# Fire fighter safety: ECG monitoring via apparel

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Fire fighters respond to calls involving emergencies such as structural and automobile fires, airplane and train crashes as well as medical issues. This is a very physical job requiring the fire fighter to climb ladders, break down doors, and perform search and rescue activities often while being present in intense heat. Currently, there are 1,066,500 active career and volunteer fire fighters in the United States (US Home Security, 2019). More than 100 fire fighters die in the line-of-duty in the U.S. each year which is three times higher than the fatality rate for the general working population (US Home Security, 2019). The leading cause of death among fire fighters is sudden cardiac death (SDC). While part of the causes of SDC can be correlated to lifestyle choices, the addition of a physically intensive, extremely hot work environment may also increase SDC. It has been determined that fire fighters have two thermal hazards to be aware in in their job – the fire itself and heat stress (Rossi, 2003). Heat stress is exposed to extreme heat and the body in unable to cool itself properly; this can result in a life-threatening condition such as a heat stroke or heart attack. Electrocardiogram (ECG) monitoring becomes essential for continued good health related to heart conditions using smart clothing design. Fire fighters are a high-risk group working in a high stress environment and need a specially designed smart clothing solution to monitor their health. For this project, smart clothing was created aimed at developing solutions to support the management of heart disease as well as provide support for daily health monitoring for fire fighters.

Traditionally, in order to obtain an ECG, a commercial hydrogel with a high adhesive factor is applied to electrodes which are subsequently applied directly to the body in order to monitor the wearer's health. Constant application and reapplication of the electrodes causes skin allergies and pruritus from wearing the hydrogel for a long time. An alternative method of applying the electrodes was researched. This project developed a prototype garment which could be worn by fire fighters as a base layer or as part of the station uniform which could monitor the health of the fire fighter as they work. Early intervention at the onset of a heart attack could save lives. Intelligent biomedical clothing usually refers to clothing with sensors that are close to or in contact with the skin. Traditional commercial hydrogel patches and one of three tested conductive textile patches (a 50% Nylon, 40% copper and 10% nickel fiber tricot knit coated with silver) were used to design two types of t-shirts with embedded ECG devices. The conductive textile was adopted to replace traditional commercial hydrogel. We used a textile-based pressure sensor which is both highly sensitive and has excellent durability, fast response, and a relaxation time based on highly conductive fibers coated with dielectric rubber materials.

The following two types of designs were tested; one used a basic t-shirt with traditional commercial hydrogel electrodes and the second used a basic t-shirt equipped with the conductive textile connected to the ECG device. The inside of the second t-shirt was designed with a 7.5cm wide elastic from the shoulder to the hem onto which the conductive textile electrodes are attached. The electrode sensors travel through the single fabric layer (design 1), or it is the conductive fabric itself that is used as the sensors (design 2). The t-shirts have a normal outer layer appearance therefore the wearer can perform normal daily activities while privately being medically monitored.

The buttonholes which allowed the wires of the leads to travel through the shirt for proper body placement of the first t-shirt design were sewn with the corresponding lead color in order to make assembly and donning easy for the wearer. For the second prototype, the outside of the patch of conductive fabric was finished in the corresponding color as well. A total of 15 subjects (5 male and 10 female) were recruited to test this prototype. All subjects were asking to first wear the traditional hydrogel/electrode in order to obtain a base reading. Then they were asked to don the second prototype to record ECG data.

Data of first set data were from the traditional hydrogel patches; the second set data used the silver conductive fabric. First, based on visual observation of the data on the smart phone screens, the information was consistent between both methods. This means that the conductive fabric can relay the electrical activity of the wearer's heartbeat as effectively as placing the traditional electrodes with commercial hydrogel. This finding allows us to continue researching different smart garment designs to determine the best system to monitor the health of the fire fighters. Secondly, all data was retrieved from iCloud and both sets of data were run through SPSS. The obtained pressure sensor exhibited high sensitivity (0.21 $kPa^{-1}$) and very fast response times in the millisecond range as well as high stability over more than 10,000 cycles. The suitability of the textile electrodes for ECG recording was varied by experimental measurements. Specifically, we compared the ECG recorded using the textile electrodes with the ECG measured by a high quality reference measurement system. This means that the conductive textile can relay the electrical activity of the wearer's heartbeat and ECG as effectively as placing the traditional electrodes with commercial hydrogel.

These findings will allow designers to place conductive fabric in a variety of garments to track the health of fire fighters and others in need of such monitoring. The textile-based pressure sensor could also be pixelated to a matrix-type pressure sensor in the form of fabric by using a weaving method and imbedded into a vest which was applied to control machines wireless as human–machine interfaces. Since this device is worn next to the body, even though the surrounding temperature may increase (as in a fire), the device is a protected by the overclothes or bunker gear. It is hoped that this research can be used to identify early on any health issues with the wearer to prevent medical issues and be used to reduce the number of deaths due to heat stress. Future research will include a larger participant pool and testing accuracy of the data when working a fireground or another emergency. Reduction of heat stress and early detection of heart irregularities is the future goal of this research.

References

Rossi, R. (2003). Fire fighting and its influence on the body. *Ergonomics*, *46*(10), 1017-1033.

United States Department of Homeland Security (2018). National Fire Department Registry Summary. Available at: https://www.usfa.fema.gov/downloads/pdf/registry_summary_2018.pdf. Accessed November 18, 2018.