Review Article

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Wildland Firefighting and Wearable Technology: A Review

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Abstract

Wildland fires remain a major problem in multiple regions of the United States, as well as across the globe, as their frequency continues to rise. This type of fire poses a unique challenge as multiple agencies and personnel are needed to manage the large geographical areas spanned by forest fires. Two of the greatest needs for wildland firefighters are location based tracking and environmental monitoring. These needs may be solved through the implementation of wearable technology within wildland firefighter personal protective clothing. The purpose of this review article is to synthesize the wearable technology needs of wildland firefighters in order to improve their health and safety. Multiple technology challenges and solutions are presented, including the need for the future development of an enhanced location tracking and environmental monitoring wearable technology system.

Keywords: Wildland Firefighting, Technology, Wearable Technology, Firefighter, Protective Clothing

Introduction

Wildland fires remain a major problem in multiple regions of the United States, as well as across the globe, as their frequency continues to rise [1-3]. In 2018, there were 1,318,500 fires in the United States with the majority (607,000) classified as outdoor fires in which 10 wildland firefighters lost their lives [4,5]. Unfortunately, in 2013, wildland firefighter fatalities were even greater due to the Yarnell Hill Fire which took the lives of 19 firefighters [6]. From 1992 to 2006, the greatest number of natural disaster occupational deaths (80) were due to wildfires [7,8]. Substantial research has been conducted to assess the physiological and environmental stresses placed on wildland firefighters [7, 9-16]. These stressors include smoke and carbon monoxide (CO) inhalation, physical exhaustion, and dehydration [16]. Tracking the status and location of wildland firefighters is also a difficult challenge as they work in large, often remote, geographic areas [16]. Determining and communicating the location and status of firefighters on the ground is crucial to both the firefighting operation and the safety of the firefighters. Future research efforts may focus on developing integrated wearable technology systems within wildland firefighter protective clothing to communicate firefighter location in remote areas and to monitor carbon monoxide exposure levels, including providing real time alerts to the firefighter and incident command.

Existing technology employed on the forest fire ground today is problematic due to GPS signal limitations in remote locations and steep terrain, as well as, the lack of systems integration into the wearable clothing system [17]. Auxiliary attachments for GPS tracking and environmental monitoring sensors have been developed but they are cumbersome and lack seamless integration into the wildland firefighting ensemble [11,12,16]. Wildland firefighters perform many different tasks including detection, suppression, and mopping on Type I hotshot, smokejumper, and helitack crews that jump from the air to the fire ground, and on Type II crews with less experience [11]. These activities involve intense, and sometimes extreme physical activity, all while the firefighter wears a significant amount of personal protective equipment (PPE) including base layers, jacket, trousers, face and neck shrouds, eye protection, hardhat, gloves, boots, fire shelter and carries large tools [18]. Although current data logging technologies exist for tracking GPS location through auxiliary radio antennas and portable, hand-held devices, these formats are inconvenient and incompatible with the nature of wildland firefighting activities [16,17]. Instead, a hands free device which tracks location in remote areas and in steep terrain, as well as, monitors environmental exposure could potentially be integrated into the wearable PPE of the wildland firefighter. Such a device meets the technology needs of the future for wildland firefighters as identified by the Department of Homeland Security, National Fire Protection Association (NFPA), and NIST Smart Fire Fighting Report [19-22].

Wildland Firefighting

A wildland fire is usually uncontrolled, unless it is a prescribed burn used for wildlife fire management, and is located mainly in forest areas, although it may quickly spread to agricultural and urban regions, as well [23]. The large land expanse over which a fire may spread and its unpredictability due to shifting winds are primary reasons why wildland firefighters need accurate location tracking information in real time. The increase in frequency of wildland

fires is another reason that justifies the need for an advanced GPS location tracking technology. Over a five year period between 2007-2011, more than 900 outdoor fires per day were responded to with large wildland forest fires causing hundreds of millions of dollars in property damage and loss [24,25].

Type I and Type II wildland firefighting crews respond to these fires from the air and the ground with each firefighter conducting specialized tasks that are key to fire suppression [11,26,27]. Recent literature indicates that the increase in the frequency and intensity of wildland fires may be due to climate change which has led to a higher number of firefighter fatalities and injuries [10]. Fire suppression agencies are combating this increased risk to wildland firefighters by attempting to improve communication, mapping, and decision making [10]. Now, more than ever, it is vital that mission-critical emergency response information be provided to wildland firefighters at the touch of a button. The most convenient way to implement such technology is within their personal protective clothing (PPC).

Hazardous Environment

Wildland firefighters put their lives at risk every time they respond to an emergency call [28]. They are trained to fight a wide range of dangers including the risk of burnover, falling trees, rolling rocks, and carbon monoxide exposure, along with many others [10,29,30]. Wildland firefighters operate on a 2:1 work/rest cycle (for every two hours of work, the firefighter receives 1 hour of rest or sleep) for shift lengths of 24 hours, running concurrently for 14 day periods with a mandatory break of only 2 days between assignments [9,31]. During these long shift durations, firefighters are exposed to multiple environmental stressors including increased altitude, heat, humidity, fatigue, and smoke exposure.

Personal Protective Clothing (PPC)

In order to combat environmental factors such as high heat and flame exposure, wildland firefighters are required to don protective clothing that meets mandatory requirements for flame resistance, material strength, thermal protective performance, and launderability [18]. These specific performance requirements are mandated by NFPA 1977 *Standard on Protective Clothing and Equipment for Wildland Firefighting*. This standard covers the certification of all wildland firefighting PPE including the jacket and pants which are made of durable, aramid fabrics such that, if exposed to flame, burning will stop upon removal of the flame. A key feature of wildland protective clothing is its loose fit which ensures protection from radiant heat and heat stress, as ventilation is necessary to allow air and moisture to pass through the clothing microclimate to the external environment [32]. It is vital that the integration of the wearable technology system into the wildland PPC maintains the integrity of the garment's thermal protection and comfort properties.

It is also crucial that any potential wearable technology system meet the NFPA certification criteria in order to develop a marketable and affordable prototype that is feasible for commercial production. Most wildland firefighters are employed by government agencies such as the U.S. Forest Service or state agencies, such as the Florida Division of Forestry [11]. These agencies are responsible for supplying wildland firefighting crews with the proper certified PPE. In order to be certified, the developed wearable prototype must meet the textile testing performance requirements specified in NFPA 1977.

Technology Assessment

Multiple wildland firefighting reports and studies cite technology and next generation uniforms as the way of the future for improving wildland firefighter health and safety [10,20,23,33]. The key to improving wildland firefighter communications is to adopt a comprehensive, multifaceted system that enables real-time, continuous monitoring for situational awareness that allows instantaneous response [23]. Technology has drastically changed the tactics for wildland fire management in recent decades [34]. Computer technology has enabled geographic location mapping, satellite imagery, and immediate agency response [34].

Recent technological advances in wildland firefighting include thermal imaging, drone surveillance, and virtual reality [35]. Thermal imaging devices allow improved mapping of wildfire patterns and detection of hot spots out in the field. In today's advancing technology world, handheld thermal imaging cameras are compatible with smartphones, also making them more affordable and applicable in the wildland firefighting environment. Drone technology is also being explored for its potential use in surveying fires instead of piloted aircrafts and virtual reality is being implemented in the three-dimensional training simulations [35]. The cost of these technologies, however, currently prevents their adoption into wildland firefighting, but as technology continues to advance, these devices will become more affordable.

Personal monitoring devices for body temperature, respiration, blood pressure, and heart rate also currently exist, although not at a level that is affordable for wildland firefighters to adopt [36,37]. Globe's Wearable Advanced Sensor Platform (WASP) is one such example currently available for structural firefighting applications. This wearable electronic system monitors structural firefighter physiological responses and reports them in real time to incident commanders [38]. The Zephyr technology bioharness for monitoring these responses is implemented into a base layer shirt worn under the structural turnout suit. The electronic system also includes a location tracking system developed by TRX Systems that is mounted on the wearer's belt and is compatible with Android cell phone apps [39]. This existing location tracking technology could be used for wearable integration into wildland PPC with algorithm enhancements.

Wearable Technology

Wearable technology refers to garments or accessories that are created using electronics [40]. These devices are worn by users in such a way that prevents them from being inhibited by the device while providing them with information about themselves and/or their surrounding environment [40]. Further differentiation of wearable technology from portable devices is its ability to be indistinguishable from everyday life such that it may go unnoticed [40]. This lack of notice by the user is a crucial part of the technology integration in wildland firefighting applications and should be done within their current PPC. For wildland firefighters, the two greatest needs for wearable technology are location based tracking and environmental monitoring [36].

Location Based Tracking

The need to strengthen the disaster response capacity for wildland firefighting still remains [23]. GPS technology has been in use in wildland fire management since the mid-1990s [17]. GPS is an all-weather, 24-hour-a-day, satellite based positioning system that

was developed by the United States Department of Defense [17]. GPS receivers on the ground use satellite signals orbiting above the earth as precise reference points in order to calculate position. These signals have been used throughout the fire management process for preplanning, detecting, and dispatching crews. This technology enables accurate location tracking of the fire region in order to plan a timely initial attack and continue fire suppression activities. Current mapping technologies are supplemented by GPS capabilities that provide unprecedented details [10]. For wildland firefighters, however, this isn't enough. A major limitation of GPS technology is signal loss due to steep terrain masking satellites and blocking their signals [17]. While the location tracking technology exists in its current GPS format, it must be elevated and advanced to meet the needs of firefighters in remote locations and in steep terrain where signal loss occurs.

In emergency situations, wildland firefighters need to know the status and location of their emergency personnel. Wildland firefighters may cover remarkably long distances during their shifts and are often unaware of how much terrain they have walked during the course of their work [7]. The ability to determine where a first responder is located in highly dynamic and dangerous environments is crucial to reduce risk of injury and loss of life. There are gaps in current GPS location tracking, particularly in remote areas with steep terrain where satellite signals are weaker or may be missing altogether [17]. Not only does the wildland firefighter need to know his or her exact location in relation to the surrounding environment, leadership personnel in multiple management agencies also need to be able to determine the location of multiple firefighters throughout various crews on the fire ground. Therefore, the need is even greater for wildland firefighter applications to develop an accurate and effective location tracking system.

Monitoring devices that track location and status have been developed and tested in wildland firefighter applications but they lack the convenience of a wearable integration [16]. Kremens, Faulring, and Phillips created a compact device to monitor firefighter health, location, and status in 2005 [16]. This device reported temperature and carbon monoxide concentration near a firefighter as well as heart rate, breathing rate, and position on the fire ground. While this research demonstrated the effectiveness of existing technology including smart sensors, wireless modems, and digital networks, it did not offer seamless integration into the wildland firefighter's current PPC at an affordable price. Another wildland firefighter technology system was recently developed and tested in an observational study [7]. This device was only tested on two firefighters who wore microphones, small video cameras, heart rate monitors, and GPS units [7]. While these devices were "worn" on the body, they were not integrated into wildland firefighting PPC. The large amount of PPE required for wildland firefighting is already at such a high level that many firefighters do not don all of the necessary accessories, including their protective shelters for burnover conditions. Instead of adding to the number of accessories, devices, and tools that wildland firefighters must carry, technology should be integrated directly into the design of the wearable clothing system through wireless sensors and devices.

The ability of such a potential integrated wearable device to send positional information to lead personnel should be a key objective of the dissemination, within location based services. Knowing the location of the firefighters at all times allows for emergency alerts to be communicated when dangerous conditions occur in certain areas of the wildfire. Such technology would also allow lead personnel to know when a firefighter, or crew, is in need of rescue or emergency response. Therefore, the development of a wearable position location and dissemination system for first responder use in wildland fire conditions is needed in order to improve the health and safety of wildland firefighters and to prevent fatalities. Furthermore, using such an advanced location tracking system would allow lead personnel to efficiently allocate available firefighting crews to the most effective locations for containment and suppression.

Environmental Monitoring

Wildland firefighters are continually exposed to smoke while on the job for long durations and periods of time. Of specific concern is the exposure to significant levels of carbon monoxide and respiratory irritants. Multiple studies have shown that carbon monoxide exposure reaches high to very high levels in a considerable portion of situations (30%), particularly when performing fire suppression, back burning, mopping up, and patrol tasks on steep slopes [11-15]. Maximum peak CO exposures were recorded between 179ppm and 319ppm within these separate studies, far exceeding the National Institute for Occupational Safety and Health (NIOSH) and Occupational Safety and Health Administration (OSHA) permissible exposure limits of 35ppm and 50ppm, respectively, as well as the ceiling limit of 200ppm. In combination with the intense workload of wildland firefighters, even at moderate exposure levels, increased inhalation of CO can cause adverse, immediate health effects. The primary concerns of CO exposure are the immediate short term health effects (eye irritation, shortness of breath, irritability, dizziness, and nausea) and long term consequences to the central nervous system [13,41].

A majority of all wildland firefighter air toxin studies also identified strong correlations between the detection of carbon monoxide and other respiratory irritants including formaldehydes [11]. These results indicate that one pollutant, such as CO, can be used to estimate exposure to another [11]. Therefore, detection of harmful levels of exposure to CO could also inform the firefighter of their probable exposure to other respiratory irritants.

While the aforementioned previous studies have measured carbon monoxide exposure of wildland firefighters using electronic data-logging dosimeters with electrochemical sensors that measure CO levels in the air up to 2000ppm, these devices are handheld, or portable, and not integrated directly into the wearer's PPC [13,14]. Given the overwhelming amount of additional tools and devices the wildland firefighter is already required to carry, this CO detection technology should be integrated as a wearable sensor directly within the clothing structure. Such a sensor should be capable of detecting and alerting the wearer when high levels of carbon monoxide are in close proximity.

This technology currently exists on the market with the need for wearable integration to be further explored for specific wildland firefighting conditions [42]. The available sensor has a measurement range of 0-500ppm with a maximum overload of 1000ppm. This device range covers that which is required by NIOSH and OSHA under their specified permissible exposure limits (35-50ppm time weighted average; 200ppm peak level exposure) [41]. This particular sensor can also withstand temperatures up to 50°C and is small enough in nature to be easily integrated into a wearable garment in such an area as the sleeve or cuff [42,43].

Conclusion

Wildland firefighters face multiple challenges during their day to day operations including smoke and carbon monoxide (CO) inhalation, physical exhaustion, and dehydration which are made more problematic by the lack of ability to accurately and continuously track the status and location of wildland firefighters. Two of the greatest needs for wildland firefighters are location based tracking and environmental monitoring. This review of technology literature as it pertains to wildland firefighting applications supports the enhanced improvement of existing market technologies for location tracking and carbon monoxide detection. Integration of these technologies into a wearable platform would meet the high priority goals of smart firefighting cited as a need for future research by multiple organizations (DHS, NIST, NFPA, etc.). Existing technology should be evolved in order to develop an innovative, yet feasible, wearable system that is certifiable and readily adoptable by the wildland firefighting community.

References

1. Hylton J.G. Haynes (2017) Fire Loss in the United States During 2016. National Fire Protection Association 01-56.
2. Hylton Haynes, Angela Garcia and Rachel Madsen (2015) Wildland/Urban Interface: Fire Department Wildfire Preparedness and Readiness Capabilities. National Fire Protection Association 01-132.
3. Nigel Chiwaya, Jiachyan Wu and Robin Muccar (2020) This is how big Australia's wildfires actually are. NBC News.
4. Ben Evarts (2019) Fire loss in the United States during 2018. Quincy, MA: National Fire Protection Association 01-20.
5. RF Fahy and JL Molis (2019) Firefighter Fatalities in the US-2018. Quincy, MA: National Fire Protection Association 01-26.
6. National Interagency Fire Center (2016) Wildland Fire Fatalities by Year.
7. R Parker, A Vitalis, R Walker, D Riley and HG Pearce (2017) Measuring wildland fire fighter performance with wearable technology. Appl Ergon 59: 34-44.
8. GM Fayard (2009) Fatal work injuries involving natural disasters, 1992-2006. Public Heal Prep 3: 201-209.
9. Missoula Technology and Development (2002) Wildland Firefighter Health & Safety Report. Center no 5.
10. P Withen (2015) Climate change and wildland firefighter health and safety. New Solut a J Environ Occup Heal policy 24: 577-584.
11. Timothy E Reinhardt and Roger D Ottmar (2004) Baseline measurements of smoke exposure among wildland firefighters. J Occup Environ Hyg 1: 593-606.
12. Olorunfemi Adetona, Christopher D Simpson, Gretchen D Onstad and Luke P Naeher (2013) Exposure of wildland firefighters to carbon monoxide, fine particles, and levoglucosan. Ann Occup Hyg 57: 979-991.
13. F Reisen, D Hansen and (Mick) P Meyer (2011) Exposure to bushfire smoke during prescribed burns and wildfires: Firefighters' exposure risks and options. Environ Int 37: 314-321.
14. Fabienne Reisen and Stephen K. Brown (2009) Australian firefighters' exposure to air toxics during bushfire burns of autumn 2005 and 2006. Environ Int 35: 342-352.
15. Ana Isabel Miranda, Vera Martins, Pedro Cascão, Jorge Humberto Amorim, Joana Valente, et al. (2010) Monitoring of firefighters exposure to smoke during fire experiments in Portugal. Environ Int 36: 736-745.
16. Robert L Kremens, Jason Faulring and Dan Phillips (2005) A Compact Device to Monitor and Report Firefighter Health, Location and Status. Eighth International Wildland Fire Safety Summit p 1-8.
17. Dick Mangan (1994) GPS Use in wildlandFire Management. Fire Tech Tips.
18. National Fire Protection Association (2016) NFPA 1977: Standard on protective clothing and equipment for wildland fire fighting.
19. Greg Otto (2014) DHS sees wearables as the future for first responders. FedScoop 2014.
20. Robert Griffin (2015) Meet the responder of the future. U S Department of Homeland Security.
21. Casey Grant, Anthony Hamins, Nelson Bryner, Albert Jones and Galen Koepke (2015) Research Roadmap for Smart Fire Fighting. Natl Inst Stand Technol p 01-247.
22. Fire Protection Research Foundation (2014) The 2014-2019 research priorities for the fire protection research foundation.
23. Antonio Molina Pico, David Cuesta Frau, Alvaro Araujo, Javier Alejandre and Alba Rozas (2016) Forest Monitoring and Wildland Early Fire Detection by a Hierarchical Wireless Sensor Network. J Sensors p 01-08.
24. Marty Ahrens (2013) BRUSH , GRASS , AND FOREST FIRES. National Fire Protection Association p 01-74.
25. National Fire Protection Association (2016) Largest loss wildland fires. Fire statistics and reports,
26. DL Smith, SJ Petruzzello, JM Kramer and JE Misner (2010) The effects of different thermal environments on the physiological and psychological responses of firefighters to a training drill. Ergonomics 40: 500-510.
27. Wildland Firefighter. USDA Forest Service.
28. Corey Campbell and Liz Dalsey (2012) Wildland fire fighting safety and health. Centers for Disease Control and Prevention.
29. National Fire Equipment System (2014) Incident Response Pocket Guide. National Wildfire Coordinating Group.
30. National Institute of Environmental Health Sciences (2014) Wildfires: NIEHS Wildfire Response Training Tool: Protecting Yourself While Responding to Wildfires.
31. Ramona Beyuka (1998) Wildland firefighter safety awareness study: Phase III implementing cultural changes for safety. TriData Corporation, Arlington, VA.
32. John Smith and Tony Petrilli (2013) Changes for Firefighter Shirts and Pants. Fire Tech Tips.
33. Seshadri Ramkumar (2016) Defining smart textiles and their standards. Advanced Textiles Resource.
34. State-of-the-art equipment and software: aids wildland fire management. US Forest Service.
35. National Fire Fighter Wildland Corp (2015) 5 Technological Advances in Wildland Fire Fighting.
36. Bill Schrier (2015) How tech could improve wildland firefighting, and protect lives. GeekWire.
37. Dennis C Wood, Edward J Dadosky (2012) Implementing physiological monitoring in the fire service: technology. Fire Rescue.
38. Bill Carey (2012) Globe's WASP Physiological and Location Monitoring on the Fireground. Backstep Firefighter.
39. WASP Wearable Advanced Sensor Platform. Globe.
40. Tom Page (2015) A forecast of adoption of wearable technology. Int. J. Technol. Diffus. 6: 18.

41. Carbon Monoxide. National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention 2013.
42. ULPSM-CO V2. KWJ Engineering.
43. FN Dost (1991) Acute toxicology of components of vegetation smoke. Rev Environ Contam Toxicol 119: 1-46.