# Tuesday, October 18

## Presentations on Electronics in PPE

### Design of a Wearable Electronics Package for Firefighter Monitoring

***Alton G. Dunn, Todd Leonhardt, Michael Masterman,*** *Extreme Endeavors*

Wearable electronics using "e-fabrics" or electronic textiles are being developed for military and Emergency Service Personnel. Also, the popularity and expansion of mobile communications has spurred interest in numerous personal electronic devices. The design of an electronic lifeline system integrated with a firefighter's personal protective equipment (PPE) is described in this paper. The purpose of this electronic PPE system is to monitor the vital signs and environment of active firefighters, while they are performing strenuous activity inside a burning structure, and transmit this data to the incident command center on the fire ground. The primary goal is to reduce firefighter fatalities, which are mainly the result of heart attacks. Secondarily, the system may be used to provide voice communications, and the location of trapped or downed personnel. The entire electronic monitoring system, including the sensors, processor, and communications equipment is embedded within the turnout coat, and is transparent to the user. Operation of the system is automatic, and requires no actions or inputs from the individual.

### Embedded Personal Location for First Responders

***Scott Thayer,*** *Carnegie Mellon University*

Presented is a new class of Personal Location System (PLS) that does not depend on the availability of external reference signals. Described is a second generation PLS that does not require Global Positioning Systems (GPS) or Radio Frequency (RF) location devices to estimate first responder position within a multi-floor urban structure. Our PLS relies on two fundamental concepts that enable a completely self-contained solution: Personal Networks and Body-Distributed Sensing.

Personal networks are analogous to wireless computer networks that are ubiquitous in modern offices and many homes. Personal networks provide a means to distribute information gathered directly at different locations on a body and wirelessly relay that information to data acquisition, filtering, and processing devices resident elsewhere on the same body.

Body-distributed sensing, enabled by reliable personal networks, provides unprecedented ability to gather precision motion, physiological, and environmental data. Improved precision is a natural consequence of directly coupling sensors to relevant locations on a body. As an example, precision measurement of leg motion by sensors embedded in footwear will be superior to indirect measurements of leg motion gleaned by beltmounted motion sensors.

Detail is provided on the major components and algorithms comprising a PLS that uses body-distributed sensing to obtain precision capture of human limb motion by direct placement of embedded sensors. Motion data from embedded sensors is communicated via personal networks to computation and processing nodes where it feeds kinematic models of human motion estimation. Kinematic motion data is then fused with standard inertial motion estimation techniques to provide a superior position reference suitable for multi-floor personal location without infrastructure requirements.

Analysis of the second generation PLS is provided for both indoor and outdoor localization tasks relative to ground truth information obtained from differential GPS or loop-closure experiments. Examples of typical errors generation during 2-D (flat floor) and 2.5-D (uneven outdoor terrain) and 3-D (multi-floor, indoor scenarios) are also outlined. The paper concludes with a description of deployment strategies, operational scenarios, and planned future work.

**First Responder Thermal Imaging Performance Evaluation Research at NIST**
***Francine Amon, Anthony Hamins, Nelson Bryner,*** *National Institute of Standards and Technology (NIST)*

Thermal imaging cameras are rapidly becoming integral equipment for first responders. Although these instruments represent a significant portion of a typical first responder organization's budget, there are no standardized performance metrics available to the users to aid in making purchasing decisions. Imager manufacturers currently don't use consistent testing methodology and are therefore unable to directly compare their products to those of competitors. The Building and Fire Research Laboratory at the National Institute of Standards and Technology (NIST) has developed a bench-scale testing facility and methods to evaluate the performance of thermal imagers used by first responders. The facility is used to test the performance of currently available imagers and advanced fire detection systems, as well as serve as a test bed for new technology.

The overall objective of this project is to establish performance metrics and testing methodologies that adequately characterize thermal imager performance in terms that are meaningful to first responders. In support of this goal, components of the research being conducted at NIST on thermal imagers for first responders include establishing typical testing conditions that are representative of the environments in which the imagers are used; identifying the relative performance of subsystems within an imager that bear directly on the imager's ability to reproduce an image, such as the display, infrared detector, and transmitter; development of new testing technology, in which spatially and spectrally accurate electronically generated target scenes are produced and projected to the imagers; and an evaluation of the performance of different thermal imaging detector technologies under field conditions.

Results of full-scale tests show that, when viewing identical scenes, thermal imagers having different infrared detector technologies produce images having significantly different quality. Individual imagers perform differently within a range of conditions as well, for example, an imager may perform relatively well compared to other imagers when looking through heavy smoke but not when looking at large or small temperature differences. These results were also evident in bench-scale testing. Results of this project will provide a quantifiable physical and scientific basis upon which industry standards for imaging performance, testing protocols and reporting practices related to the performance of thermal imaging cameras can be developed.

## Use of Combination Hearing Protectors and Communication Earpieces for First Responders

***Jeremie Voix,*** *Sonomax Hearing Healthcare, Inc.*

First responders often are placed in training and field situations where environmental noise levels pose a risk to their hearing, but they are still required to effectively use their ears to receive critical communication. This has been accomplished traditionally by two approaches.

The first requires use of hearing protection, and using radio systems with shoulder or chest mounted speaker/microphones. The output level of the speaker is typically adjusted to make it audible over ambient noise and through the hearing protector. Difficulties ensue, including insufficient signal-to-noise ratio for critical first-transmission understanding, and distortion inherent in speaker devices driven to their limit.

The second uses ear microphone technology, where in-ear systems transmit and receive auditory information. These systems can work well, but require an earpiece with a reliable acoustic seal, which has proven difficult to obtain.

A new technology called the Sonomax Solution addresses this situation.  It includes an instant-delivery custom earmold with individually tested and documented acoustic seal and attenuation characteristics. Once fabricated and tested, the hearing protector can be interfaced with a wide range of radio and communication systems to serve as a communication earpiece, offering the first responder both protection from the effects of noise and enhanced communication ability. The communication signal, delivered though the earmold, is no longer required to compete with outside noise and a traditional hearing protector for audibility. Technology will be described and case studies provided.

Bio: Jeremie Voix is an Acoustics Engineer with field experience in industrial noise reduction projects. He holds a Bachelor of Fundamental Physics from University of Lille (France) and a Mater of Applied Sciences in Acoustics from Sherbrooke University (Canada). Jeremie is Director of Research and Chief Scientist of Sonomax Hearing Healthcare, Inc. (Montreal, Canada). He also is currently finishing his Ph.D. at the University of Quebec (Montreal, Canada).

# Presentations on Test Methods for PPE

## Thermal Protective Performance Test for Firefighter Protective Clothing

***Kuldeep R. Prasad,*** *National Institute of Standards and Technology (NIST)*

Significant technological advances have been made in the area of fire fighter protective clothing, however fire fighters are still being seriously burned and fatally injured while wearing protective clothing systems that satisfy all existing performance standards. To understand how these burn injuries can arise and therefore be prevented, a physics-based model, capable of describing heat and moisture transport across multiple layers of protective fabrics, has been developed. The inclusion of moisture transport is considered a significant advance in the predictive capabilities of the model as the energy absorption due to evaporation and the energy release associated with condensation may play important roles in determining the overall protection offered by a protective garment.
A computational tool has been created that is capable of describing the thermal response of multi-layered fabrics under a wide array of moisture conditions and heat exposures. The tool has been integrated with a graphical user interface that simplifies the input of simulation conditions and fabric configurations as well as provides for visualization of the results obtained from the simulation. The tool and interface, termed the Protective Clothing Performance Simulator (PCPS), has been utilized to demonstrate the importance of moisture inclusion under long-term low-level exposures. These tests determined that the presence of moisture, under these conditions, enhanced the protective capabilities of a turnout coat. In addition, PCPS has also been used to simulate the response of protective fabrics to higher levels of incident heat. The Thermal Protective Performance rating, obtained experimentally from standard tests for protective fabrics, has been successfully predicted for a variety of both single and multi-layered fabrics. As the model is physics-based, it is capable of conducting parametric analyses whereby measurable properties can be varied so as to determine how the maximum protection may be realized while simultaneously minimizing undesired properties such as overall fabric weight.

## Development of a Test Method for Measuring Stored Energy in Firefighter Turnouts

***Anthoney S. Deaton, Roger L. Barker,*** *North Carolina State University*

Fire fighters can receive burns in thermal exposures that are considerably lower than flashover conditions. These burns occur as a result of prolonged exposure in thermal environments classified as routine, or hazardous, in heat flux less than about 0.3 cal/cm2sec. These exposures are usually several minutes in duration, and the exposure levels are generally not sufficient to degrade the turnout shell fabric. Burns are thought to occur as a result of thermal energy transmitted to the garment through both radiant and convective source. Subsequent compression of the heated ensemble onto the body due to fire fighter movement or external pressure can discharge stored thermal energy.

This presentation describes a laboratory test method for measuring stored thermal energy in firefighter turnout materials. It presents the results of a study designed to show the effect of thermal exposures, and material variables, including the effects of outer shell, moisture barrier, thermal liner, and reflective trim on stored energy phenomena.

**A Passive Aerosol Sampler for Evaluation of Personal Protective Ensembles**
***William P. King, Pengfei Gao,*** *NIOSH/NPPTL*

Aerosol measurements are usually not limited by the aerosol volume or space for equipment. However, both are a consideration in measuring the aerosol penetration of protective ensembles, as in a man-in-simulant-testing (MIST). Induced airflow from sampling confounds results and the clearance under ensembles is small. With multiple samplers inside the ensemble, sampler size must be small. In chemical MIST, simulant is collected on passive adsorbent dosimeters. No comparable passive aerosol dosimeter exists that can avoid particle penetration overestimation.

A passive aerosol personal sampler for protective ensemble evaluation has been developed in our laboratory. Neodymium iron boron (NdFeB) magnets were selected as key component of the sampler, and iron oxide (Fe3O4) was selected to generate challenge aerosols. This combination allows aerosols to be passively collected by magnetic fields without air flow. The use of iron oxide as challenge aerosols has other advantages including low cost, availability in various particle sizes, and very low toxicity (OSHA PEL 10 mg/m3). In this study, aerosols at concentrations of 500 mg/m3 were generated. Four types of permanent magnets were initially compared including iron tape (13mm x 20mm x1mm), alnico-V bar (24mm x 9mm x mm9), NdFeB grade N35 ring with steel backing, a diameter of 12 mm and a thickness of 3mm, and as plated disc with a diameter of 18 mm and a thickness of 3mm. The magnets were covered in parafilm. The iron oxide collected on the parafilm was dissolved in dilute acid, and oxidized to convert all iron to iron (III) using H2O2. The iron was then determined colorimetrically. The iron oxide collected was 3.8, 44.7, 38.4, and 76.8 micrograms for iron tape, alnico-V bar, NdFeB ring and nickel-plated NdFeB disc, respectively. Parafilm alone collected 2.5, 1.0, 2.5 and 0.3 micrograms for 25.8 cm2. The increase in iron oxide collection was 23, 335, 310, and 490-fold greater than that measured for parafilm for iron tape, alnico-V bar, NdFeB ring and NdFeB disc, respectively. The iron oxide collected generally varied with the maximum surface field strength. The NdFeB magnets were selected due to the higher collection capacity and smaller size. We conclude that small magnet-containing samplers are capable of passively collecting iron oxide and could be the basis for methods to measure protection factors for clothing ensembles against aerosols. Evaluation of parameters, conditions and performance is currently under way.