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REVIEW PAPER

Smart Textiles for Soldier of the Future

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ABSTRACT

The textile-based materials, equipped with nanotechnology and electronics, have a major role in the development of high-tech military uniforms and materials. Active intelligent textile systems, integrated to electronics, have the capacity of improving the combat soldiers performance by sensing, adopting themselves and responding to a situational combat need allowing the combat soldiers to continue their mission. Meantime, smart technologies aim to help soldiers do everything they need to do with a less number of equipment and a lighter load. In this study, recent developments on smart garments, especially designed for military usage owing to their electronic functions, and intelligent textile-based materials that can be used in battlefield, are introduced.

Keywords: Smart textiles, nanotechnology, helmets, high-tech military uniform, smart garments, robotic suits, intelligent textile system, high-tech textiles, military shelter, heated-clothes,modular integrated communication helmet

1. INTRODUCTION

The high-tech textiles have attracted much attention in recent years and there will be a boom in research for their developments and applications in the next few years. The smart textiles can sense, react, and adapt themselves to the environmental conditions. These are the highest level of smart textiles. A revolutionary new property of high-tech textiles would be the possibility to exchange information. If clothing would be capable of recording, analysing, storing, sending, and displaying data, a new dimension of intelligent high-tech clothing could be reached[1,2]. Considering the needs of the combat soldiers of the future, some military materials, each of which is individual equipment, become a part of the military uniforms[3].

In this paper, the advances in the military equipment and uniforms are presented. After reviewing the details of recently developed systems, a smart textile capable of being heated, was designed. It can be used by the military or the security staff to continue their duty in the tough environmental conditions.

2. MILITARY ASPECTS OF SMART TEXTILES

During the last decade, there has been an increasing interest in integrating electronic capabilities and components with textile materials and equipment used by the soldier.

Future warrior systems would be equipped with head-up display, wireless weapons, global positioning systems, chemical and biological threat detectors,

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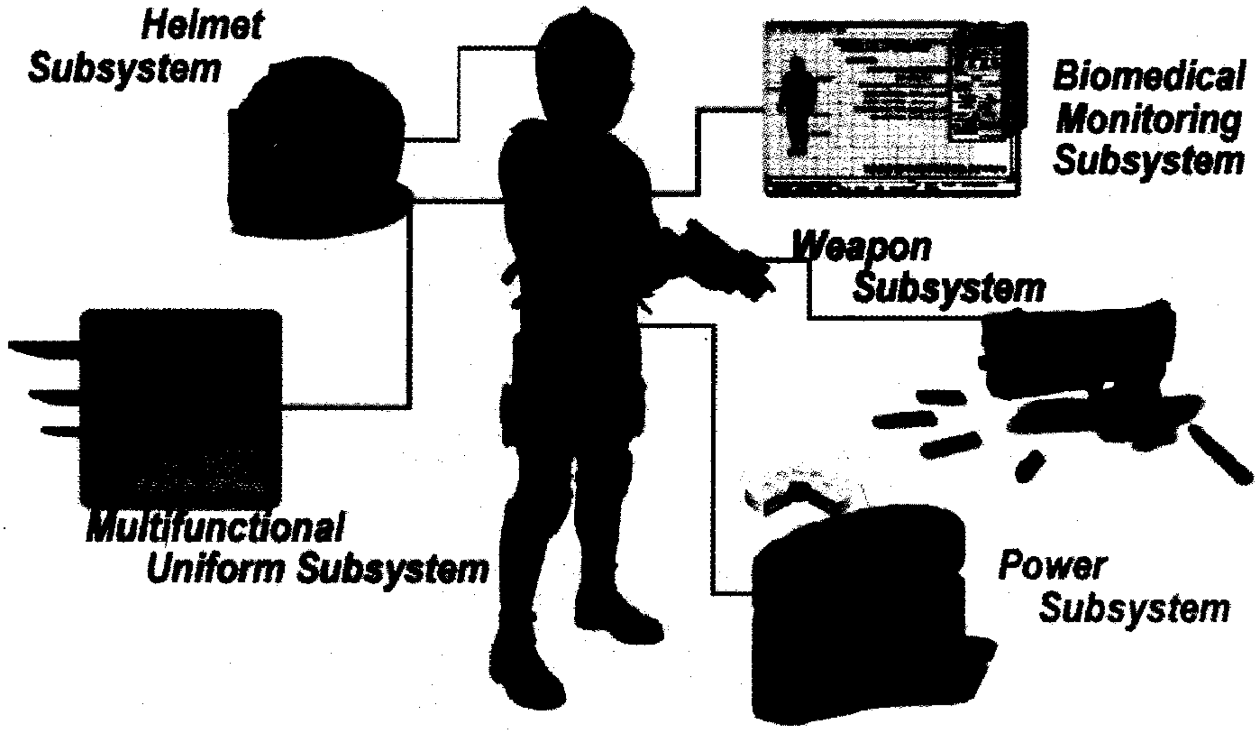

Figure 1. Soldier of the future

battery power, personal physiological status sensors, combat ID sensors, as shown in Fig. 1, all linked up to the combat soldier's personal computer to assist him in situational awareness and understanding. Network cables for data and power transmission, and a variety of antennas for near and remote communication need to be integrated into the warrior's clothing and equipment to reduce weight and bulk of current electronic system interface[4].

Nanotechnology will play a major role in the development of the new generation of the Army uniforms and equipment. With the advent of nanotechnology, chemically-protective overgarments, which shield soldiers against hazardous chemicals and deadly microorganisms, will enter a new phase of development. The new Army uniforms will be breathable and 20 per cent lighter in weight than the standard battle-dress overgarments[6].

Much of the smart fabric, soldier of the future, research is centred at the US Army Soldier Systems Centre. There, scientists and technologists are tackling a variety of textiles that can transport power and information. One such example is a soldier sticking his intelligent glove-finger into water to see if it is safe to drink[7].

Among the goals of the newly-created Institute for Soldier Nanotechnology (ISN) will be the development gadgets that can heal soldiers and also equip them with uniforms that are nearly invisible, and clothing that can become a rigid cast when a soldier breaks his or her leg[8].

The Defense Advanced Research Projects Agency (DARPA), USA, focusses on research in the area of electronic textiles, besides the other next generation products. The DARPA mission is to develop imaginative, innovative, and often high-risk research ideas offering a significant technological impact that will go well beyond the normal evolutionary developmental approaches; and, to pursue these ideas from the demonstration of technical feasibility through the development of prototype systems[9].

Figure 2. Next generation helmet

The Army Research Laboratory and The Army Soldier Systems work with Massachusetts Institute of Technology (MIT) to equip the future soldiers with uniforms and gear that can heal them, shield and protect them against nuclear-biological-chemical (NBC) warfare[4].

2.1 Modern Helmet Systems

In today's modern helmet systems, the soldiers can get up-to-the-minute information via a helmet-mounted global positioning system (GPS), a small wireless voice and data communication system, and a wearable computer linked to an intra-squad wireless local area network (LAN).

A flip-down display on the helmet allows the soldier to scan the surroundings in the darkness, using thermal and night-vision sensors connected to his weapon. This display also gives each soldier a view of a situation map that can pinpoint where both the friends and the foe are located, in real-time. With that knowledge, the soldier can better figure out how to tackle the enemy. If he's on a battlefield, he can call in fire, just like sending an e-mail. He'll specify the kind of attack. It's sent, it happens, and just that easily, he's in touch with his commanders. On the other hand, an electric wire integrated into the helmet cover would be connected to another part of the uniform. The goal is to provide the combat soldier with executable functions that require the fewest possible actions on his or her part to initiate a response to a situational combat need by means of intelligent textiles[10,11].

Figure 2 shows a sample helmet that has been turned inside out. It illustrates how an electrical wire can be embedded in fabric through stitchless seam technology.

2.1.1 *Modular Integrated Communication Helmet*

The modular integrated communication helmet (MICH) is a modular helmet system that provides ballistic, fragmentation, aural and impact protection. It is also compatible with night vision, communication, and nuclear, biological, and chemical (NBC) equipment. The helmet allows maximum sensory awareness for the user, which includes unobstructed field of view and ambient hearing capabilities. The subsystem provides aural protection, occluding and non-occluding communications, omni-directional hearing, ear-specific communications (dual channel), low-profile microphone(s), microphone adapter for mask microphone, multiple radio and intercom adapters, and push-to-talk access[13]. As shown in Fig. 3, the headset may be worn alone or with

Figure 3. Modular/integrated vehicle communications helmet

the ballistic helmet retention system and pad suspension system.

2.1.2 *Advanced Combat Vehicle Crewman's Helmet*

The advanced combat vehicle crewman's helmet (ACVCH) ballistic shell has protection level equal to the current infantry helmet and has the configuration of the standard combat vehicle crewman's helmet shell. The helmet design incorporates an electronic talk through communications capability with passive hearing protection incorporated into the standard

Figure 4. Advanced combat vehicle crewman's Helmet

communications headset for vehicle intercom and squad radios[14]. In Fig. 4, an advanced combat vehicle crewman's helmet has been illustrated.

2.2 Textile-based Health Products in Military

The Army isn't the only branch of the military which actively develops smart textiles. The US Navy funded a project in 1996 that eventually turned into the smart shirt, a product commercialised by SensaTex Inc in Atlanta, with technology from Georgia Tech Research Corp. The T-shirt functions like a computer, with optical and conductive fibres integrated into the garment. It can monitor the vital signs such as heart rate and breathing of the wearers, including security officers, military personnel, and astronauts[7].

Sensatex is an e-textile startup that is creating shirts which can be used to monitor the soldier's location and status in the battlefield. One of the biggest problem for medical staff is locating the soldier's wound and determining his vital signs amid battlefield chaos. A uniform that monitors a soldier's vital signs can relay the exact location of the wound through the wireless, saving a lot of time and valuable lives in the battlefield. The life shirt system is a comfortable garment that can be worn under normal uniform and it can automatically and continuously monitor over 40 physical signs such as respiratory rate, ventilation, swallow counts, arterial pulse wave, and heart rate[15,16]. The life shirt system is shown in Fig. 5.

On the other hand, the scientists also give emphasis on nanotechnology solutions for defence against biological and chemical warfare, and terrorism. Since the attacks on the US on 11 September 2001, this effort has received greater attention with a new research and development focus on the use of nanotechnology for chemical/biological/radioactive/ explosive detection and protection. DARPA has sponsored a project for the development of a biosensor to identify bacteriological infections in a biowarfare. The American military institutes try to integrate a wearable biosensor in clothing. The sensor can identify bacteria and the project team hopes to prove the principle in three years[17].

2.3 Carrying Heavy Equipment with Textiles

Embedding electronics into clothing used in harsh, dangerous environment is no small task. Already, soldiers such as those currently deployed in Afghanistan, carry up to 47 kg of equipment, including items such as cold-weather gear, nuclear-biological and chemical gear, and each new technology, whether it be a head-mounted display or an antenna that runs up the soldier's back or around his or her waist as a long belt, adds weight. Such new technology potentially could double the load for today's combat soldier. That's one of the reasons that lightweight

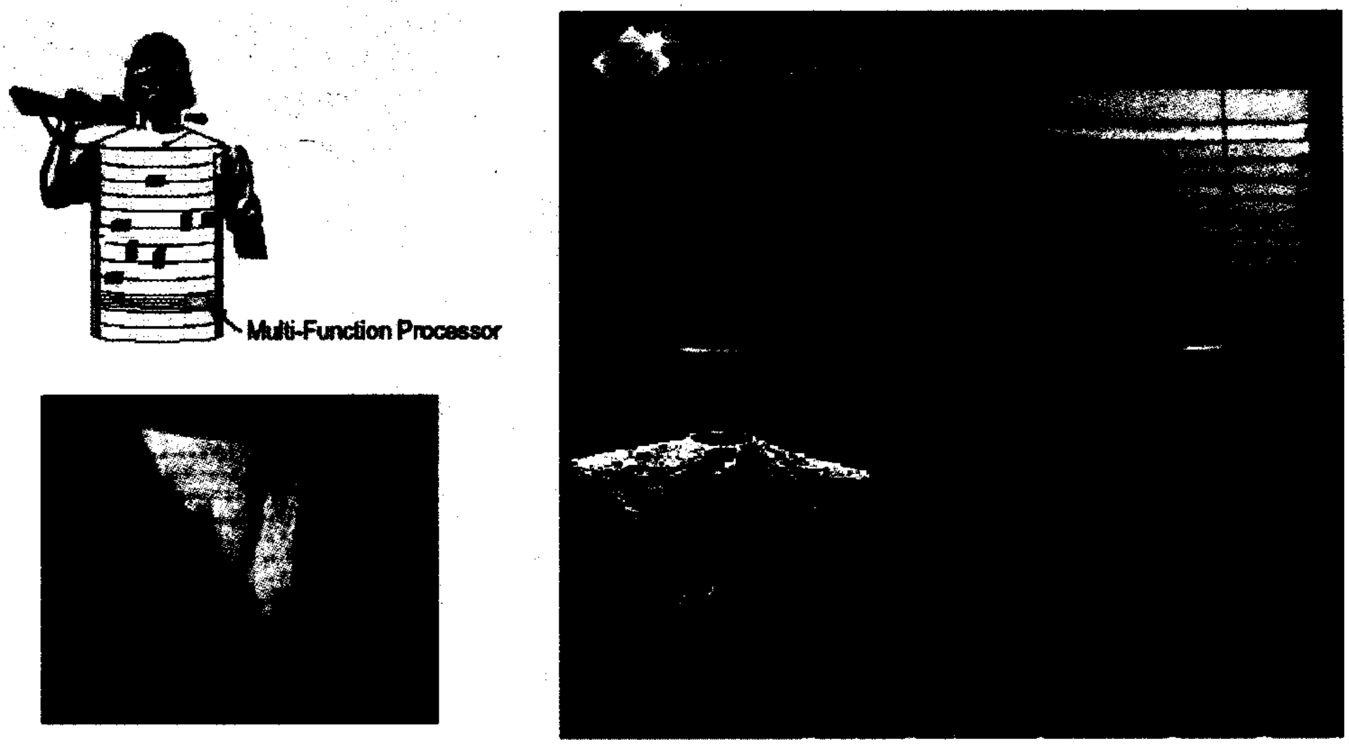

Figure 5. The life shirt system

and flat-fabric technology is of such keen interest to the military. The goal is to reduce the load to that carried by Roman legionnaires: 20 kg by 2008. The result will be an exoskeleton–essentially a powered suit of armour. Such a device could give a soldier a big advantage in the battle and give the troops at least a two-horsepower augmentation of strength and endurance. The mandate had a legs-only exoskeleton ready for trials by 2003 and a whole-body version by 2005. Wearing a device built by DARPA specialists, a soldier could lift 181.5 kg, including bigger weapons, bulletproof armour, better communications devices and more food, and this device remains continuously active for at least four hours. Exoskeletons could be optimised for other combat tasks too such as running much faster than the ordinary human beings, jumping over fences, or picking up rubble during rescue efforts[19]. A robotic suit developed by Sarcos, can mimic the wearer's body motions (Fig. 6).

In Fig. 7, load reduction achieved by embedding the electronic devices in the military uniforms and textile-based equipment is illustrated.

2.4 Development of Artificial Muscles

The Institute for Soldier Nanotechnologies gives new focus to materials research, including research into artificial muscles. The muscle (actually a polymer-called polypyrrole) is activated by electricity. When a current is applied, the polymer's accordion-shaped molecules stretch out like human muscles; when the current stops, the polymer contracts. Incorporated into a battle suit, the material could store energy generated by walking and release it in a super-leap or other feat of strength. The suit may stop (or at least slow) bullets. Certain liquids called ferromagnetic fluids, change properties, including density, in the presence of an electromagnetic field[20].

2.5 Interactive Camouflage

Scientists are conducting studies on animals to develop technology that could be used for *chameleon*-like battle suit that changes the colour depending on its surroundings. The researchers are trying to catch the interest of the military

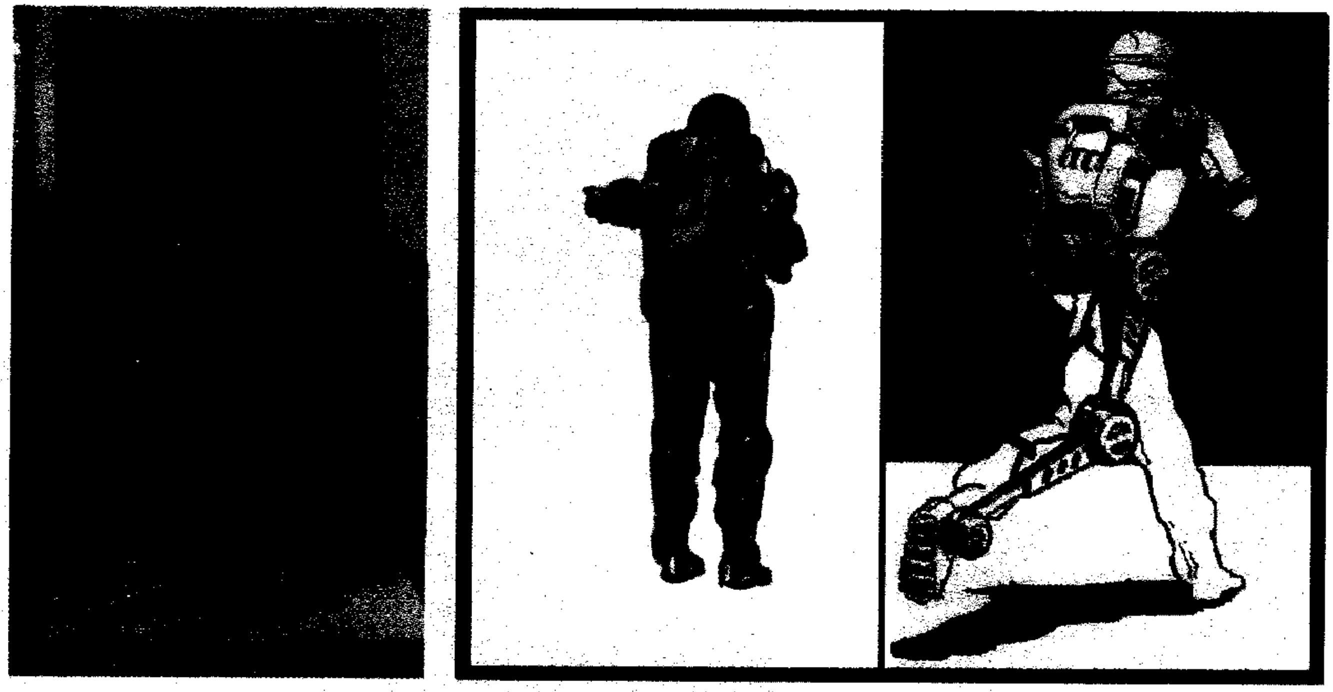

Figure 6. Robotic suit

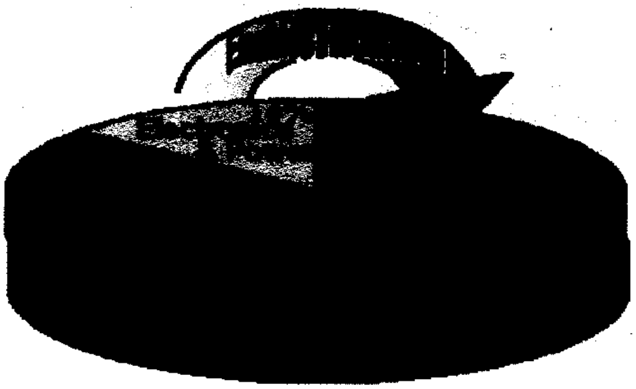

Figure 7. Load Reduction

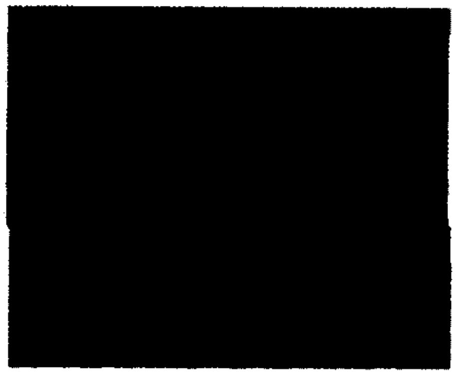

Figure 8. *Chameleon*-like battle suit

with fabrics that change the colour when conductive fibres stitched into the clothing heat and cool the material's thermochromatic inks. The technology is advanced to build a battle suit which has a surface like a *chameleon*[15]. If a soldier is leaning against a marble wall, the suit changes its colour to that, or if a soldier is lying on a black tarmac, it changes its colour to that (Fig. 8).

2.6 Wearable Cables

2.6.1 *Universal Serial Bus & Wired Vests*

The Soldier Systems Centre, USA has already collaborated with Foster-Miller Inc, USA, (Engineering and Technology Co.), to develop a fabric-based version of a universal serial bus cable. The universal serial bus cables are in common use in today's office and household computers to connect to the internet, among other things. Normally stiff, heavy, and coated with plastic, the universal serial bus cable has been transformed into something thin, flexible, and wearable with flat connectors[7]. It can be integrated into the clothing and is currently under consideration for an advanced combat uniform programme.

After testing and evaluation, it actually functioned like a normal universal serial bus. Learning that power and data can be sent through textiles, the next step is to determine how and where to place the sensors that will transmit information to the soldier's computer. Sensors could be attached or embedded into the material, or be the fabric itself, and could be located on the inside, middle, or outside layer of the clothing system. Integration of both the electronic network and sensors also presents new design issues and human factors issues of safety, comfort, performance, and durability[3]. Figure 9 shows atextile-based universal serial bus and wired vests.

2.6.2 *Wearable Antenna for Tactical Communications Radio*

The success of the wearable cable led to other applications such as a wearable, flexible and textile-based squad-level antenna for a tactical communications radio. The antenna was integrated into the modular lightweight load-carrying equipment vest.

2.6.3 *Wearable Electric Blanket*

Afterwards, an electric blanket was developed without the stiff, bulky wires traditionally used. The new blanket is lighter, more flexible and can be machine-washed and dried. Plugged in, it warms evenly using the same amount of power as a 100 W light bulb. It is a successful example of military research in electro-textiles which has been applied to commercial markets[3].

2.7 Fibre Keyboard

A keyboard built into a military uniform sleeve is a way to remove bulky control units from a

Figure 9. Textile-based universal serial bus and wired vests

soldier's load. The soldier could communicate with others either by a fabric keyboard that might be unrolled from the pocket of a military uniform, or simply sewn or woven in as part of the military uniform's sleeve (Fig 10).

The fibre keyboard would be pressure-sensitive, not touch-sensitive, for use on the battlefield. Combat soldier's soldier control unit is a box that sits on the chest. It would be better to integrate that into the clothing for reducing weight. One of the goals is to produce a keypad on the uniform sleeve that can function as the soldier control unit with specific military functions. A textile databus and necessary connectivity to transport the signal from the keyboard to the control electronics is another goal. An initial prototype is expected to provide three or four keys needed for a few simple commands to prove the concept. Further development should lead to a BDU housing to hold the electronics and a fabric-based display[10].

2.8 Radio Frequency Identification

2.8.1 *Smart Cards*

For the past 20 years, the technology has improved and the idea for control of inventory has spread from a simple store to be used in military. There are two basic types of smart cards. The contact smart cards and the contactless smart cards. The contact smart cards have to be inserted into a small card-reader slot to be read. The contactless smart cards have an embedded antenna connected to a microchip, enabling the smart card to pick up and respond to radio waves. These smart cards do not require any direct contact with the reader because these use the passive transponder technology of radio frquency identification. These do not require batteries either; powered instead by the electromagnetic field generated by the smart card reader.

2.8.2 *Wearable Computers*

Some of the best uses include a new class of radio frquency identification systems implemented

Figure 10. Keypad on the military uniform's sleeve

in assembly and maintenance to be used for military applications. The major fascinating use for radio frequency identification is in clothing. It would be a wearable computer that allows one to take ones electronics and roll, and crumple it up and still it works. The system will include sensors, actuators, photovoltaic devices, batteries, storage devices, and maybe even reconfigurable software, all in a low-power design. DARPA will dedicate tens of millions of dollars to what some are calling e-textiles over the next five years. The first projects will be for military applications such as parachutes that generate solar power or track satellite signals[23].

2.9 Military Shelters

The military shelters may change their colour to fit in the environment, repel chemicals, change shape, and become rigid in response to weather or ballistic threats by an electrical charge, or even these may be self-erected. These will also provide protection from heat sensors or electromagnetic detectors. These shelters will be able to convert sunlight into electricity for the powering of onboard electric components such as computers, radio transmitters, or soft displays.

2.10 Heated Clothing Project

The best way to improve the individuals' performance is to control their environmental conditions. People who work outside, especially the military or security staff, need to control their thermal comfort. An additional electrical heating option in the uniform widens the operating temperature range of the garment and improves the protection against cold. The previous studies about heated clothing mainly took place in Tampere University and University of Lapland, in Finland. There are some prototypes about heated garments which are designed for arctic environment in northern countries[24]. The locations of the sensors of the prototypes are illustrated in Fig. 11.

In Dokuz Eylul University Engineering Faculty, Turkey, the first step of the implementation project was to design the heated clothing. The research staff included different researchers from Textile and Electrical and Electronics Engineering Depts

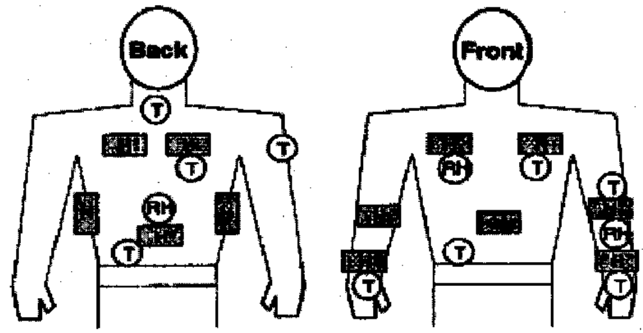

Figure 11. A sample figure for the location of the sensors

of the Faculty. The prototype will include sensors in different places; textile-based heating elements, measurement control unit, humidity sensors, and small batteries. The temperature control system uses the digital sensors. The heating decision of the heated uniform is taken according to the skin temperature measurements. A great deal of energy is required for heating the staff in cold weather conditions. In this system, rapidly increasing heat is thought to be used for short periods[25].

3. CONCLUSION

In the future, combat soldiers can be dressed in high-tech uniforms, fitted with everything, from navigation and water purifying systems to climate control. More than a decade will pass before super suits make the combat soldiers stronger, smarter, and perhaps even invisible.

The main aim is to increase the protection and survivability of the combat soldiers. The nano materials and smart structures can also provide the future soldiers with super strength, protection against bio-weapons, and even a way to communicate covertly. Another goal is to help soldiers to do everything they need to do with smaller equipment and a lighter load. If electronics and optical technologies could be integrated successfully into the textiles, there could be a striking improvement in the battlefield communications.

The future warrior systems include global positioning systems, combat identification sensors, monitors, chemical detectors, and electronically-controlled weapons, all connected to the soldier's computer to provide him instant access to information. But getting the wire, and more futuristic technologies such as optics, into the uniforms and smart vests, and making these easy to use, is challenging. Wires must be flexible enough to be comfortable, carry signals, be safe to the soldier, and not give away his or her position.

In the future, by the development of the high-tech textiles, the battle dress uniform can be hardened into an instant shield with the push of a button; also there can be *chameleon*-like battle suits that can change their colour depending on the surroundings. If a combat soldier is hit in the leg, sensors relay information about his injury and location to the field headquarters. Sensors inform the field headquarters about the soldier who is the closest to the wounded soldier; new orders and the target's position appear on the rescuer's head-up display.

The materials of the new era will benefit the soldiers in the following ways:

- Lightweight, high-durability fabrics: Uniform, packs
- Lightweight materials: Rock-frame, bayonet, rifle, ammo, tools
- Reduced weight ballistic protection: Small arm plates, fragmentation vest
- Laser eye protection
- Next generation displays: Ultra thin high-resolution displays
- Information processing and storage: Small, massive durable storage devices, distributed microprocessors, conductor fibres embedded in the fabric
- Artificial muscles: Actuator for increased human performance
- Power storage/energy generation: Harvest energy from fabric flexure, hydrogen storage, embedded flexible batteries
- Drug and nutrient delivery on demand.

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