, even the basic vest system could viably incorporate a small-scale e-textile-based con-

nection network that connects some of the officer's electronic equipment and components. In terms of power (item 3 on the list above), some small-scale wireless charging solutions could be considered for embedding in the textile. The advanced version of the vest could also incorporate sensors into a network together with more advanced power solutions. Tables A.4 and A.5 in the appendix list relevant smart textile companies and related products with potential application to the vest systems.

## 2.6. Sensors

Advances in nanotechnology, organic electronics, and conducting polymers are rapidly creating solutions for monitoring biometric data, such as heart rate, or environmental factors, such as temperature, producing real-time feedback—e.g., in the form of electrical stimuli. Three distinct “generations” of textile wearable technologies can be identified (see, e.g., Cientifica Research, 2016):

1. products in which a sensor is attached to apparel
2. products that embed the sensor in the garment
3. products where the garment is the sensor.

Major areas of growth of such technologies include medical applications for patient monitoring, sports, and well-being. Athletes and sports teams in particular already rely on a range of biometric sensors, especially within generations 1 and 2, to monitor and evaluate performance and endurance (Platoni, 2016). Similar technologies could be utilized by police officers in an integrated vest system. The biometric sensors that would provide information about vital statistics include, for example, the following:

- heart-rate sensor (see, e.g., Stables, 2016)
- blood pressure measurement (Indiegogo, 2016; Medical Design and Outsourcing, 2016)
- oxygenation (Vandrico, 2016)
- drug and alcohol monitors (there are several commercial miniature alcohol sensors that “sniff” air, as well as new breathalyzers that can also detect marijuana, cocaine, or heroin; see Koebler, 2013).

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## 3. BASIC SYSTEM

The idea of incorporating electronics into clothing has many names, including smart textiles, integrated components, and e-clothing. There are several reasons for integrating electron-

ics into clothing. The first is utility—e.g., developing heated jackets for construction workers. A second is for athletic training and competitions, in which real-time lightweight body sensors can provide valuable information. The third is for entertainment—specifically, costume design. The overall market for e-clothing has grown substantially in the last ten years because of the miniaturization of electronics and the emergence of widespread amateur circuit design. Useful e-clothing pieces are still finding their way gradually into the market, as their producers try to understand the relative appeal to customers of embedded electronic devices. Integrated components for entertainment, however, are already a very large market that is driving much of the component innovation. Costume design or costume play (also known as cosplay) has driven this market to new levels, allowing individuals to create low-cost costumes with embedded or integrated electronics. This new demand has also driven down the electronic component price because of new marketplaces and higher demand signals.<sup>6</sup>

### 3.1. Overview of the System

The basic system provides incremental improvements to officers' current equipment. It is comprised of commercial or near-commercial technologies, with the objective of moving equipment from belt to vest and providing a convenient platform for BWCs, microphones, and wireless charging. This technology may require innovation to integrate into the vest system properly, but the basic technology is off the shelf. This basic integrated vest or shirt system will provide information collection, energy storage, and charging technology. The information collection technology includes an integrated BWC and an integrated microphone. The energy storage consists of light, easily embedded batteries located in the vest or shirt with connectivity to the BWC and microphone. The charging technology makes use of the midrange wireless transmission technology that is currently under development and in early stages of commercial use.

The vest or shirt would be worn over the current body armor that police wear and would be lightweight enough to not be a hindrance to the officer. The vest would be a new component for the officer to wear; the shirt possibility would be in place of the current modular shirts that officers wear. Currently, officers wear shirts designed to hold, carry, and contain several items. This basic system would place the electronic components

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<sup>6</sup> For example, see the large variety of components available for under \$20 at Adafruit, undated(b).

in a similar fashion. The following sections discuss each of the components and how they would be integrated into the basic vest system.

### 3.2. Body-Worn Camera Components

BWCs are becoming a standard piece of law enforcement equipment, with a variety of manufacturers and styles but with common uses and problems. The most common usage is for simple recording of events for future analysis. Law enforcement agencies are increasingly implementing such usage in response to community pressure for transparency, enhanced by high-profile incidents involving police shootings (Pelt, 2015). Taking the components of the camera and embedding them into a vest allows for a lower profile and an integrated power source. The lower profile and integrated components will prevent the camera from moving around or sliding into nonoptimal positions for data collection.

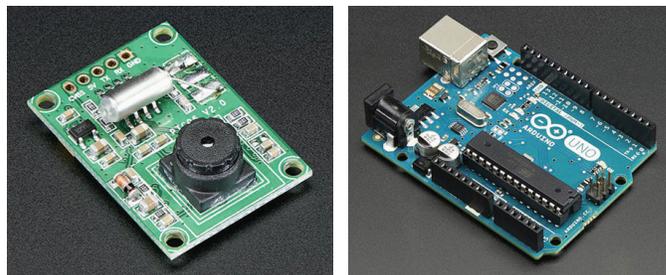
The BWC components, like many electronic components, have been successfully miniaturized to the point at which embedding them in the vest has become feasible. The components of a camera, including the CCD and lens, are small enough to sew into textiles. Figure 3.1 shows two components that make up the BWC. On the left is a camera module with all needed lenses. This chip module includes a CCD sensor, lens, and necessary internal wiring. It is 25 mm by 20 mm and weighs just 3 grams. On the right is one example of an off-the-shelf processing device. This device is easily wired to the camera module and will handle all of the required processing to transmit an image. It is 69 mm by 53 mm and weighs 25 grams. Similar components, as well as additional components to enhance such properties as frame size and sensitivity, are available from multiple vendors.<sup>7</sup>

The benefits of embedding the BWC in the vest, rather than wearing it on the chest or helmet, include the elimination of the mounting or attachment hardware and the ability to wire the camera directly to embedded batteries, thus eliminating the need for separate battery components to power the camera and any other electronic component.

The processing device shown in Figure 3.1 is a single-chip computer that can handle the entire load of a BWC and allow for intelligent collection of video. Such single-chip computers collect, compress, and store real-time video as it is received. This video can then be stored on board or transmitted if there

<sup>7</sup> See, for example, Arduino, 2017; Raspberry Pi Foundation, undated(b); Arrow, 2017; and AliExpress, undated.

**Figure 3.1. Body-Worn Camera Components**



SOURCES: Promotional images, Adafruit, undated(c) and undated(a).

RAND RR2012-3.1

is a proper channel, such as a cell phone or Bluetooth connection.<sup>8</sup>

### 3.3. Microphone Components

Microphones are not currently as commonly employed by officers in the field as BWCs are. While officers carry several different microphones—e.g., in their cell phones, radios, BWCs, and other devices—these devices typically are not actively collecting sound and storing the events or used to inform the officer's situational awareness. Microphones and their accompanying software could allow for sound detection and triangulation, source identification, and audio monitoring of events involving the officer. As with other technology considered in this report, there are a variety of policy issues under consideration by law enforcement organizations nationwide regarding the optimal and appropriate use of technologies, such as microphones and BWCs, that can be selectively turned on and off. For example, issues include whether officers should be allowed to turn off devices themselves or whether devices should always be activated and recording while an officer is on duty. As in other cases, these issues, while important, are policy issues beyond the scope of this report, but a variety of technical options currently exist that are compatible with a wide range of departmental preferences and policies.

Hearing one's environment gives a tactical advantage over just seeing and provides more information for better decision-making. We suggest placing three outward-facing microphones on the vest and processing the input data. This will allow audible mapping of the officer's environment. For example, in the case of a distant gunshot, the officer may have trouble determining direction. With three strategically located micro-

<sup>8</sup> The amount and length of time that BWC video should be stored is a current issue confronting law enforcement agencies that is outside the scope of this report.

phones, these sounds can be processed to potentially identify distance and direction. While the distance over which this triangulation is effective may be limited for a single officer, linking microphones on different officers—for example, using the mesh network discussed for the enhanced system in the next chapter—could solve this problem. Collection of audio as well as video data provides a better basis for documenting and analyzing events involving the officer, as well as an opportunity for improved transparency.

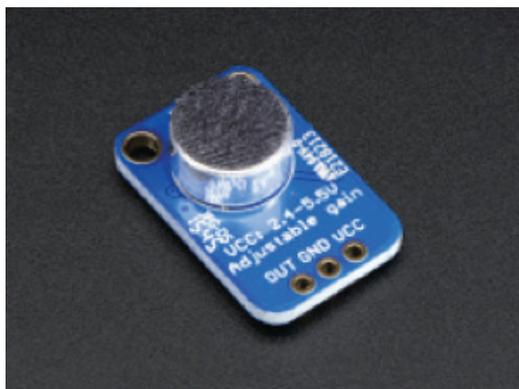
Some of the BWCs worn by officers provide audio, but many do not. The microphone components, being small and lightweight, can be placed at different locations on the vest to create an all-encompassing acoustic environment. This acoustic environment can be synched with the video recording through the same processor. This processing unit has its own clock, allowing acoustic and visual events to be matched.

Figure 3.2 shows an example of a possible microphone component for the basic vest system. This fingertip-sized component requires so little energy that placing several of them on the vest will not noticeably change power requirements or increase weight.

### 3.4. Battery Components

An officer in the field is constantly using power to drive several electronic devices. Most of these devices have their own batteries and their own charging systems. This can cause confusion, unnecessary complication, and power loss. A unified power source with the necessary plug-in components built onto the officer's vest allows for longer time in the field with a lower risk of power loss. Separate batteries for each device add to the officer's weight burden. Small, high-energy-density batteries

**Figure 3.2. Microphone Component**



SOURCE: Promotional image, Digi-Key, 2017.

NOTE: For detailed specifications, see Digi-Key, 2017.

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embedded in the vest distribute the weight evenly and allow for a more streamlined look.

Lightweight batteries are becoming more common because of consumer desire for smaller and more portable devices. The basic vest leverages this trend. Small, lightweight batteries that supply between 1.5 and 10 volts with power output between 600 Ah and 2,000 Ah are widely available for under \$5 per component. Such a battery component would be able to supply the vest's camera for between one and two hours of constant recording and could be stacked to increase available power. Credit-card-sized batteries are also now widely available (see, for example, PowerStream, 2016; Panasonic Corporation, 2016) and are becoming more flexible and tailored to the needs of the purchaser, partially driven by desire to serve the emerging Internet of Things market.

Along with lighter-weight batteries, having a modularized battery system allows for flexibility in placement. Many battery systems are large, bulky, and placed in one spot—usually on the back. Ten to 20 smaller batteries wired together allow for more movement across the body than placement in one centralized location does. Taking these battery cells and placing five to ten on either side of the vest, similar to a ribcage, creates a natural feel that could greatly benefit the mobility and overall wellness of the officer. Such battery systems could power all of the current devices that an officer carries for the duration of a shift for much less than the cost of the batteries that are currently in use. As with power conduction and transmission systems, there may be a need to consider and address perceived health concerns from systems distributing batteries along an officer's body. Similarly, as with other equipment, it would be important for the presence of batteries to in no way impair the integrity of an officer's ballistic protection; the batteries must either enhance protection or have a neutral effect.

### 3.5. Wireless Charging Components

Wireless charging will enable officers to stay in the field longer by increasing the time between necessary charging of electronic components. Rather than needing to plug and unplug devices, wireless charging allows *frictionless* charging experiences, leaving the officer more time to focus on other functions of the job. There are currently two main approaches to wireless charging: contact wireless charging and noncontact wireless charging.

Contact wireless charging involves coils tuned to each other in the transmitter and receiver. These coils need to be very close together (typically less than one meter apart) to

transmit or receive sufficient energy for convenient charging. We suggest placing the contact wireless charging receiver on the lower back of the vest system. A charging pad, the transmitter, would be placed in or attached to patrol car seats. With the receiver on the lower back of the vest and the transmitter in the car, all of the devices connected to the vest would be charged automatically any time that an officer sat in the car.

Noncontact wireless charging, in contrast, does not require the transmitter and receiver to be as close together. Researchers and companies selling products claim effective ranges of 15 to 20 meters for their devices. Such a range enables the capability for a wireless charging transmitter to be placed in the general vicinity of an officer in order to charge all of the devices on the vest. This gives officers freedom to focus on the job and not on the battery life of their electronic devices.

Regardless of the approach used, wireless charging devices, while not as cheap or ubiquitous as the other components of the basic vest system described above, are available from multiple vendors (Corda, 2014; Mims, 2015; Ossia, 2013; WiTricity, 2016).

### 3.6. Representation of the Basic Vest System

The basic vest system is designed to be lightweight, useful, and composed of off-the-shelf solutions. The components discussed previously are all inexpensive, readily available from

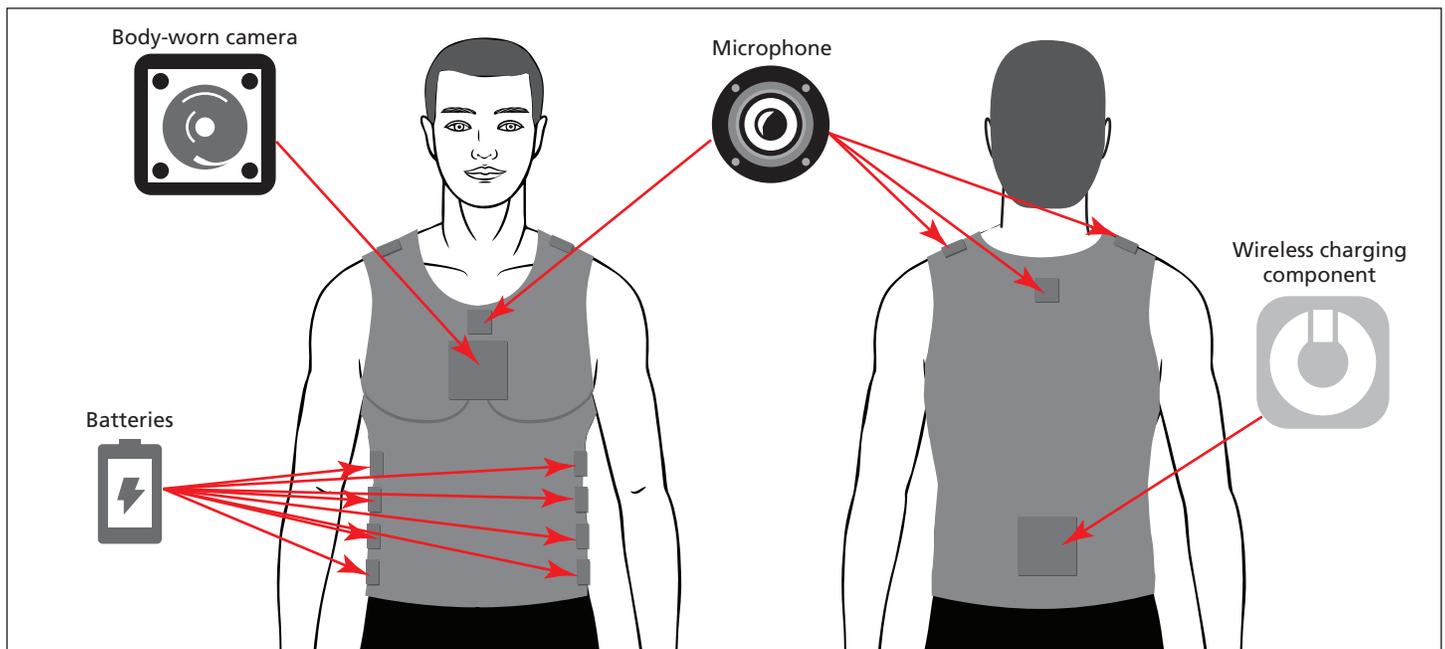
commercial vendors, and easy to embed using current technology. Figure 3.3 shows a possible representation of a basic vest that incorporates a BWC, microphone, batteries, and wireless charging.

The batteries are located along the side of the vest, along the ribcage, which allows for full flexibility of the vest while maintaining the required supply of power. The microphones are placed high and wide apart from each other, allowing simultaneous audio collection to enable triangulation, sound event triggering, and a full recording of any incident. The camera, right in the center of the chest, is small and lightweight enough that it will not inhibit the officer. Embedded in the vest, it will be barely noticeable by the wearer and is not subject to becoming detached from an external mount, as many currently used cameras are. The wireless charging component is on the lower back; this allows for a car seat, a bike seat, or a charging station to be quickly utilized by simply putting the lower back into close proximity. As this technology progresses, new locations for the charging transmitter will likely be possible.

## 4. ENHANCED SYSTEM

The enhanced vest system contains two features not found in the basic system: connectivity to a WiFi mesh network and sensors that can provide indications of officer health and safety.

**Figure 3.3. Representation of a Basic Vest System**



## 4.1. WiFi Mesh Network

The ability to maintain a constant communication link with one another and with centralized data systems is a significant technological problem facing police officers. While there are many commercial solutions to provide connectivity between a base station and a police vehicle, there is an equal or greater need to provide data connectivity with and for police officers on foot, including both officers on foot patrol and officers who leave their vehicles.

Police officers engaging with the public on foot can often become separated from their vehicle for considerable periods of time, sometimes on an unexpected basis, such as when responding to a call for service that escalates in seriousness and duration. Similarly, in many cases, officers are deployed on foot patrol and do not have an accompanying vehicle. While all police officers are typically equipped with a handheld radio, these devices have limitations in both functionality and connectivity. This can reduce police officer situational awareness and decrease officer safety and effectiveness.

To overcome connectivity problems, we investigate future digital communications systems available in the next three to five years that would provide WiFi mesh networking to enable real-time situational awareness for a police officer on foot. Situational awareness can take the form of pushed messages from fellow officers or police dispatch and information centers or can take the form of real-time data streamed to all officers in a specific geographic area to increase officer safety and awareness. In addition, information can be streamed from officers in the field into central locations for monitoring. This could include information on the location of officers, as well as their health and safety, from sensors described in a later section of this chapter.

Human beings have perception limitations, and, as a result, police officers may not always be aware of approaching dangers that may otherwise be detectable using technology. These perception limitations include physical limitations, such as limited line of sight, as well as informational limitations, such as lack of awareness of the criminal history of a potentially dangerous or actively wanted individual encountered during a routine interaction. The enhanced vest system will provide for the development of and access to a distributed mesh network to link on-foot police officers to a central base station and to each other.

The communication resources and protocols for this network will be different than those of traditional wireless sensor networks (WSNs) with respect to

- rapid node mobility

- ad hoc agility to change topology
- distance over which messages must travel
- system control.

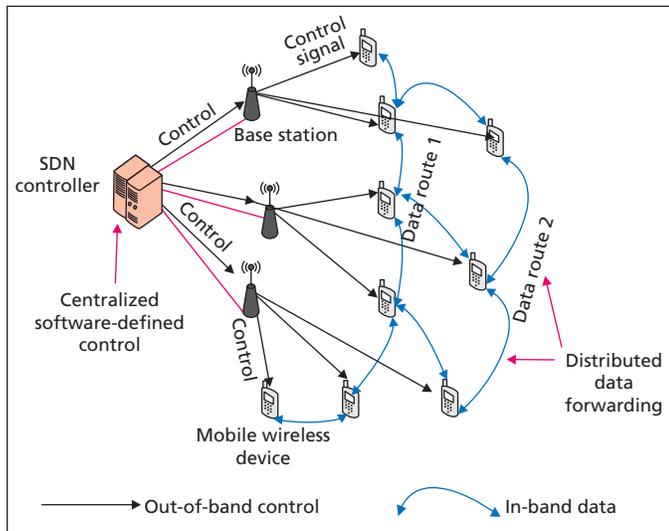
Computing nodes in the mesh network include personnel who may move quickly, whereas in a traditional WSN, the nodes are static or move at lower speeds. Thus, communication protocols for a mesh network must take into account the high speed of nodes when considering broadcast frequency and range.

Due to unpredictable movement of police officers, a mesh communication network may not have a stable topology. For example, the number of officers will not be static, and there will always be police officers moving out of the network and new officers entering into the network, or vehicle networks joining in, so that officers within the communication range of a roadside infrastructure will change dynamically. Hence, the communication topology is only a temporary assembly of officers and infrastructure nodes and lasts for a short time. Because of this dynamic nature of the network, it is inefficient and impractical to establish and maintain routes for message propagation.

One of the aims of the mesh network is to improve officer and public safety. By delivering warning messages to officers in a timely manner, the mesh network enables notification of other officers and the public of potential danger, giving them sufficient time to take action. This imposes stringent requirements on the transmission delays of safety-critical messages. Message redundancy is also a significant issue. Concurrent message transmissions by police officers in a group will increase the probability of message corruption and decrease the successful message transmission rate because of competition for the shared channel.

Recent research on mesh network construction addresses these issues (Abolhasan, Lipman, and Hagelstein, 2015). Figure 4.1 shows a schematic example of a mesh network to which an officer wearing the enhanced vest system would be connected. The centralized control would be located in a police station or other facility, and the base stations would be appropriate fixed locations in the field. These could be established by law enforcement or other agencies or could use existing WiFi nodes, such as those established by commercial Internet providers.

**Figure 4.1. Schematic of a Mesh Network**



SOURCE: Abolhasan, Lipman, and Hagelstein, 2015. Used with permission.

NOTE: SDN = software-defined networking.

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## 4.2. Components for WiFi Mesh Network Connectivity

There are hardware limitations set by the FCC related to transmission power and frequencies. Typical WiFi systems have limited range, dictated by the FCC, and are limited to line-of-sight transmissions. The mesh network of the enhanced vest system will have to seamlessly transfer from commercial to noncommercial transmission systems. Commercial hardware is available for this task.

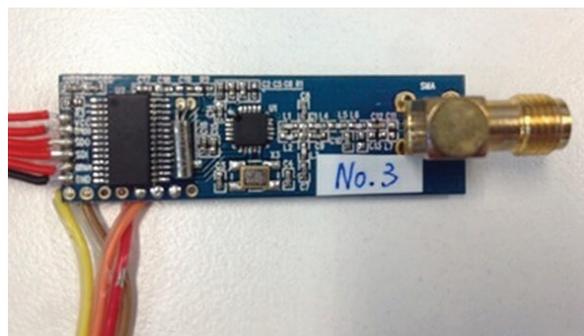
Figure 4.2 shows, for example, one currently available option with throughput capability to transmit images to an officer's display device. The cost of the Texas Instruments low-power sub-1-GHz radio frequency (RF) transceiver is typically about \$18 in very low volumes. Another option (not shown) is the AMR Module FC-621-DAU for Mesh Network, which is available for about \$14 in high volume.<sup>9</sup>

Figure 4.3 shows an example of a commercial chipset for use with either of these that includes a Universal Serial Bus (USB) port and dual-band printed-circuit board antennas and coaxial connectors for external antennas. This chipset has been in production for nearly a decade and has a cost of about \$2 at production volumes.

Finally, standard messaging and communication protocols need to be evaluated to determine the options best suited to the amount of data security and data being transmitted. Additional

<sup>9</sup> These are two of many possible options and are provided only as examples to demonstrate the feasibility of the approach with commercial technology.

**Figure 4.2. Commercially Available Option for WiFi Mesh Network Transmission**



SOURCE: Promotional image, Texas Instruments, 2017.

RAND RR2012-4.2

technology-related questions not discussed here concern the broadcasting of messages, communication topology, and data storage.

## 4.3. Officer Health and Safety

The enhanced vest system will incorporate biometric monitoring to provide real-time information that can improve officer health and safety. In this context, *officer health* refers to all aspects of an officer's long-term well-being as it relates to both chronic and acute health and medical conditions (for example, high blood pressure or a cardiac incident). *Officer safety* refers to all aspects of an officer's physical safety and well-being while on the job as it relates to an external threat or situation that might imperil that officer's safety.

Technology for monitoring officer health generally consists of personal biometric monitoring devices. In the case of officer safety, key applications include all aspects of officer situational awareness, for example, as discussed in the previous section, as well as the addition of technology capable of detecting certain types of physical injuries. In each case, key design and implementation questions include the following:

- what information is monitored (e.g., heart rate, blood oxygen level, location and nature of injury)
- whether data are stored and who sees them
- whether, and when, to take action based on the data.

The most important choices associated with components relate to configuration and placement (e.g., wristband, waistband, vest), data transmission and storage (e.g., smartphone versus local processor), and integration (e.g., worn externally or incorporated into a garment). Consequently, there are a number of different possible ways to implement officer health and safety

**Figure 4.3. Example of a Chipset for the WiFi Mesh Network**



SOURCE: Promotional image of Qualcomm Atheros UB 134 reference design; see Intelligraphics, undated, and WikiDevi, undated.

RAND RR2012-4.3

devices in the enhanced vest system. The following subsections describe options for the first two types of choices noted above. Incorporation into the garment is discussed in the next chapter on the advanced vest system.

#### 4.3.1. Configuration and Placement of Components

Personal biometric monitoring devices have become popular among athletes, fitness advocates, and the public in general. Numerous commercial options exist for biometric monitoring in the enhanced vest system.<sup>10</sup> We suggest using a wrist-mounted device, either a band or a smartwatch, with the choice left to the users (some of whom may already be using such a device).

Ongoing research presents new opportunities for measurement and real-time display of biometric data with wearable technology. These include flexible sensors that perform chemical analysis of sweat and flexible oxide thin-film transistors for displays, both of which have been attached directly to skin, as well as flexible (easily removable) tattoos with electronic capabilities.<sup>11</sup> As this field continues to develop, a wider variety of biometric monitoring and data display options will become available for the enhanced vest system.

Technology for detection of injury using an insert to body armor currently exists and could be included in the enhanced vest system. This technology detects a broken link in a conducting layer of the insert that could occur from a blunt force impact or a projectile and sends a signal to a linked radio or other receiver.<sup>12</sup>

<sup>10</sup> For a review, see Gandhi and Wang, 2014. For descriptions of the latest highly rated technologies, see, e.g., Duffy and Colon, 2016, or Tucker, 2016.

<sup>11</sup> See, for example, Majcher, 2015; Gao et al., 2016; Lee et al., 2016; and Kim et al., 2016.

<sup>12</sup> See, for example, DataSoft, 2015.

#### 4.3.2. Data Transmission and Storage

Most current biometric monitoring systems either store data locally or transmit to and store data on linked devices with processors (personal computers, tablets, smartwatches, etc.). Connection to the mesh network described in a previous section provides the enhanced vest with the capability to transmit biometric or injury data to other nodes in the network (for example, to another officer's phone or tablet or to a local control node). Were the officer wearing the enhanced vest system to have a health or injury crisis that the monitoring system recognized, this capability could be used to call for help immediately. If the mesh network were used in simulation or training exercises, the monitoring data could be transmitted and analyzed in real time to provide data for strategic and tactical planning.

Although it is beyond the scope of this document, there are likely to be a variety of important policy issues that departments will need to consider with regard to the collection and transmission of health information outside of acute, emergent situations and who in the department (if anyone) is allowed to access it. The availability of biometric data over time also raises a variety of issues with regard to discovery in legal proceedings (for example, officer blood pressure level during an interaction with a citizen). The monitoring of health information could turn out to be a showstopping issue for some law enforcement agencies. For example, the Boston police union filed an injunction to prevent the implementation of a pilot program to use BWCs (Boss, 2016), which might be a much less contentious issue than biometric monitoring.

## 5. ADVANCED SYSTEM

The advanced vest system incorporates features that are in the development stage or that are not currently widely available

from commercial vendors. This includes integration of biometric monitoring into the garment that makes up the vest, as well as onboard processing, capacity for recharging batteries by harvesting energy from officer motion or the environment, and increased situational awareness provided by advanced sensing capabilities.

## 5.1. Integration of Biometric Monitoring into the Vest System

The previous chapter described biometric monitoring devices worn externally, independently of the vest. The advanced vest system has two properties that provide opportunities for integration of biometric monitoring into the vest system itself: onboard processing and an electrically connected garment.

### 5.1.1. Onboard Processing

Onboard processing allows biometric information to be analyzed locally so that the advanced vest provides a constantly updated health status to the officer, including alerts and warnings if any vital signs move beyond a prearranged threshold. The Raspberry Pi device shown in Figure 5.1 is one example of a currently available processor that could be incorporated into the advanced integrated vest system.<sup>13</sup> This device sells for \$5 and has the following capabilities:

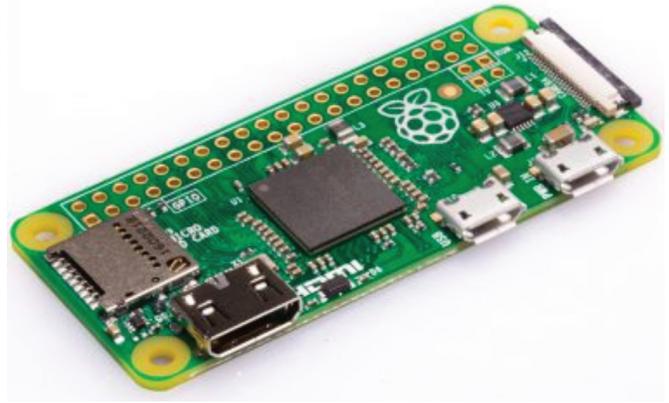
- 1-Ghz, single-core central processing unit (CPU)
- 512 MB random access memory (RAM)
- mini High-Definition Multimedia Interface (HDMI) and USB on-the-go ports
- micro USB power
- hardware attached on top-compatible 40-pin header
- composite video and reset headers.

### 5.1.2. Electrically Connected Garment

The advanced vest system will integrate the electronic components into the vest itself, either through an electrically conducting woven textile or through direct electrical connections to its components without any mounting hardware. Several

<sup>13</sup> The Raspberry Pi Foundation is a UK-based charity with the purpose “to further the advancement of education of adults and children, particularly in the field of computers, computer science, and related subjects” (Raspberry Pi Foundation, undated[c]) To this end, it produces inexpensive computers that enable a wide variety of experiments and practical applications. See Raspberry Pi Foundation, undated(a). Raspberry Pi Zero is its \$5 computer. For details, see Raspberry Pi Foundation, undated(d).

**Figure 5.1. Raspberry Pi Zero Miniature Computer**



SOURCE: Promotional image, Raspberry Pi Foundation, undated(d).  
RAND RR2012-5.1

companies are already integrating biometric monitoring devices into clothing.<sup>14</sup> For example, there are “smart shirts” that incorporate monitoring for potentially dangerous heart irregularities.<sup>15</sup> Officers are likely to wear an undershirt of some sort beneath their ballistic vest. Existing smart shirts are designed for athletic performance and are lightweight; they could simply replace whatever undershirt the officer would regularly wear without adding weight or hindering movement. Alternatively, the electronic components could be wired directly into the vest using built-in wiring or conducting fabric. Several options of this type are listed in Tables A.4 and A.5 in the appendix.

## 5.2. Power Generation

The advanced vest system will incorporate power generation. Projections for the emerging needs of wireless sensors and network applications suggest that this can be accomplished by combining energy harvesting with thin batteries that already have superior form factors (He, 2016). Energy-harvesting options include embedded devices to capture heat from the body or the environment or to capture the kinetic energy generated by officer motion. Commercial systems exist to generate electricity from either type of energy (for example, see Tellurex, 2016, and Ampy, 2016). A multi-university research program sponsored by the National Science Foundation is developing nanotechnology-enabled wearable energy-harvesting systems of both types (Assist, 2012). Systems have also been developed to convert the kinetic energy of foot strikes into electrical energy

<sup>14</sup> For example, see Sawh, 2016.

<sup>15</sup> See, for example, Sensoria, undated; Hexoskin, 2017; and Athos, 2017.

(Sensitile Systems, undated; Instep Nanopower, 2016; Hsu et al., 2015). Several research groups are developing prototype flexible and wearable energy-harvesting devices with potential for incorporation into a garment (Wen et al., 2016; Li, Islam, et al., 2016; Li, Torres, et al., 2016; Niu et al., 2015). Options for the advanced vest system using one or a combination of these emerging technologies include energy-harvesting garments and shoes.

### 5.3. Advanced Situational Awareness

There are important differences between the technologies and components considered for the enhanced and advanced systems. These differences are especially relevant in the area of situational awareness. While the enhanced system uses off-the-shelf components that are intended to be achievable at low cost and within a short timeline, the advanced system uses some technologies that are available in the laboratory environment or have not yet been included in a mesh network situation. Situational awareness using the advanced system requires computation based on data sensed from the environment via imaging or capture of electromagnetic signals from such devices as cell phones or CCD cameras. This computation can occur either on the vest or at another location, such as a cloud-based computer. In addition, some components for the advanced system may require technical advances, and their implementation would likely involve issues associated with surveillance and privacy.

#### 5.3.1. Real-Time Video Analysis

WiFi connectivity such as that enabled by the mesh network described for the enhanced system allows for near-real-time access to data and feedback from analysis of information obtained by onboard sensors. For example, portions of the video stream from a BWC can be forwarded to server-based analysis systems to provide feedback about issues related to information in the video feed, such as license plate and facial recognition, to indicate whether persons nearby have outstanding warrants or a criminal history. The advanced vest system will contain a microcomputer, such as a Raspberry Pi (see Figure 5.1), that acquires frames from a video source. These frames can be analyzed at a cloud-based interface that provides facial recognition.<sup>16</sup> The same type of analysis could be performed on information about passengers in a vehicle obtained

by shining a facial imaging flashlight into the vehicle. In either case, the facial images could be compared with driver's license or booking photographs or with those published in commercial databases, such as Facebook or Google.

Another option for obtaining real-time video is a 360-degree camera mounted at a fixed location, such as a police vehicle or an officer's hat or helmet. Such camera systems are presently used to produce video content for VR and AR systems. The same technology provides the capability to perform analysis of license plate reader or facial recognition data, although the large amount of data generated by these cameras typically requires specialized routers.

#### 5.3.1.1. Performance of Facial Recognition Systems

The ability of facial recognition algorithms to correctly and positively identify persons varies significantly, depending on the number of distracting faces within the image field of view. The University of Washington conducted a study of a number of facial recognition algorithms and found that those that were successful with 100,000 faces were much less so for a million faces. They then tested the algorithms to see how accurately they could match the photo of a single individual to a different photo of the same person in a group of a million photos of different individuals. This is exactly the type of problem that an officer wearing the advanced vest would be faced with in trying to use facial recognition in the field. They found that those algorithms trained on larger sets of data performed better (Kemelmacher-Shlizerman et al., 2016). However, this is still an active field of research. Moreover, moving images from standard chest cameras to systems where faces can be actively measured will likely subject the images to rigorous challenges. Facial recognition systems for the advanced vest will thus have to be tested and validated under real-world conditions.

#### 5.3.2. Digital Atmosphere Awareness

While image analysis can provide information related to the identity of individuals in a particular area, there is a potentially more-effective, albeit controversial, method to accomplish this. The Pew Research Center found that 68 percent of U.S. adults used a smartphone in 2015 (Smith, 2015). These smartphones are constantly emitting identifying emissions when they attempt to reach 2G, 3G, and 4G wireless networks. Many smartphones also emit self-identifying signals when they attempt to contact WiFi networks. At the time of this writing

<sup>16</sup> Several different organizations provide such services. For example, see Kairos, 2017b; Face++, 2017; and Microsoft, 2017.

(January 2017), the rules governing the government's ability to use signal transmissions are unsettled (U.S. Department of Justice, 2015). Although a warrant may be needed to simulate a cellphone network to capture the flow of traffic through a network, it is an open question whether the government requires a warrant to capture electromagnetic signals that are continuously emitted into the environment.

Low-cost Arduino-based devices that capture and analyze the continuous emission of identifying information from smart cellular devices are currently available through the Internet. These include, for example, the WiFi Pineapple from Hak5 LLC.<sup>17</sup> These devices, which are advertised for use in penetration testing and auditing of cellular networks, have prices ranging from \$99 to \$150. Their small footprint<sup>18</sup> would allow them to be incorporated into the advanced vest system.

While these devices provide the capability to conduct “man-in-the-middle” evaluation of signals, which may require a warrant, they can also simply capture identifying emissions from smartphones. These emissions can be analyzed or saved for future use to determine who may have been in a specific location at a particular time. Moving collectors, such as police vehicles, can catalog such data, as many presently do with vehicle license plate readers. Similar data may be gathered by placing these detection devices at fixed locations, such as police stations or emergency phone boxes. Real-time analysis of these data is possible using the techniques described above with relation to facial recognition.

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## 6. CONCLUSIONS

We live in an era in which technology is changing and improving rapidly. The advent of wearable technology and other key trends present a significant opportunity for law enforcement. Key trends with implications for law enforcement include the miniaturization of technology; the ability to generate power reliably through new and easy-to-use mechanisms; improvements in cameras, GPS, and other recording technologies; improved connectivity to broadband service; improvement and growth in data collection on all facets of life; and general reductions in the cost of technology. The technologies described in Chapter 2 have resulted from these trends, and we made use of them when developing the three integrated vest systems described in Chapters 3 through 5. Collectively, these trends,

as embodied in the integrated vest systems described in this report, represent a significant opportunity to improve the efficiency and effectiveness with which law enforcement officers do their jobs, while making those officers safer on a day-to-day basis and increasing their accountability to the public.

One key implication of this report is that while no singular law enforcement wearable technology package has been developed and adopted nationally, there is no need to wait. Wearable technologies with the potential to provide significant benefit to officers in the field are available today at reasonable cost. More-sophisticated wearable technologies are under development and rapidly improving. Earlier chapters of this report used currently available technologies for the components of a basic integrated vest system and technologies still under development in the enhanced and advanced systems. As noted earlier in this report, we recognize the significant barriers to diffusion of these technologies into systems that will be widely adopted by law enforcement agencies. However, we are encouraged by the rapid adoption by law enforcement of such technologies as BWCs, smartphones, and license plate readers.

More generally, there are several findings from our research with potential ramifications for the law enforcement community:

- **The burden of officer-mounted audio and video recording devices can be greatly reduced.** As shown in Chapter 3, small and inexpensive camera components and microphones are available commercially and can relatively easily be incorporated into a vest or shirt without special or bulky mounting hardware.
- **Increased access to portable, reliable, uninterrupted power in the field that travels with the individual officer is currently feasible and will likely be more so in the future.** An individual officer's need for electrical power may increase in the future as technology improves and officers become more and more likely to carry devices requiring power sources. Conversely, as technology improves, devices are also likely to become more efficient and use less power, and, as suggested in Chapters 2 through 5, the technology already exists today to provide access to significantly more power than is currently available to officers in the field. Accordingly, law enforcement should be thinking now about how it would use these additional sources of power. For example, rapid refresh of GPS location, 3-D geolocation, and other power-intensive operations might be among needs that are currently too power intensive to accommodate but would be beneficial to law enforcement.

<sup>17</sup> See WiFi Pineapple, 2017.

<sup>18</sup> For example, the WiFi Pineapple fits into a pocket.

- **Law enforcement access in the field to broadband data and communication is likely to improve rapidly.** The federal government's FirstNet project is designed to provide fast, low- or no-cost, reliable broadband access in the field to first responders nationwide.<sup>19</sup> Whether through FirstNet or other providers (e.g., see the discussion of mesh networks in Chapter 4), law enforcement should assume that access to broadband—and, therefore, the ability to send and receive data to and from the field—will improve rapidly in the near future. Curating this information in a manner that makes it most useful to and accessible to officers in the field and to dispatchers and analysts supporting them, including novel forms of visualization, will be critical to leveraging these capabilities. Alternatively, failing to do so effectively could result in lost opportunities or, perhaps worse, confusion and information overload.
- **Wearable health and safety technology is improving rapidly and represents a challenge and opportunity for law enforcement.** The law enforcement community should carefully consider how to use wearable technology that collects and reports data related to health appropriately and in a manner that protects officer privacy but leverages this potentially valuable tool. As discussed in Chapter 4, the development of technology for injury detection is promising and could have implications for improving officer safety in the field. Law enforcement should consider such applications to officer safety and identify other currently unfilled needs to guide research and development in this area.
- **There are significant and challenging policy questions associated with the technologies that are becoming available to law enforcement and are being adopted and expected by the public.** Technology often outpaces policy and practice, as well as societal mores and expectations. This appears to be the case today for law enforcement. Although outside the scope of this report, law enforcement should assume that such technologies as facial recognition, license plate readers, and real-time access to personal data on subjects encountered in the field, as well as new and novel technologies, like unmanned aerial vehicles, will continue to become cheaper, more efficient, and more accessible. Addressing difficult ethical and policy issues as soon as possible will greatly increase the likelihood that new technology can be adopted and leveraged as rapidly and

efficiently as possible while maintaining core law enforcement and societal values and principles.

- **Bulk and appearance matter and can be critical factors in the adoption of technology by law enforcement.** Law enforcement is making a pronounced effort to avoid having a militarized appearance, and even absent these concerns, bulk and weight of equipment are perpetual concerns and, in some cases, significant barriers, to officers carrying new items on a regular basis. Officers already have limited—or no—excess capacity on their belts and are reluctant to carry items in vest carriers or pockets that may make benign items appear to be tactical equipment. In addition, they face significant movement and bulk constraints from existing equipment, such as ballistic vests and BWCs, that may fall off during foot pursuits. New technology intended for law enforcement use, such as incorporation into the integrated vest systems discussed in this report, must be designed with these constraints in mind. Failure to do so will likely result in important missed opportunities for both law enforcement and technology providers.

Perhaps the single most important conclusion of this report is that there is no reason for law enforcement to wait for wearable technologies that can provide improvements in the bulk, weight, and flexibility of carried equipment—major incremental improvements are available today using currently available commercial technology. However, law enforcement needs to think about how to engage with manufacturers now to specify its needs and provide input on the directions that research, development, and design should take in the near future to best accommodate its unique challenges and opportunities. By the same token, manufacturers should reach out to law enforcement agencies and practitioners as the technologies described in this report continue to develop in order to secure their positions in a large and rapidly evolving market.

<sup>19</sup> See FirstNet, undated, for additional information.

## Appendix

This appendix provides further information about technologies, products, and developers relevant to the vest systems.

**Table A.1. Commercial Body-Worn Cameras**

Model	Size	Weight	Video Resolution and Field of View	Battery Life	Cost
Wolfcom Vision	3.8 x 7.4 x 1.5 cm	62 g	1920 x 1080p, 120°	17 hours (with external battery); 2.5 hours (with internal battery)	\$249
Viewu 2	4.8 x 4.8 x 1.9 cm	68 g	1920 x 1080p, 95°	1.5 hours at 1080p; 2 hours at lower resolutions (internal)	N/A
Viewu LE4mini	4.8 x 4.8 x 1.9 cm	68 g	1920 x 1080p, 95°	3 hours (internal)	N/A
Viewu L3	7.6 x 5.3 x 3.8 cm	79 g	1280 x 720p, 68°	5 hours (internal); 12 hours (external)	\$200
TASER Axon Body 2	8.4 x 6.6 x 3.8 cm	99 g	1080p, 142°	12 hours (internal)	\$399
TASER Axon Body	8.4 x 6.6 x 3.8 cm	99 g	480 VGA, 130°	12 hours (internal)	\$399
Digital Ally First Vu HD	2.8 x 3.8 x 2.5 cm	111 g	720p, 130°	4.5 hours (external)	N/A
Coban Echo	7.9 x 5.1 x 2.7 cm	113 g	1080p, 110°	8.5 hours (internal)	\$500
Watch Guard Vista	7.6 x 4.8 x 3.3 cm	150 g	720p, 130°	9 hours (internal)	N/A
Wolfcom 3rd Eye	9.4 x 6.0 x 3.2 cm	156 g	1920 x 1080p, 120°	6 hours (internal)	\$475
Viewu LE4	8.4 x 5.3 x 2.8 cm	161 g	1920 x 1080p, 95°	12 hours (internal)	N/A
TASER Axon Flex (Google Glass type)	8.1 x 2.0 x 1.8 cm (camera), 8.4 x 6.6 x 3.8 cm (controller)	15 g (camera), 93 g (controller)	480 VGA, 130°	12 hours (external)	\$599

NOTES: HD = high definition; VGA = video graphics array.

**Table A.2. Batteries for SWIPES**

Battery	Nominal Voltage	Capacity at C/5	Energy Density	Weight	Operating Temperature	Dimensions
LI-145 rechargeable Li-ion battery	14.4V	@23°C: 9.4Ah	140 Wh/kg, 220 Wh/l	1.021 kg	-32°C to 55°C (-26°F to 131°F)	20.96 x 4.22 x 7.37 cm
BA-5590 Li/sulfur dioxide	13.5V/27V	@21°C: 12V mode, 15 Ah; 24V mode, 7.5 Ah	—	1 kg	-40°C to 71°C (-40°F to 160°F)	See Saft (undated) for details.
BB-2590 rechargeable Li-ion battery	15V/30V	@23°C: 15V mode, 15.6Ah at 1.0A; 30V mode, 7.8Ah at 0.5A	171 Wh/kg, 256 Wh/l	1.34 kg	-32°C to 60°C (-26°F to 140°F)	See UltraLife (2016) for details.
BA-8180 zinc air battery	12V/24V	12V mode, 56Ah; 24V mode, 27Ah	220 Wh/l	2.7 kg	-20°C to 60°C (-4°F to 140°F)	31.0 x 18.5 x 6.0 cm

NOTES: A = ampere; Ah = ampere hour; C/5 denotes a discharge rate of 0.2C; V = volt; Wh = Watt hour; Wh/kg = Watt hours per kilogram; Wh/l = Watt hours per liter.

**Table A.3. Key Technologies and Products for Communications and Data Collection, Transmission, Storage, and Processing**

Technology	Accessories and Products
<b>Bluetooth</b> (using radio waves to communicate with other devices over short distances without wires)	Adaptors (e.g., Pryme’s Bluetooth headset adaptors that allow different devices to plug into at once); hubs (e.g., Motorola’s SI-500, which is a hybrid between a speaker microphone and a BWC); sensor integration is also possible
<b>Bluetooth Low Energy (4.0+)</b> (allows devices to run for long periods of time on standard coin-cell batteries)	
<b>Integrated hearing protection</b> (typically integrated into other communications products, such as headsets)	In-ear headsets (e.g., the Clarus Line by Silyn Communications and the Talon headset by Threat4 that merges hearing aid algorithms that allow for hearing environmental sounds while having ears protected)
<b>Control and display devices</b> (for visual inspection and manipulation of relevant data)	Laptops, tablets, mobile phones, watches, smart glasses
<b>Products to integrate control and display devices with communications devices</b>	Systems that allow officers to connect to any radio or phone (e.g., by Silyn); tactical headsets that connect to portable radios and incorporate cell phones into the radio to receive audio stream (Threat4’s Talon); any push-to-talk apps to answer radio calls and change settings
<b>Computing/processing</b> (a small-size computer is required, including CPU, chip graphics processing unit, RAM, ports)	Raspberry Pi Zero (inexpensive and popular; CPU 1.2 GHz 64/32-bit quad-core, 1 GB RAM, power 800mA, 4W)
<b>Hard drive technology</b> (for data storage)	E.g., solid-state drive products available

**Table A.4. Companies Developing Smart Textiles**

Company	Product
Intelligent Textiles Limited	A company developing products with complex electrical circuits woven into conductive fabrics (cotton, wool, and polyester). Intelligent Textiles Limited appears to provide a solution for vest materials with mature power transmission in the garment. Previous product areas include consumer apparel, medical uses, heating, and defense (e.g., fabric personal area networks or an e-jacket to streamline the batteries carried). The products are potentially expensive to access because the company only develops custom applications in collaboration with clients, such as defense agencies.
Carre Technologies Inc.	Produces biometric clothing (Hexoskin) that directly captures body metrics, including heart rate, breathing rate, and acceleration. With its mission to “record and organize personal health information and make it accessible and useful,” Hexoskin also has apps available for mobile devices and smartwatches to work with its Bluetooth connection and sensor data.
Globe	A U.S.-based company developing smart fabrics to measure the extreme physiological stress that can be experienced during the course of an individual’s duties (e.g., a firefighter or a soldier).
Cityzen Sciences	A French company that produces a “D-shirt” (digital T-shirt). The shirt has such functions as a heart rate monitor, built-in GPS, accelerometer, and altimeter.
AiO Smart Clothing	Produces clothing that lights up, heats up, and monitors biometrics. AiO uses stainless steel yarn, which reduces the risk of a decrease in conductivity over time.
Om Signal	Also specializes in biometric clothing. The wearer is given simple-to-read information on an app about effort level, calories burned, steps taken, sweat levels, and heart rate.
UK Smart Life	Has developed a wearable technology with textile sensors capable of reading a range of biometric signals (being integrated into sportswear).
Sensoria	Has developed smart socks infused with textile sensors that can detect foot pressure. Conductive fibers in the sock then relay data to an anklet that uses Bluetooth to communicate with a mobile app.
Google	Unveiled Project Jacquard a few months ago, which weaves interactive features into clothes through standard looms (Google ATAP, undated).
Others	LifeBEAM, Leo by Gesture Logic, Antelope Suit by Wearable Life Science, and the UK’s National Physical Laboratory. The latter developed a method for producing conductive textiles that could end up turning a fabric into, effectively, a wearable printed circuit board, connecting all the active parts of a wearable. It can be applied to almost all woven and knitted fabrics, not just nylon and polyester.

**Table A.5. Particular components and cables (related to smart clothing, sensors, and connectivity)**

Solutions	Details and Developers	References
Textile cables	Companies such as Interactive Wear AG and Wintex produce flexible and lightweight woven textile cables and other similar structures for wearables. Interactive Wear's cable solution is made of single-coated copper litz wires, mechanically protected by polyester yarns.	Interactive Wear, 2017d; Wintex, undated
Communication functions integrated into textiles	Several smart textile devices with sensors use Bluetooth to wirelessly transmit information to the phone or computer. Interactive Wear AG is an example of a firm that integrates wireless communication directly into textiles. The company's solutions combine these functions with textile wiring, earphones, and microphone.	Interactive Wear, 2017a, 2017b
GPS integrated into textiles	Textiles integrated with sensory devices and GPS capability can detect a user's exact location anytime and in any weather. Interactive electronic textiles with integrated GPS can, for instance, enhance safety by quickly locating the wearer. The main purpose of such solutions in commercial products is facilitating offsite monitoring of vital signs. Cityzen Sciences' wearable physical activity monitor with GPS and Interactive Wear's combined Global System for Mobile Communication and GPS chip in coats are among many examples.	Tekcarta, 2014; Interactive Wear, 2017c
Helmet integrated into a collar	Hövding in Sweden has developed a bicycle helmet in the form of an airbag integrated into a collar. The airbag is shaped like a hood and protects the bicyclist's head. It is triggered by a gyro sensor that tracks angular rotational shifts and an accelerometer that notes sudden changes in the cyclist's speed. It is powered by Li-ion polymer batteries. When an accident is detected, the airbag inflates and surrounds the head using an integrated gas inflator with helium. The airbag covers a larger area of the head and can cushion a shock better than a plastic helmet.	Hövding, undated
Wireless body area networks embedded in smart fabrics	Fabric area networks (FANs) enable electronic devices to exchange digital information, power, and control signals within the user's personal space and remote locations. FANs use wireless RF communication links. One example of a related project is "EU Wear-a-BAN," which provided a demonstration of ultra-low-power wireless body area network (BAN) technologies that enable unobtrusive human-to-machine interfaces in smart fabrics. The platform is available for integration into other products.	Wear-a-BAN, undated
Protective hats and related personal protective equipment	New products provide individualized warnings to workers. For example, the Bradley Department of Electrical and Computer Engineering at Virginia Tech has explored prototypes of a hard hat that can give a construction worker a warning about carbon monoxide poisoning based on blood chemistry. Similarly, the lab is working on a vest for roadside construction workers to provide them with a few seconds of warning when they are at risk of being struck by a passing car.	Virginia Tech News, 2013
Fabric transistors	Several projects are under way that convert fabric into transistors and thermistors. A team of fiber scientists at Cornell University, for instance, has converted cotton fibers into such electronic components. These innovations are expected to lay the groundwork for creating even more complex devices, such as cotton-based circuits.	Innovation in Textiles, 2015; Nuruzzaman-Cornell, 2011
Electroluminescence for light-emitting textiles	Researchers at Centexbel, a Textile Competence Centre in Belgium, are currently working on printing electroluminescent light bulbs and organic LEDs onto electrically conductive textiles and prepared textile substrates.	Centexbel, undated

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## Abbreviations

A4WP	Alliance for Wireless Power
AR	augmented reality
BAN	body area network
BWC	body-worn camera
CCD	charge-coupled device
CPU	central processing unit
DHS	Department of Homeland Security
FAN	fabric area network
FCC	Federal Communications Commission
GPS	Global Positioning System
Li-ion	lithium-ion
RAM	random access memory
RF	radio frequency
SWIPES	Soldier-Wearable Integrated Power Equipment System
USB	Universal Serial Bus
VR	virtual reality
WSN	wireless sensor network

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Questions or comments about this report should be sent to the principal investigator of the Priority Criminal Justice Needs Initiative, Brian A. Jackson, at [Brian\\_Jackson@rand.org](mailto:Brian_Jackson@rand.org). For more information about the Justice Policy Program, see [www.rand.org/jie/justice-policy](http://www.rand.org/jie/justice-policy) or contact the director at [justice@rand.org](mailto:justice@rand.org).

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## About This Report

On behalf of the U.S. Department of Justice, National Institute of Justice (NIJ), the RAND Corporation, in partnership with the Police Executive Research Forum (PERF), RTI International, and the University of Denver, is carrying out a research effort to assess and prioritize technology and related needs across the criminal justice community. This initiative is a component of the National Law Enforcement and Corrections Technology Center (NLECTC) System and is intended to support innovation within the criminal justice sector. For more information about the NLECTC Priority Criminal Justice Needs Initiative, see [www.rand.org/jie/justice-policy/projects/priority-criminal-justice-needs](http://www.rand.org/jie/justice-policy/projects/priority-criminal-justice-needs).

This report reviews the current and projected status of wearable technologies with potential for use by law enforcement and describes three conceptual integrated vest systems that incorporate these technologies. These three systems are meant to represent what could conceivably be implemented very quickly to enhance existing capabilities, what might be done in the near term to provide additional capabilities, and what might be considered to take advantage of technologies that are still in development and could provide even greater capabilities. This report will be of interest to law enforcement practitioners and academics, as well as individuals and organizations involved in research, development, and applications of wearable technologies. Mentions of products do not represent approval or endorsement by the National Institute of Justice or the RAND Corporation.



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