Innovative, wearable snap connector technology for improved networking in electronic garments

Andrew A. Kostrzewski[a], Kang S. Lee[a], Eric Gans[a],
Carole A. Winterhalter[b], Tomasz P. Jannson[a]

[a]Physical Optics Corporation, 20600 Gramercy Place, Torrance, CA, USA 90501
[B]Natick Soldier Center, Kansas Street, Natick, MA, USA 01760

ABSTRACT

This paper discusses Physical Optics Corporation's (POC) wearable snap connector technology that provides for the transfer of data and power throughout an electronic garment (e-garment). These connectors resemble a standard garment button and can be mated blindly with only one hand. Fully compatible with military clothing, their application allows for the networking of multiple electronic devices and an intuitive method for adding/removing existing components from the system. The attached flexible cabling also permits the rugged snap connectors to be fed throughout the standard webbing found in military garments permitting placement in any location within the uniform. Variations of the snap electronics/geometry allow for integration with USB 2.0 devices, RF antennas, and are capable of transferring high bandwidth data streams such as the 221 Mbps required for VGA video. With the trend towards providing military officers with numerous electronic devices (i.e., heads up displays (HMD), GPS receiver, PDA, etc), POC's snap connector technology will greatly improve cable management resulting in a less cumbersome uniform. In addition, with electronic garments gaining widespread adoption in the commercial marketplace, POC's technology is finding applications in such areas as sporting good manufacturers and video game technology.

Keywords: Connector, USB, e-garment, networking, wearable electronics, communication, RF

1. INTRODUCTION

Electronic devices have become so pervasive that one would be hard pressed to identify an individual who is not constantly carrying a cell phone, PDA, or digital media player. In fact many commercial efforts have been striving to integrate specific pockets for these devices in everything from jackets to ties[1]. Additionally, military officers are also becoming more "wired" as they are outfitted with laptop computers, GPS receivers and head mounted displays (HMD). Although the aforementioned devices are now ubiquitous in the military and civilian lifestyle there is no comprehensive technology to integrate and network these devices into clothing[2]. To address this issue, Physical Optics Corporation has developed wearable connectors that are body conformable, environmentally stable, and intuitive to allow the networking of body worn electronic devices in a personal network known as WEARNET[3]. These connectors have an extremely small from factor and both resemble and function like a standard garment button and hence have been trademarked as SNAPNET. Presently, these innovative connectors have been utilized to route high-speed data and/or power (i.e., USB 2.0) as well as RF communications for interconnecting such devices at frequencies as high as 3GHz. Implementation into standard garments, such as vests and jackets, have not only allowed for networking such devices as GPS receivers, wireless cameras, and PDA's but also allows for all the components to be powered by only one battery source. This is critical to the user in terms of both ergonomics and weight-savings. The robust design has also undergone full environmental testing to MIL-STD610F has qualified SNAPNET performance at extreme temperatures, humid environments and also exposure to harsh chemicals. These qualities have sparked considerable interest in both the military and commercial arenas and have recently been implemented as alternatives to existing commercial-over-the-shelf (COTS) connectors.

2. SNAPNET DESIGN AND FEATURES

The SNAPNET connectors have been designed with the following features in mind in order to achieve **fully wearable** connector integration:

1. Comfortable and conformable to the human body
2. Compatible with civilian or military garments such as MOLLE[4] and SPEAR[5]
3. Compatible with USB connector standard for the transmission of data and power
4. Mimics connectors on standard clothing (i.e., button or snap)
5. Environmentally stable at extreme temperatures/humidity as well as water, laundry and chemical-proof.

The major components of the SNAPNET design are presented in Figure 1 (from Pro-Engineer Wildfire 3.0) detailing the "male" and "female" components with an inset detailing the mated configuration and associated dimensions. The joining of the two halves initiates the electrical connection between the pair of flexible cables/webbing and results in audible feedback of a "click" or "snap" as would a standard garment button. This coupled with the slight haptic, or force, feedback allows the user to not only join the two halves without focusing on the objects (i.e., blind-mating) but also confirms a stable connection. Note the incredibly slim form factor of the mated configuration which is comparable in size to a standard USB connection. The SNAPNET configuration seen in Figure 1 is USB 2.0 compatible allowing for the transfer of up to 2A in electrical current and allowing for high-speed data transfer at rates up to 480 Mbit/s.

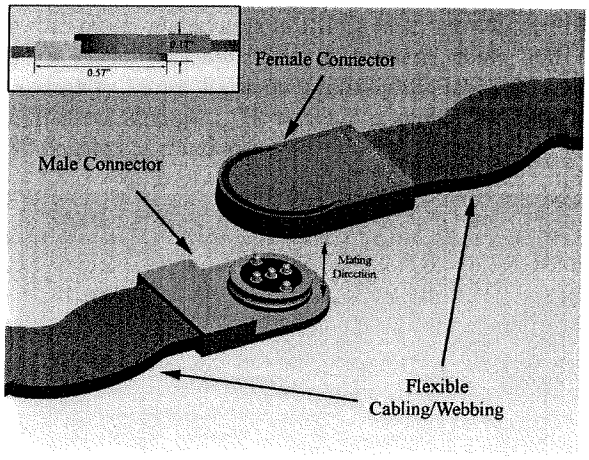

Fig. 1. "Male" and "female" portions of SNAPNET™ with inset detailing the relative dimensions in the "mated" configuration

In addition to the small form factor of each connector (roughly 0.57" x 0.14"), each half is designed to allow mating in a wide range of angles, nearly 180 degrees, while still providing a constant electrical connection. This is a critical feature in body worn applications as the connectors themselves can accommodate the movement of the individual wearer in dynamic situations such as running, climbing, crawling, etc. In order to maintain a secure connection under extreme conditions, certain SNAPNET configurations incorporate an angular positional locking mechanism, illustrated in Figure 2. In this case, the "female" snap has an integrated toe wedge that rests under a locking plate affixed to the underbody of the "male" connector. This design only allows mating when the connectors are within the angle range "T," roughly 15 degrees, and is utilized in applications where extreme tension could cause undesired de-mating during usage.

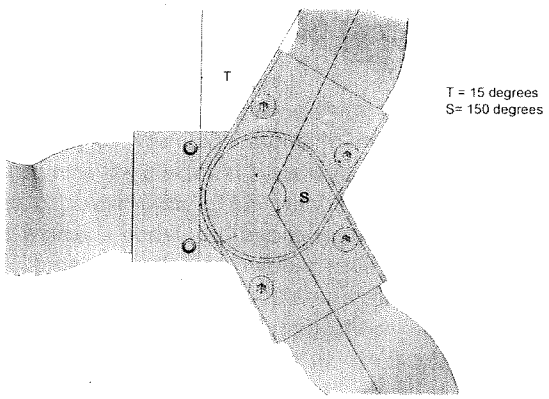

Fig. 2. SNAPNET connector variants with angular locking over 150 degrees (i.e., "S")

In addition to a USB-based connector, a similar design methodology has been implemented by POC to produce a flexible and wearable radio frequency (RF) connector for the networking of body worn antennas and receivers. This SNAPNET variant is illustrated in Figure 3 and facilitates communication transfer across a single RG188 coaxial cable, manufactured by Huber+Suhner[6], for data transmission up to 6GHz. The embedded COTS cabling provides the necessary RF shielding through a thin silver-plated copper (SPC) layer surrounded by a polytetrafluoroethylene (PTFE) jacket. The connector housing is entirely nonmetallic to prevent noise and other adverse effects on the RF communication. This required a slightly larger form factor (roughly 10%) as compared to the standard USB-based SNAPNET version to ensure mechanical strength. However, the connector itself still retains a low profile with RF connection allowing for nearly 180 degrees of rotation.

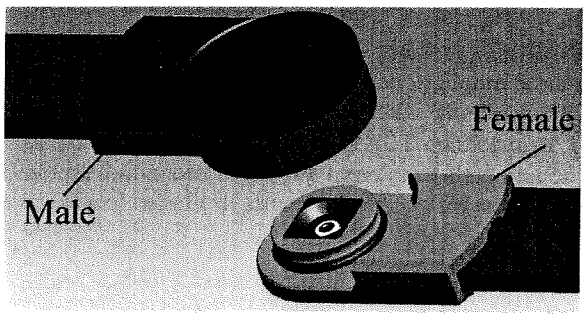

Fig. 3. SNAPNET™ connector variants for RF communication

Critical to the broad application of SNAPNET connectors is their environmentally stable performance through the use of features such as double o-ring seals and high precision manufactured parts. A series of environmental tests has certified operation in accordance with MIL-STD-810F[7] with successful operation under extreme environmental conditions including such scenarios as high temperature, high humidity, blowing rain, and fluid contamination to name a few. Some examples of the tested conditions are as follows:High temperature storage at 125°C for 24 hours

- Low temperature storage at -55°C for 24 hours
- High temperature operation at 120°C for 24 hours
- Low temperature operation at -40°C for 24 hours
- High shock operation during 40g acceleration for 0.011 seconds
- Rain exposure at 4 inches/hour with winds at 40 miles per hour
- Exposure to chemicals such as diesel fuel, antifreeze, and runway deicer

3. SNAPNET NETWORKING AND WEARABILITY

The USB- and RF-based SNAPNET connectors allow for a more practical application of wearable computing without the use of standard cabling that typically proves cumbersome to the user. In addition to the low profile of these designs, the webbing material which encapsulates the electrical lines is manufactured from standard garment material and is thus comfortable when resting against exposed skin. This combined with the inherent flexibility allows for routing of electronic devices throughout the wearer's body. Additionally, the narrow width of the cabling (less than 0.5") can be easily fed through the standard webbing that exists in outdoor gear (i.e., backpacks) as well as military garments such as vests and load bearing rucksacks. This provides the opportunity to easily mount electronic devices anywhere on the individual's body, which is especially critical in military applications where the dynamic environment might require, for example, a soldier to alternate placement of a critical sensing device from their shoulder to wrist, for example.

To demonstrate the significant potential for wearable networks, POC fabricated a fully functional electronic garment based around a standard issue military vest. The electronic garment contained the following equipment, many of which are currently used by military officers during various operational scenarios:

- Vest w/ snap connectors
- 1 – Dell Axim ×51 Pocket PC w/ 1 Gb compact flash memory card
- 1 – GPS sensor
- 1 – Head mounted display w/ NTSC video viewfinder (HMD)
- 1 – HMD controller
- 1 – 12 V rechargeable battery pack
- 1 – Analog video camera

Figure 4 and Figure 5 detail the location of each component on the garment. SNAPNET connectors were used to mount and connectorize the various devices according to the scheme detailed in Figure 6. A single 12-volt rechargeable battery supplied electrical power directly to the HMD controller and PocketPC. The PocketPC still contained a standard battery, but was recharged via a dock in the pouch mounted with SNAPNET connectors. The GPS sensor and analog video camera were modified with flush-mounted connectors for the transfer of data and/or power in the networking scheme. The connections also provided the additional benefit of structural support for secure placement of these devices.

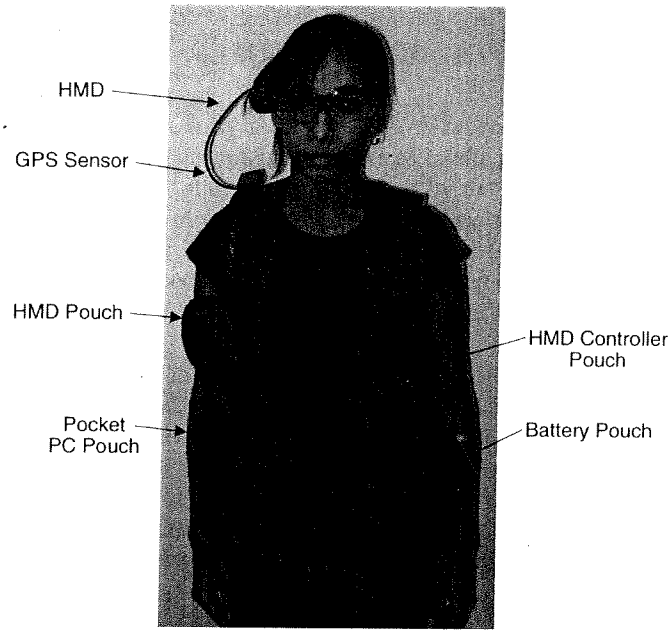

Fig. 4. Front view of vest detailing components.

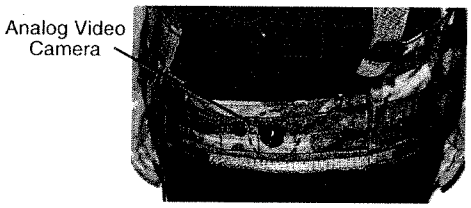

Fig. 5. Rear view of vest detailing video camera.

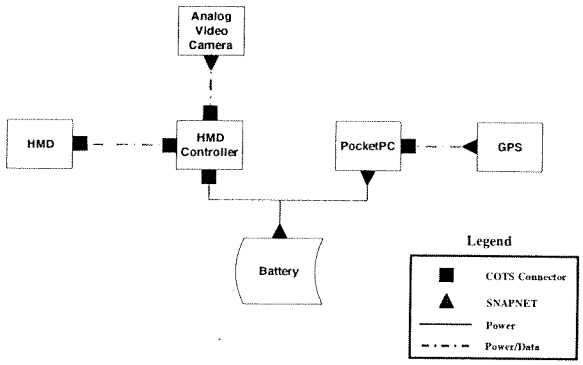

Fig. 6. Connectivity Schematic of SNAPNET-based electronic vest

4. WEIGHT BUDGET

With an increased usage of electronic devices by military Soldiers, recent research into improved uniforms treats the garment as an interactive system not only examining such issues as tactile comfort[8] of the garment itself, but also power management[9] issues as well. However, the total weight supported by the individuals is still one the most fundamental concern when considering military uniforms. Essentially the extra functionality of electronic devices is quite insignificant if the added weight of their utility proves too taxing. To fully appreciate the importance of ensuring a reasonable "weight budget" for the soldier, consider the following statements that were taken from the first battlefield study[10] of equipment load performed by the U.S. Army during actual combat operations.

"The dismounted Infantryman continues to be over-burdened while conducting modern combat operations..... Soldiers are carrying mission essential equipment that simply weighs too much. The excessive weights on the backs of these fit Soldiers, coupled with the harsh environments found in Afghanistan, prove detrimental to maximizing Soldier performance."

The study was performed on Coalition Forces during combat operations in Afghanistan over a one-month period from April to May 2003. Four configuration of gear worn by soldiers depending upon the type of mission:

1. Combat Load - only mission-essential equipment, as determined by commander, required for survival in immediate combat operations
2. Fighting Load – includes bayonet, weapon, clothing, helmet, load-bearing equipment (LBE) and ammunition. Up to 48 lbs.
3. Approach March Load – includes clothing, weapon, ammunition, LBE, small assault pack, and poncho roll. Up to 72 lbs.
4. Emergency Approach March Load – this configuration is required during marches through terrain that is impassable to vehicles and/or ground and air resources are unavailable. Up to 150 lbs.

The fourth configuration requires that a soldier carry nearly their entire body weight in military gear. Such large equipment loads not only affect the health and energy level of the soldier but also slows their traveling time making them more susceptible to the enemy. It is both difficult and dangerous to reduce the number of items carried by each soldier as each unit serves a critical purpose during the mission (i.e., environmental protection, food/rations, ammunition, etc).

One of the most effective ways to reduce weight of the overall system is to integrate system components within the military uniform itself to provide comparable function but with enhanced wearability. Utilizing SNAPNET connectors in conjunction with wire integrated textile cabling (WITC) can provide a significant weight reduction for the soldier by eliminating portions of the standard device wiring for all the electronic components and instead, weave electrical cables directly in the garment as seen in Figure 7. Integrating these power/data lines directly into the vest material provides three main advantages:

1. Overall cable length reduced as equipment is placed at any point on the soldier's body (**weight reduction**)
2. Reduced cable insulation as existing textiles provide necessary protection (**weight reduction**)
3. Eliminates extraneous wires hanging from soldier's body (**improved safety and comfort**)

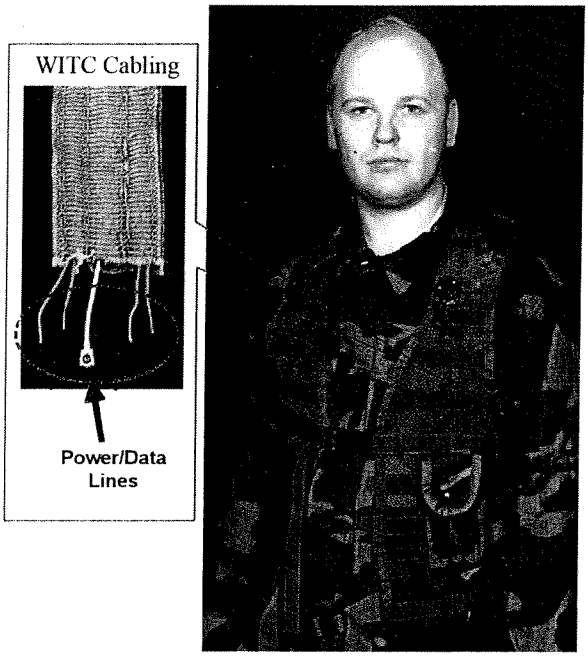

Fig. 7. Standard Military Vest with wire integrated textile cabling (WITC)

The first advantage of reduced cable length provides the most significant weight reduction as overall cabling can easily be cut in half by routing electrical lines along the contours of the uniform. Standard electrical cable insulation typically utilizes a minimum of 15 mm of polymer polyvinyl chloride (PVC) for protection and strain relief. Considering the large assortment of standard wearable devices such as GPS systems, wearable displays, and radio communication, the weight reduction by connectorizing components directly through the garment material can easily translate to a savings of several pounds from the soldier's carrying load. This affords to option of transporting additional essential equipment such as an extra canteen of water (2.5 lbs) or ready to eat (MRE) meals (1.5 lbs/each). This weight savings combined with the superior wearability and comfort enhances the soldier's effectiveness and ultimately increases the likelihood of a successful mission objective.

5. CONCLUSIONS AND FUTURE APPLICATIONS

SNAPNET connectors in conjunction with wire integrated textile cabling (WITC) provide an innovative connectivity platform for the distribution of wearable electronic devices. The connectors themselves provide the convenience of blind mating over a wide range of angles, all within an environmentally sealed, low profile housing. Current efforts at POC are concentrated on the transmission of other data types by designing a VGA video based connector for the mounting such devices as small, COTS LCD displays. Standard VGA connectors typically require up to 15 electrical pins complicating the design of a SNAPNET-based connector. However, serialization protocols are being investigated to reduce this mechanical and electrical design burden. Ultimately, SNAPNET connectors will be routed in a hub-like fashion to produce a series of "e-Harnesses" for the transferring data and power between wearable devices. This concept is presented in Figure 8, detailing the layout of a series of SNAPNET-based electronic hubs around a vest (wireframe). This scheme provides power from a single source and routs electrical data efficiently by decentralizing the cabling to the central computer. This ultimately allows for a wearable garment, commercial or military, that has enhanced electronic capabilities while still maintaining comfort and flexibility for the wearer.

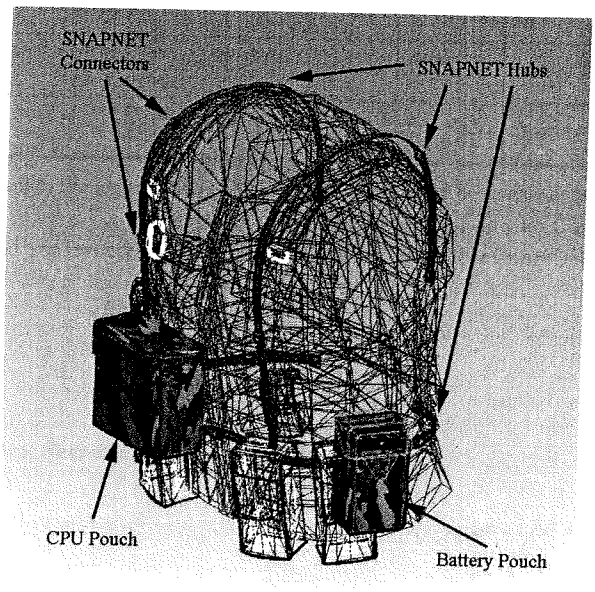

Fig. 8. Conceptual Design for wearable "e-Harness"

REFERENCES

1. http://www.mobilemag.com/content/100/342/C6627/
2. C. Winterhalter, J. Teverovsky, P. Wilson, J. Slade, B. Farrell, W. Horowitz, and E. Tierney, "Development of Electronic Textiles to Transport Data and Power in future U.S. Military Protective Clothing Systems," Journal of ASTM International, Vol. 2, no. 7 (2005)
3. T.P. Jannson, A.A. Kostrzewski, K.S. Lee, T.J. Hester, T.C. Forrester, and G.S. Savant, "Soft Computing and Small System Integration," SPIE Proc., Vol. 5558, no. 10, 47-56 (2004).
4. http://en.wikipedia.org/wiki/MOLLE_(military)
5. http://www.natick.army.mil/soldier/media/fact/individual/SPEAR_BALCS.htm
6. http://www.hubersuhner.com
7. http://www.dtc.army.mil/
8. H.G. Schutz, A.V. Cardello, and C. Winterhalter, "Perceptions of Fiber and Fabric Uses and the Factors Contributing to Military Clothing Comfort and Satisfaction," Textile Research Journal, Vol.75, no. 3, 223-232 (2005).
9. S.F. Womack, D. Mcconnell, A. Reese, and D.M. Sanders, "Power Management for the Land Warrior System," 2003 IEEE Systems and Information Engineering Design Symposium, Iss. 24-25, 83-88 (2003).
10. http://www.thedonovan.com/archives/modernwarriorload/ModernWarriorsCombatLoadReport.pdf