SMARTER: Advancing Health-Related Technology

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SMARTER Project seeks to develop and advance technologies in key areas of health and safety

Firefighters are on a relentless quest to do their job better. But, increasingly, they are also concerned about doing their job more safely. Everyone recognizes that firefighting is dangerous and that the danger comes from multiple sources on the fireground. Perhaps the greatest danger that firefighters face is their body's response to the stress of firefighting. Too many firefighters are injured or killed on the fireground or in training by a cardiac event, heat stroke or musculoskeletal injury. Early detection of physiological abnormalities and real-time monitoring of toxic particulates that threaten firefighters' health offer opportunities to address these physiological vulnerabilities.

In 2016, the Department of Homeland Security Assistance to Firefighting Grant (AFG) funded a program titled "Science, Medicine, And Research & Technology for the Emergency Responders (SMARTER)" to explore the potential use of technology to address some of the most pressing health concerns in the fire service. The SMARTER team was led by researchers at Skidmore College's First Responder Health and Safety Laboratory, and included leading scientists, fire service professionals, and gear manufacturers (see partners below). The collaborative teams were designed to include expertise from science, technology and industry, and to be guided by a deep understanding of the fire service culture and the needs of firefighters. Some technologies explored were already on the market but needed to be adapted for potential use in the fire service, while other technologies still needed to be developed.

Specific goals of the project were to study the feasibility of specific technologies and to develop/advance technology in targeted areas. Specifically, SMARTER focused on:

- Electrocardiogram (ECG) monitoring for detection of arrhythmias and ischemic changes
- Improving and extending a heat stress algorithm to accurately assess core body temperature
- Developing a low-cost, portable sensor to monitor particulate matter
- Exploring the use of physiological status monitoring in a fire department

Additionally, in October 2017, the SMARTER team partnered with the National Fallen Firefighters Foundation (NFFF) to host a Technology Summit that shared the current state of the project with a larger group of fire service personnel.

In the following pages, you'll learn more about each of the targeted areas of the SMARTER project as well as insights from the Technology Summit.

— Dr. Denise Smith, professor of Health and Human Physiological Sciences, Skidmore College; director, First Responder Health and Safety Laboratory

SMARTER Partners

Skidmore College

National Fallen Firefighters Foundation

Fire Protection Research Foundation

Globe by MSA

Hanover Park, IL, Fire Department

Houston Fire Department

International Association of Fire Fighters

New York State Office of Fire Prevention and Control

UCLA—The Ozcan Research Group

University of Illinois Fire Service Institute

U.S. Army Research Institute of Environmental Medicine

Zephyr Performance Systems

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SMARTER & Technology Summit: skidmore.edu/responder/smarter-project.php

First Responder Health and Safety Laboratory and related studies: skidmore.edu/responder

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Technology to Aid the Fire Service

Fire injury and fatality reports shine a light on where to focus resources

by Denise Smith & Craig Haigh

The fire service is experiencing changes on multiple fronts. Gone are the days when the fire chief could justify purchases, policy changes and directives simply based on experience and gut instinct. Mayors and managers expect performance metrics to justify expenses, and firefighters have information and research data immediately available via the smart device they carry in their pocket. In this new age of technology, progressive fire service leaders now demand "data-based decision-making" for not only organizational management decisions but also on-scene emergency response operations. Included with this change is a greater focus on firefighter health and safety.

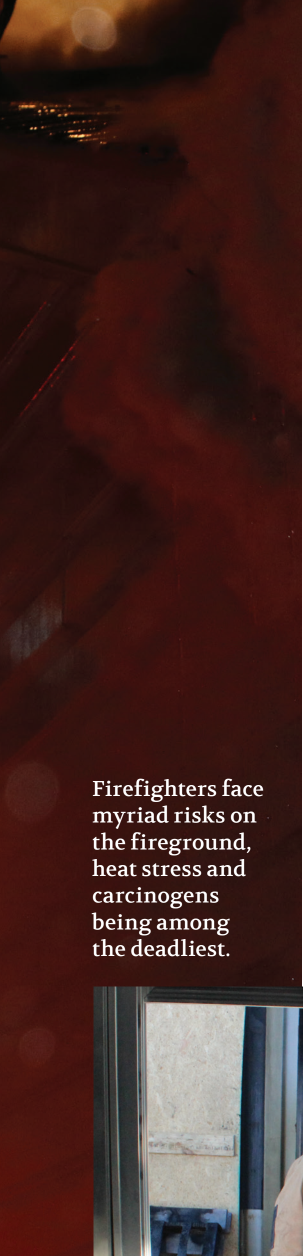
Embracing technology

The world is not just changing for the fire service. All around us we see the infiltration of technology into almost everything we do. We all know the technology in our phones far exceeds what was available on a desktop just a few years ago. Cars have on-board computing capabilities ranging from diagnostics to navigation to assisted driving. And the use of apps to measure and track fitness and to help motivate individuals to achieve healthy behavior is skyrocketing. Just look around and notice how many people are using Fitbits or Apple watches.

Recognizing that technology is all around us raises an important question for the fire service: How do we embrace technology to make firefighters safer and more effective at their jobs?

The SMARTER project has focused specifically on how technology—and especially lightweight technology that is wearable or can easily be carried—can help improve firefighter health and safety. To better understand how technology can be used, we need to understand the following questions:

- What problems or challenges are we hoping to address with technology?



- What technology is available that can be used, adapted or developed for use in the fire service?
- What are the challenges with incorporating any given technology?

Pressing health challenges

A review of firefighter fatality and injury reports is certainly a good place to begin to understand the most pressing health challenges facing the fire service.

Sudden cardiac events (SCEs) have been the leading cause of line-of-duty deaths (LODDs) among firefighters in the United States for many decades. Heat stroke accounts for an unacceptably high number of fatalities, especially in training (see article by Captain King, A12), and heat stress regularly leads to impaired performance on the fireground. Additionally, the devastating toll of cancer in the fire service is increasingly clear, and it is obvious that exposure to fireground smoke and toxins is one important component of the risks that firefighters face. These health challenges are all complex, and there is the potential for technology to help mitigate risks in all cases. But, at present, there is no single technology that addresses all these concerns, or even addresses one concern in a way that can seamlessly be integrated into operations. Thus, one of the important components of this project was to understand how fire departments can begin to incorporate technology.

Firefighters face myriad risks on the fireground, heat stress and carcinogens being among the deadliest.

This project included testing prototypes of technology, adapting existing tools and validating results—but it also considered some of the challenges.

This project included testing prototypes of technology, adapting existing tools and validating results. But we also considered some of the challenges. Understanding and addressing challenges will undoubtedly be critical to having the fire service embrace technology.

Major concerns of the existing wearable technologies tested with this study include the expense, comfort level and durability. Interpreting and using data in real time can be challenging due to time constraints, expertise, and the urgency to complete the mission. Similarly, agreeing upon algorithms for decision-making based on information provided by the technologies is a substantial challenge. Measuring heart rate is relatively easy, but what constitutes a heart rate that is of concern, or perhaps a better way to look at it is what heart rate for what period of time should be used for decision-making? Likewise, what core body temperature is excessive?

The answer to these questions varies by individuals, and the concern for high physiological strain must be balanced against the need to complete the work that firefighters do. It is undoubtedly less complicated to employ wearable technology during planned training, and it is easier to check on the firefighter if concerns arise. Thus, training may be where wearable technology is first used routinely.

Next generation tools

Yet with all of the challenges, the fact remains that technology is advancing every day, and talented engineers and dedicated fire service personnel will address many of the challenges. Like the development of SCBA many years ago, we are now entering a new era of the next generation of firefighter safety tools.

Yes, challenges exist, and solutions will need to be developed, but the early data suggests a promising future for enhanced firefighter safety. ■

Read more about the SMARTER project and related studies at skidmore.edu/responder.

Dr. Denise Smith is a professor of Health and Human Physiological Sciences at Skidmore College where she holds the Tisch Family Distinguished Professorship and serves as director of the First Responder Health and Safety Laboratory. Her research focuses on physiological responses to firefighting and cardiovascular events in the fire service.

Craig A. Haigh is chief of the Hanover Park, IL, Fire Department and an instructor with the Illinois Fire Service Institute (IFSI). He is a regular research partner with Skidmore's First Responder Health & Safety Laboratory. Haigh has a bachelor's degree in fire and safety engineering, and a master's degree in executive fire service leadership.

ECG Monitoring During Fireground Operations

Reviewing the challenges associated with ECG monitoring—and what's ahead

by Andrea Wilkinson & John Ames

Sudden cardiac events (SCEs) are the leading cause of line-of-duty deaths (LODDs) among firefighters in the United States, so it is obvious why there is such an appeal for electrocardiogram (ECG) monitoring during fire calls. The appeal for a wearable ECG device for firefighters largely comes from the desire to allow for early detection and intervention of SCEs.

As part of the SMARTER project, our team investigated the feasibility of using existing wearable devices in the fire service to monitor heart rate and rhythm. Perhaps not surprisingly, despite the appeal of ECG monitoring, we found several significant challenges. Here we outline several types of challenges that must be overcome before ECG monitoring will be feasible for routine use in the fire service.

Logistical challenges

The first area of concern is the logistical challenges, specifically, how to utilize the devices in a way that makes sense for the fire service. Common feedback from firefighters who tested the wearable products is that they don't want to wear the devices 24/7. However, due to the nature of the emergency response, a use-model needs to be developed that would permit the firefighters to be monitored en route to a call and on scene. Almost certainly, a firefighter would not want to don another piece of equipment or layer of clothing once the alarm tones sound.

Perhaps the most significant logistical challenge is determining who should be monitoring the ECGs as they are being captured in real time. For most departments, having an individual on call to monitor incoming data would not be feasible; therefore, it may make sense to use a device that has automated arrhythmia detection software built in and can alert users/command staff of any abnormalities. The problem: The current state of arrhythmia-detection software is likely not precise enough for incident commanders to be willing to pull a firefighter from the job just because an arrhythmia was detected. Finally, for the products to be universally beneficial for the fire service, they must be cost-

Investigation into the feasibility of using existing wearable devices to monitor heart rate and rhythm identified several significant challenges.

efficient so that they can be readily accessible for departments of all sizes to utilize.

Clinical challenges

The next layer of challenges for ECG monitoring for firefighters is the medical perspective. Currently, most wearable devices commercially available today utilize a single-lead ECG, not a standard 12-lead, to view the heart. The lead placements are non-traditional and differ from device to device. Additionally, even when you are able to obtain good ECG tracings, which is a major challenge in itself, a significant question remains: What arrhythmias are you able to detect, and which ones are clinically relevant? It is well known that many individuals have benign ECG abnormalities that have no clinical significance. Also, major life-threatening arrhythmias typically lead to a loss of consciousness, which means that they are detected right away during work at an emergency scene, without the use of ECG, so it is unclear whether the ECG would lead to earlier detection.

Contextual challenges

The definition of life-threatening arrhythmias (LTAs) is problematic in and of itself, as these classifications have origins in clinical settings where the subject is assumed to be resting in bed. This contextual assumption does not easily apply to the dynamic nature of the fire service and first responders.

While some LTAs, like asystole and atrial dysfunction, can be classified irrespective of heart rate, other rate-centric arrhythmias present additional challenges. Some very fit responders will have naturally low heart rates that may be confused with classic definitions of bradycardia, and others involved in stressful situations where high heart rates are a normal response to metabolic or adrenal stimulation could confound the classification of tachycardia. Circadian and hormonal cycles may also contribute to improper interpretation.

New personalized definitions addressing fitness and activity will be required to effectively address cardiac surveillance applications. Additionally, electrolyte imbalances from over/under-hydration should be considered in future designs as they can affect the ECG recordings.

Technological challenges

A final layer of challenge is in the technical realm. In order to effectively use wearable ECG technology, good signal quality is essential. Signal quality could suffer for a multitude of reasons, ranging from improper placement of the electrodes, to poor conductivity with the skin, to movement artifact (a type of interference due to movement of the body, which produces false or messy ECG tracings), to interference from SCBA straps or electronic devices. Because the lead placements are non-traditional, and vary between devices, there are individual technological challenges that exist as well. For example, some of the commercially available devices would require the firefighter to remove their gloves and remain still for 60 seconds while an ECG is recorded—obviously not ideal for use during fireground operations. Further, devices need to be able to accurately interpret the ECG signal from movement artifact or interference. The cleaning of data that needs to occur for some single-lead ECGs to be usable is not time-efficient enough to be of use for real-time monitoring. Algorithms that make rhythm assumptions to track beats through noisy periods can be confounded, producing erroneous rate metrics.

Using ECG monitoring now

Despite the challenges to using wearable ECG monitors on the fireground at this point, there are some appropriate and available uses for ECG now. Current technologies may be useful in a rehab setting where firefighters are in a more controlled stable environment. This is a period when firefighters may present rhythm dysfunction exacerbated by dehydration and heat. Whenever it is available, a 12-lead ECG and oxygen saturation (SpO2) monitoring is still strongly preferred for anyone exhibiting cardiac symptoms.

Current technologies may be useful in a rehab setting where firefighters are in a more controlled stable environment.

With the rapidly evolving world of technology, it is possible that ECG monitoring may progress to a point that it could support decision-making on the fireground. For now, a full 12-lead ECG stress test should be conducted for individuals at elevated risk before firefighters respond to a fire. This should be done as part of a routine comprehensive medical evaluation, and should be done to ensure that firefighters are safe and healthy enough to operate on the fireground. The fireground is no place to be performing a stress test with new technology and nobody interpreting the results! ■

Read more about the SMARTER project and related studies at skidmore.edu/responder.

Andrea Wilkinson, MS LAT/ATC, serves as project manager for the First Responder Laboratory at Skidmore College. She is certified and licensed in athletic training and cardiac rehabilitation, and has extensive clinical experience in cardiac care and sports medicine. Wilkinson has a special interest in preventative medicine for the tactical athlete.

John Ames is an independent analyst and engineer focusing on advanced bio-signal processing and sensor innovation. He has successfully developed consumer, medically regulated and military health assessment systems. His background includes both research and commercialization.

Heat Stress Algorithm

Working with the military to develop better means of measuring core temperature

by Denise Smith & Mark Buller

Firefighters use heavy and fully encapsulating PPE, perform strenuous work, and often operate in high environmental temperatures. Thus, an increase in core temperature is a nearly universal response to firefighting activity.

Heat stress is familiar to all firefighters, but perhaps it is so familiar that we fail to recognize the devastating consequences that accompany this condition. While most firefighters recover from this stress given adequate rest, cooling and hydration, the demands of firefighting can lead to serious heat illnesses. Heat stress can cause exaggerated cardiovascular strain, impaired cognitive function, early onset of fatigue, and heat illnesses, including heat exhaustion, heat stroke, and the related condition of rhabdomyolysis, which is the breakdown of damaged muscle tissue that releases proteins and electrolytes into the blood.

The physiological consequences of heat may impair job performance and, if severe enough, may progress to life-threatening challenges. However, the magnitude of the heat stress challenge is not uniform at every fire; in fact, it differs considerably from fire to fire depending upon the type of fire (e.g., wildland vs. structure), duration of the work, type of work performed, and environmental conditions. Training presents a special challenge because of repeated evolutions. We are occasionally reminded of the devastating consequences of heat stress when a recruit suffers heat stroke during training (see article A12).

Despite the common nature of heat stress, and how devastating the consequences can be, body temperature is seldom assessed during firefighting or training because the technology simply does not exist to accurately and conveniently measure core temperature during firefighting. For example, oral temperatures significantly underestimate core temperature following heavy breathing or ingestion of fluids, tympanic thermometers severely underestimate core temperature, and the amount of the underestimation varies depending upon work performed and environmental conditions. Thus, both of these convenient and inexpensive tools are likely to underestimate core temperature and may lead to a missed diagnosis.

The physiological consequences of heat may impair job performance and, if severe enough, may progress to life-threatening challenges.

Heat stress is familiar to all firefighters, but perhaps it is so familiar that we fail to recognize the devastating consequences that accompany this condition.

Military research

Firefighters are not the only personnel who face heat stress challenges as they perform critical and strenuous work. Military personnel also face heat stress challenges and suffer casualties due to the combination of heavy work, the use of PPE and environmental extremes.

Exertional heat illness at military training facilities has been a perennial problem. Even with greater recent awareness of the heat injury problem, over 3,600 cases of heat illness, with nearly 600 life-threatening heat strokes were recorded at military training installations in the last four years. The U.S. Army Research Institute of Environmental Medicine (USARIEM) has been tackling this problem by developing real-time physiological status monitors, but also found that, similar to other occupations, assessing core body temperature accurately in the field is a complex undertaking.

To address this problem, the researchers used advanced computational methods utilizing a tracking algorithm borrowed from engineering to estimate core body temperature from measurements of heart rate. These approaches, often used in engineering tracking problems, utilize two pieces of information to better estimate core body temperature: 1) how core body temperature changes over time and 2) how heart rate and core body temperature are related over time.

The USARIEM researchers used data from U.S. Army soldiers engaged in 24 hours of field training to develop these relationships. This Estimated Core Temperature (ECTemp™) algorithm has been validated across many laboratory, field and operational settings, including cool (11 degrees C) to very hot (42 degrees C) environmental conditions; various clothing ensembles (shorts and T-shirt, combat uniforms, body armor, and encapsulating PPE); different work rates, from sleep to heavy exercise; hydrated versus under-hydrated conditions; and heat-acclimated versus non-heat acclimated conditions. Overall, the ECTemp™ algorithm has been validated in over 14 studies with more than 300 subjects, and generally performs reliably from study to study with an error margin of ±0.30 degrees C. For the military, the algorithm is proving successful and is being implemented in its current form in several commercial physiological monitoring systems, and used with success in both the National Guard Weapons of Mass Destruction Civil Support Teams and with the U.S. Air Force.

While ECTemp™ has proved successful for the military, moving it into another setting requires adjustments. As the algorithm uses time sequences of heart rate to assess core body temperature, the basic underlying relationship needs to be adjustable for age, as both resting heart rate and maximal heart rate change by age. Similarly, for firefighting applications, the algorithm needs to be able to work for multiple sequences of firefighting bouts encompassing high-intensity work with recovery periods. Additionally, as firefighters encounter extreme heat, the algorithm must adapt to passive heating scenarios where the body can no longer dissipate any heat but instead is gaining heat from the fire.

Next steps

The SMARTER program is collaborating with USARIEM researchers to address these improvements, initially examining past firefighter research data of intermittent bouts of firefighting where the algorithm appears to perform as well as for military subjects. The collaboration will further update the algorithm and validate these updates from field research data planned with the SMARTER team. ■

Read more about the SMARTER project and related studies at skidmore.edu/responder.

Learn more about the research happening at USARIEM at usariem.army.mil/index.cfm/research.

Dr. Denise Smith is a professor of Health and Human Physiological Sciences at Skidmore College, where she holds the Tisch Family Distinguished Professorship and serves as director of the First Responder Health and Safety Laboratory. Her research focuses on physiological responses to firefighting and cardiovascular events in the fire service.

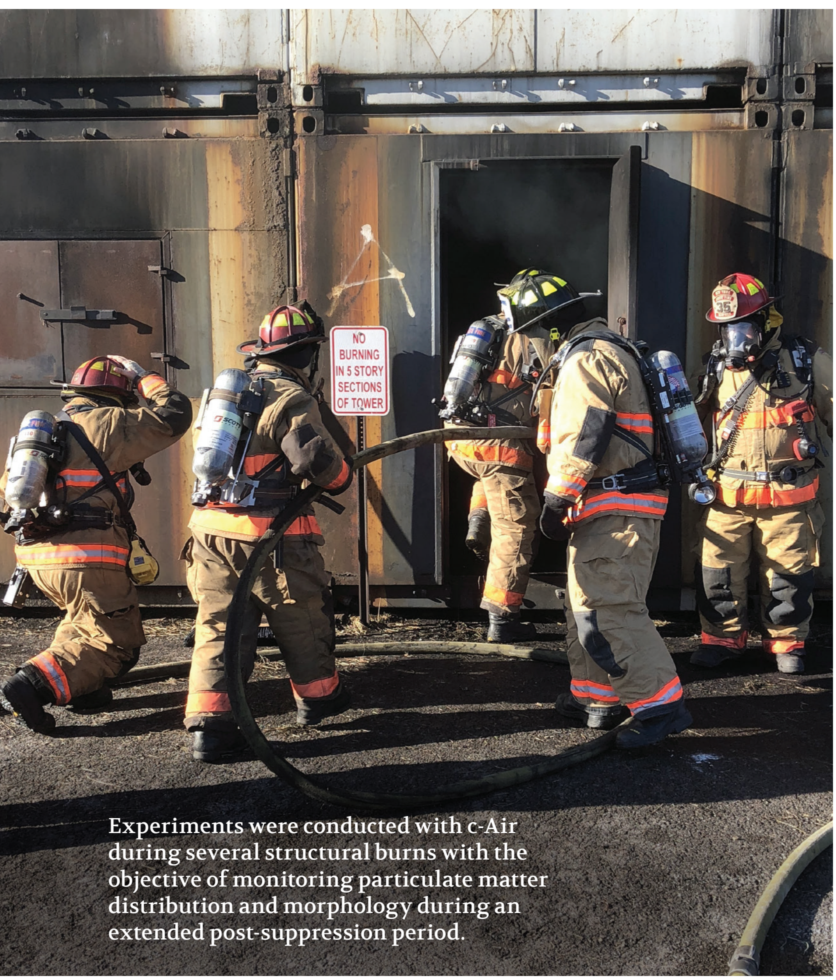
Dr. Mark Buller gained his doctorate in computer science from Brown University in computational physiology. He is a principal investigator with U.S. Army Research Institute of Environmental Medicine with over 20 years of experience fielding physiological monitoring systems for warfighters. His current research focuses on real-time feedback and performance optimization.

Particulate Monitoring

c-Air shows elevated particulates in air during test overhaul operations

by Yichen Wu, Maxim Batalin & Aydogan Ozcan

Smoke is ubiquitous on the fireground. Recently, we have come to better understand the composition of smoke and all of its components, including particulate matter (PM). PM with a general diameter of 10µm or smaller, called PM10, can cause serious health problems as it can become lodged deep in the lungs and enter the bloodstream. The PM2.5 category represents particles with a diameter of 2.5µm or smaller and has been declared a cause of cancer by the World Health Organization.[1]



Experiments were conducted with c-Air during several structural burns with the objective of monitoring particulate matter distribution and morphology during an extended post-suppression period.

Currently, state-of-the-art PM monitoring is performed by stationary instruments, such as beta-attenuation monitoring (BAM) systems, which are bulky and expensive. Various commercial portable devices are also available, although they focus primarily on counting particles in several size ranges.[2] PM from fires has a unique chemical composition and morphology,[3] and a more detailed analytical approach may improve understanding of PM and the dangers it presents.

Introducing c-Air

In collaboration with the SMARTER program, we have advanced the development and evaluation of a lensless microscopy-based PM monitoring device, called c-Air. Figure 1 shows c-Air utilizing a micro-pump, an impaction-based air-sampler (i.e., an impactor), and a lens-free holographic on-chip microscope. The impactor consists of an impaction nozzle and a sticky sampling coverslip. A pump drives the airstream through the nozzle at high speed. The PM inside the stream impacts with and is collected by the sticky coverslip. Particles captured by the impaction sampler are subsequently imaged by the computational microscope, and the data is reconstructed and analyzed by the custom-developed image processing algorithms[4] to obtain characterization of individual particles. The device is powered by a rechargeable lithium polymer battery. It is controlled and automated by a microprocessor.

Recently, we have performed a successful validation experiment estimating the number of PM with c-Air running alongside a BAM system, with the particle counts closely tracking each other.[5] Furthermore, we have also demonstrated the accuracy of c-Air estimating the size of particles with approximately 93 percent accuracy.[5] And we have successfully demonstrated the application of c-Air to monitoring and tracking the evolution of PM concentration and morphological features during a live wildfire.[6] These results showed that the c-Air system can be used for accurate PM measurement and characterization, while offering a portable and inexpensive alternative to existing state-of-the-art systems.

Using c-Air on structural burns

Unlike wildfires, structural fires often produce PM of non-biological origin, which may also include additional toxic particles and chemi-

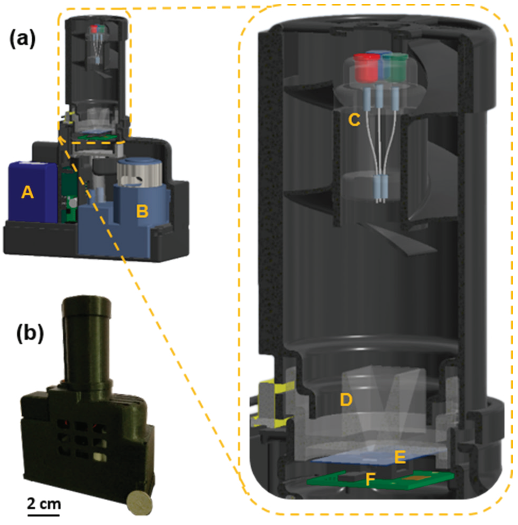


FIGURE 1: Lens-free microscope-based air-sampler, c-Air. (a) 3D computer-aided-design (CAD) overview of the device, including (A) rechargeable battery, (B) vacuum pump (13 L/min), (C) illumination module with fiber-coupled LEDs in red (624 nm), green (527 nm), and blue (470 nm), (D) impaction-based air sampler with (E) a sticky coverslip on top of (F) the image sensor. (b) Photo of the c-Air device. A U.S. 25-cent coin (quarter) is placed next to the device for scale.

cals. Recently, in collaboration with our colleagues—Dr. Denise Smith and her team from Skidmore College, as well as Shawn Brimhall, a fire protection specialist from the Division of Homeland Security and Emergency Services, State of New York—we have performed experiments with c-Air during several structural burns with the objective to monitor PM distribution and morphology during an extended post-suppression period (representing overhaul).

The first five burns were wood-based, followed by two wood pallets (100–120 pounds of class A material). The last three burns were "sofa"-based and each included overstuffed material with plywood composite, polyurethane foam, and synthetic materials over the top.

Figure 2 shows plots of counts for the total suspended particles (TSP) and PM10 detected at different post-suppression time intervals after a wood-only burn (experiment 3, Fig. 2a) and after a "sofa" burn (experiment 8, Fig. 2b). Note that in both cases, c-Air detected a significant number of particles still present in the air until 9–12 minutes post-suppression. Importantly, these values remained elevated despite the fact that interior fire instructors indicated that the room was "clear" of smoke and they thought it was OK to go off air. The time required for the PM counts to subside depends on many factors, including the scale of the fire and environmental conditions. This result emphasizes the importance of firefighters continuing to wear a breathing apparatus during post-suppression activities and the need for appropriate tools to monitor air quality.

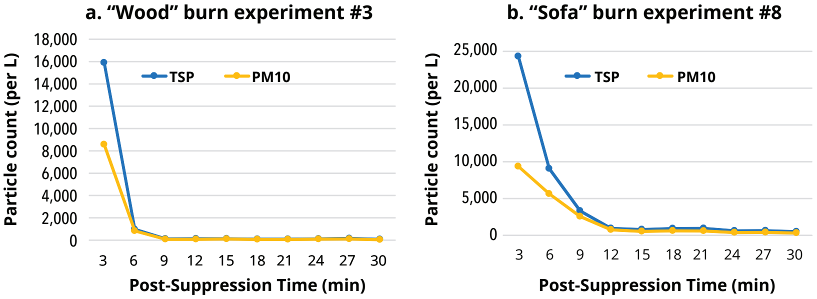


FIGURE 2: Particle counts post-suppression detected by c-Air. TSP is total suspended particles, PM10 stands for particles.

Looking ahead

We are continuing to develop the device to improve durability, increase range of PM concentrations, and extend analysis to vapor particles as well as solid phase or particles. Our goal is ultimately to provide firefighters with a low-cost portable monitor that measures PM concentration and its characteristics during emergency operations. ■

To learn more about c-Air and Dr. Ozcan's research lab, visit innovate.ee.ucla.edu/welcome.html and org.ee.ucla.edu.

Read more about the SMARTER project and related studies at skidmore.edu/responder.

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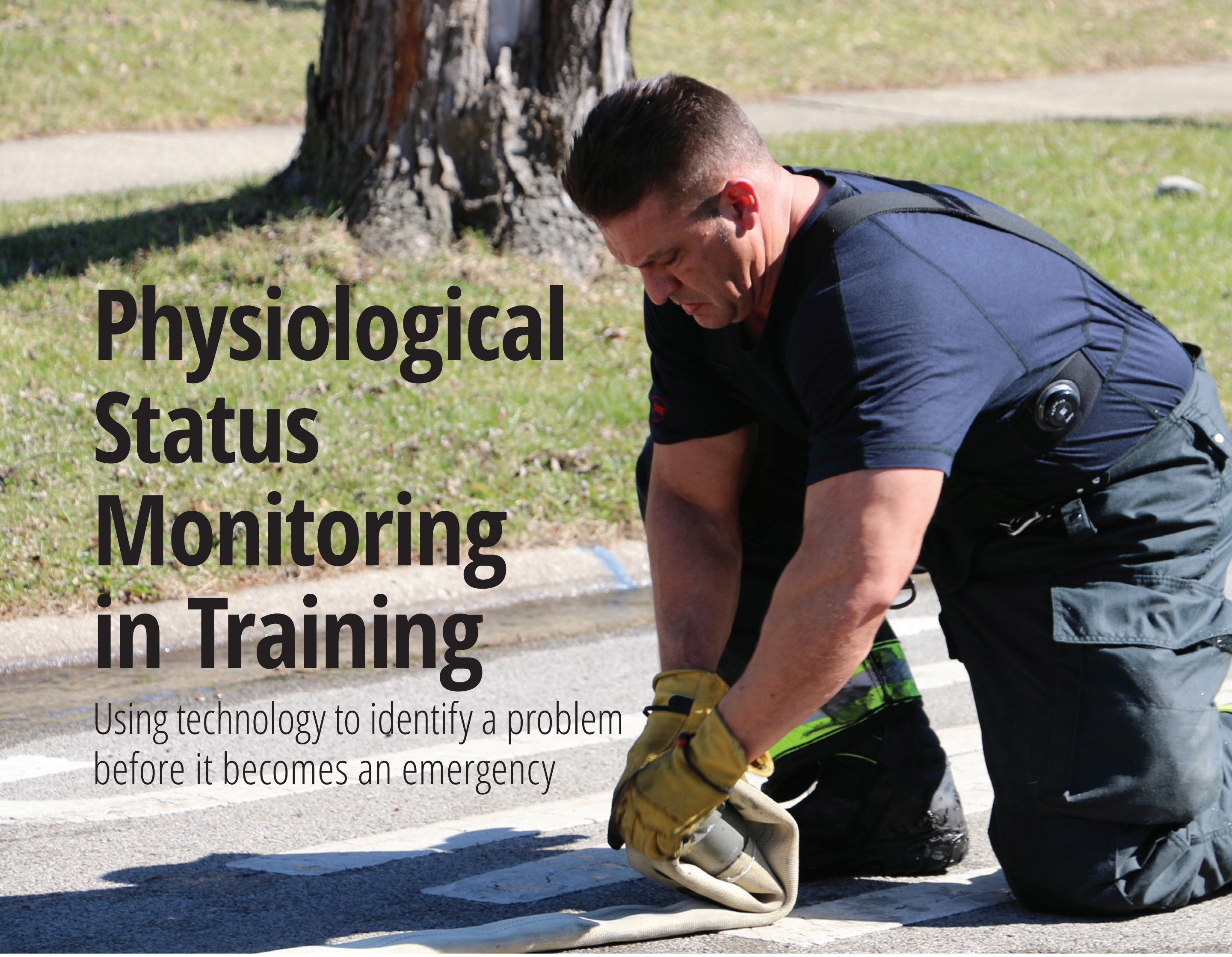
Yichen Wu is a PhD candidate at the Bio-Photonics Lab led by Professor Aydogan Ozcan in the ECE Department at UCLA. His research focuses on combining computational algorithms with optics to build novel imaging and sensing tools, and their applications in biomedical diagnosis and air quality monitoring.

Maxim Batalin, PhD, is an associate director at the UCLA Engineering Institute for Technology Advancement working with the UCLA Ozcan Research Group on new program development and project management. Batalin is focusing on the area of intelligent system innovations with applications to biomedical, environmental and sensor/actuator networks fields.

Aydogan Ozcan, PhD, is the chancellor's professor at UCLA and an HHMI Professor with the Howard Hughes Medical Institute, leading the Bio- and Nano-Photonics Laboratory at UCLA Electrical Engineering and Bioengineering Departments, and is also the associate director of the California NanoSystems Institute (CNSI) at UCLA.



Physiological Status Monitoring in Training

Using technology to identify a problem before it becomes an emergency

by Jeffery L. King

Firefighter Cadet Steven Whitfield was a member of Houston Fire Department (HFD) cadet class 2015G. On the morning of March 31, 2016, Cadet Whitfield's class was participating in a training evolution in the "Survival House" located on the campus of the Val Jahnke Training Facility (VJTF). Cadets, encapsulated in full structural PPE while wearing SCBA, maneuvered themselves through the structure in a non-immediately dangerous to life and health (IDLH) environment, under the supervision of training academy instructors.

At approximately 11:07 a.m., Whitfield, nearing the end of the course, stopped moving, which activated his personal alert safety system (PASS) device. Within seconds, instructors removed Whitfield from the course and started providing advanced life support accompanied with active cooling. He was then transported to the hospital and pronounced dead just before 1 p.m.

Seconds before collapsing, Whitfield spoke with instructors and was able to confirm his orientation to the environment and his surroundings. After having his cognitive ability evaluated, Whitfield remained on the course to complete the evolution. Whitfield was 10 feet from the exit when he collapsed.

What went wrong?

Men and women who serve in this industry understand the inherent risk associated with saving lives and protecting property. It is part of the job. Training, on the other hand, should not carry the same level of risk. Instructors carefully script training evolutions designed to maximize a cadet's potential for success while minimizing the cadet's exposure to risk. The bottom line is very simple: Losing a life during a training evolution is unacceptable.

The days following the loss of Whitfield at the training academy were incredibly difficult for everyone. Investigation into the line-of-duty death (LODD) began immediately. Cadets from class 2015G were questioned about the incident along with the instructors who were working in the Survival House that morning. Although I was not personally involved with the training evolutions, I found myself plagued by two simple questions: Why did this happen? Was it preventable?

Zephyr has partnered with Globe to integrate its PSM into a fire-resistant base layer shirt. Inset: Data is transmitted from the Zephyr system to a computer being monitored by fire personnel who can see when there is a physiological problem.

The *why* was answered within the autopsy report. The cause of death was hyperthermia and dehydration. The importance of hydration and a proper diet is introduced to the cadets prior to stepping foot on campus as a firefighter trainee during the conditional job offer. Once on campus, cadet instructors reinforce the importance of nutrition and hydration throughout the training program. Any problems with hydration were not due to a lack of effort on the part of academy personnel. As such, the only question left to ponder was if this incident was preventable.

Monitoring the body

The fixation on prevention started to shift early in the process. Prevention is really an extension of predictability. If we can accurately predict that something will occur, then we should be able to put mechanisms in place to prevent it from happening. Unfortunately, the ability to predict hyperthermia in a firefighter in a full PPE ensemble seemed difficult. A temperature can be obtained pre- and post-event, but not during the evolution. We did not have technology that was capable of providing a temperature reading of a firefighter who was wearing a full set of bunker gear.

With the help of another member of the Professional Development team, Firefighter Darryl Green, we started looking into wearable technologies that might have the ability to provide us with some insight into what was happening, on a physiological level, with a firefighter in full PPE. Our thought process was simple: If we could identify something going wrong with a firefighter (elevated heart rate, elevated respiratory rate, elevated body temperature, etc.), then maybe we could remove them from training before a medical emergency occurred.

We looked into a number of companies that sold wearable solutions, but the deeper we dove into the issue, the more we realized we had a another issue: Not only did we need to be able to identify the physiological status of a firefighter, we also had to transmit the information back to someone who could provide oversight on the issue. We needed to be *alerted* to a problem before it had the opportunity to become an emergency. Ultimately, this led us to Zephyr and their Physiological Status Monitoring (PSM) System. Zephyr has partnered with Globe to integrate its PSM into a fire-resistant base layer shirt.

Today, the training academy of the HFD has the ability to deploy two Zephyr PSM systems on campus. Each system can monitor up to 50 participants. Currently, the system is deployed to oversee the physical training of cadet firefighters when they are participating in evolutions that require the use of full PPE. A member of the VJTF Professional Development staff is dedicated to overseeing the entire PSM program. Engineer Operator Vidal Molina is responsible for deploying the system, monitoring the cadets during the training evolution, alerting instructors when there is cause for concern, and collecting the data for each evolution. The HFD uses the data collected to fine-tune criteria for removal from a training evolution. The removal criteria is evaluated on a case-by-cases basis and is measured against the baseline numbers of the participant.

A vital tool

We are working with the SMARTER research team to better understand the physiological strain associated with firefighting training scenarios and to help refine protocols to use wearable technology to keep cadets safer during these training scenarios. Physiological status monitoring is a potential technological solution that helps instructors "see" how the recruits are doing. We do not believe that physiological monitoring can replace a vigilant instructor, but it can be a useful tool to assist those who are committed to safely training firefighters in our care. ■

Read more about the SMARTER project and related studies at skidmore.edu/responder.

To learn more about the Globe by MSA WASP System, visit globeturnoutgear.com/innovation/wasp.

Jeffery L. King, BSFS, MSESM, CTO, FSCEO, is the district chief of fire training for Cy-Fair Volunteer Fire Department and a senior captain in the Houston Fire Department. He holds a bachelor's degree in fire science and a master's in Emergency Services Management. He is a chief training officer and a fire service chief executive officer.

Harness the Promise of Technology

Working together to determine where to focus our work and resources

by Denise Smith

We must form a true collaboration among members of the fire service, technology experts, researchers and commercial partners

The U.S. fire service has faced and adapted to many challenges over its celebrated history. Often, the fire service has met challenges by embracing or advancing technology. Consider SCBA. As it became clear that firefighters needed respiratory protection to operate deep within structures, SCBA was developed and then adopted by the fire service. The adoption of technology then, and now, is not without challenges. But there is no doubt that technology has made the fire service safer, and has the potential to do more to protect firefighters.

The SMARTER project has continued the tradition of exploring the use of technology and adapting it when necessary to serve the needs of the firefighters. This project has focused on multiple ways that technology may improve health and safety, focusing on data that indicates that firefighters are at risk due to high levels of cardiac strain, heat stress and exposures to particulate matter.

The technologies we explored were in different stages of development, from a prototype particulate monitor to a commercially available wearable physiological monitoring system. Throughout the project, we have advanced technology, better understood how to apply the technology to the fire service, and identified challenges that remain before technology can be relied upon to protect first responders. And we are still at the early stages of what we believe will be rapidly developing technology that may support the fire service.

It is likely that in coming years, we will hear about using physiological monitoring during rehab or wildland fires; integrating physiological monitoring with gas sensors and possibly even integrating them into PPE; smart fabrics with embedded sensors and tattoos that sense physiological responses; and miniature devices to obtain biological samples.

Perhaps the greatest challenge we face as we continue to search for and evaluate new technologies for the fire service is to be guided by leaders who have the judgment to discern when technology offers the opportunity to improve the situation and when it is a bright shiny object that distracts our focus. To truly harness the promise of technology, we must form a true collaboration among members of the fire service, technology experts, researchers and commercial partners. And the fire service must ultimately determine which technology helps them do their job, and do it more safely.

— Dr. Denise Smith, professor of Health and Human Physiological Sciences, Skidmore College; director, First Responder Health and Safety Laboratory

For more about the SMARTER project and related studies: skidmore.edu/responder

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