

NANOTECHNOLOGY FOR BODY PROTECTION

Main aspects of body protection of soldier, like vest, helmet, smart uniform, against small caliber ammunition, in which some elements are made with the use of nanotechnology, are shown. The directions of nanotechnology are concentrated on the following issues: materials, information, biology and energy. Nanomaterials for protection of body soldiers as different types of fibers and nanoparticles, G-Lam nanofibers, fibers and mixture of polymer and nanoparticles in fibers, nanocoated metal, shear thickening fluids and silliputty-type of elastomers in combination with ceramic armour, are mentioned. The different type of technology and measure means in dependence on scale and main parameters of technology nanofibers by electrospinning are explained.

1. The introduction

The discovery of novel materials, processes, and phenomena at the nanoscale, as well as the development of new experimental and theoretical techniques for research provide fresh opportunities for the development of innovative nanostructured materials. Developments in weapon technology, especially with using nanotechnology, take place both in the direction of more lethal as well as non-lethal weapons. For lethal weapons the focus is on precision targeting, minimum weight and signature, optimal impact damage, but for non-lethal weapons - on neutralization.

Nanotechnology enables the following material functionalities:

- lightweight: high strength nanocomposite plastics and biomimic (human bone type) structures to reduce weight and radar signature,
- smart components: components with built-in condition and firing monitoring sensors, such as fiber bragg,
- adaptive structures: active structures that adapt and correct firing conditions,
- super penetrator materials: nanostructured cone material that sharpens upon impact or gives additional damage,
- high-energetic propellants: e.q. nano-dispersed aluminum as propellant agent.

2. Nanotechnology for soldiers

Nanotechnology for soldiers can be divided for several subjects:

1. Sensors - multi-spectral and acoustics.
2. Fightability - mechanical / human enhancement.
3. Stealth - reduced signature.
4. Environmental protection:
 - one piece multi-functional suit,
 - NBC threat protection,

- physiological and causality care.
5. Medical - automated self medicating system.
 6. Goals - enhance Objective Force Warrior survivability, leverage breakthroughs in nanoscience and nanomanufacturing.

All directions of nanotechnology are concentrated on the following four issues [1]: materials, information, biology and energy (Fig. 1).

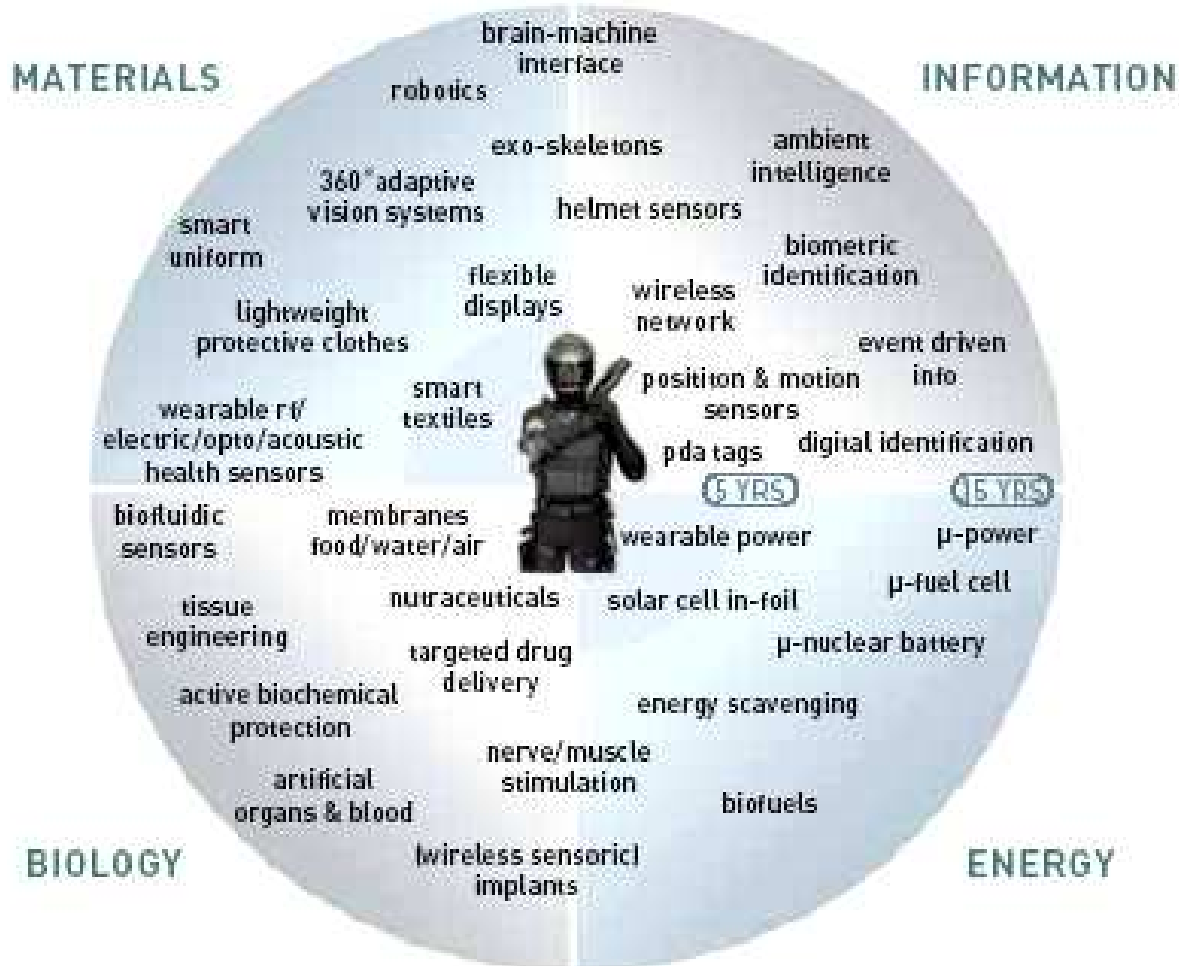


Fig. 1. Human centric: connectivity; mobility and ambient intelligence

Nanotechnology enables high strength, durable, sensoric and active materials. Nanostructures and nanocomposites are in development for the following functionalities:

- lightweight protective clothes: flexible antiballistic textiles, self BC decontaminating,
- nanofiber fabric,
- adaptive suits: switchable fabrics for improved thermal control, switchable,
- camouflage,
- microsensors for body and brain sensing, environmental and situational awareness,
- to be integrated into a smart suit or a smart helmet,
- wearable and/or flexible displays for visual feedback,
- auxiliary supports: flexible/rigid textiles for additional strength, exoskeletons,
- robotics to assist the human tasks.

The different kind of options, fibers and particles, which can be used as products with nanomaterials for soldiers, are presented in Figure 2 [1].



Fig. 2. Anti-ballistic materials for suit

Concepts for flexible armour have been proposed and are now in development such as:

1. Shear-thickening fluid STF (Fig. 3, 4) [2]: a nanoparticle-filled binder for highstrength textile that is flexible under low shear rate and that becomes rigid under high shear rate impact. This nanoparticle-filled system inhibits deformation and sliding of the high-strength fibers in the fabric at high shear rate.



Fig. 3. Kevlar fabric with shear thickening fluid, after impact by a fragment simulating projectile

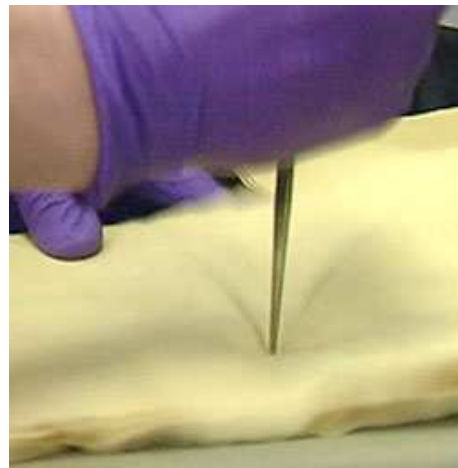


Fig. 4. Liquid Armour: Kevlar soaked in shear thickening fluid

2. Magneto-Rheological MR or magneto-restrictive fluid (Fig. 5) [3]: a nanoparticle filled flexible medium that can be electrically activated to become rigid.

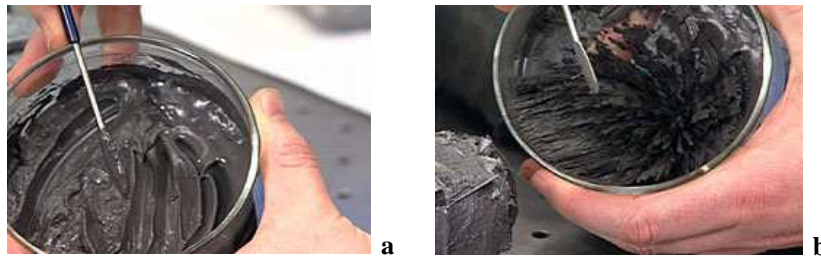


Fig. 5. Oily fluid full of tiny iron particles (fluid aligned to magnet) before being near (a) and after (b)

3. Silliputty-type of elastomers in combination with ceramic armour: elastomer system which is deformable and elastic at low shear rate and stiff at high shear rate. Similar to shear thickening fluids, but up until now less effective in anti-ballistics (passive system, e.g. D30 material).

The CCLRC Daresbury Laboratory team, together with researchers from Tuskegee and Florida Atlantic universities in the USA (in 2006), are evaluating new nanocomposite materials which can be woven into fabrics to provide greater flexibility as well as better ballistic protection. They have found that incorporating spherical nanoparticles of silicon or titanium dioxide or carbon nanotubes in a plastic or epoxy matrix offers improved ballistic resistance together with greatly improved flexibility.

A unique application of nanotechnology, as STF (shear thickening fluid), that has the ability to enhance the performance of ballistic fabrics and protective armours [4]. Developed by the University of Delaware's Center for Composite Materials (UDCCM), testing has indicated that the technology appears to allow conventional ballistic fabrics to increase the level and quality of protection they provide without compromising their weight, comfort or flexibility.

The STFs are special materials with hard nanoparticles that exhibit properties normally associated with both solids and nonevaporating liquids, but are rarely found in the same material. Sometimes referred to as "liquid armour," the material is actually a nanotechnology that exists in a flexible, fluid-like state under normal conditions but adopts seemingly rigid qualities and becomes less penetrable when impacted. This temporary stiffening is caused by the nanoparticles forming tiny clusters inside the fluid and occurs less than a millisecond after impact.

As a result, this special material can be applied to conventional ballistic fabrics or other materials used in armour applications, allowing them to remain flexible under normal wear, but simultaneously becoming resistant to penetration when impacted by a high velocity projectile (Fig. 3) or fragment, a spike or knife (Fig. 4). In addition, fabrics treated with STF have been shown to reduce "back face deformation" (an indication of blunt trauma) from high energy ballistic impacts. This type of armour can be used as body armour vests and extremity protection, helmets and gloves for protective use worldwide.

The liquid - called shear thickening fluid STF is actually a mixture of hard nanoparticles and nonevaporating liquid. It flows normally under low-energy conditions, but when agitated or hit with an impact it stiffens and behaves like a solid. This temporary stiffening occurs less than a millisecond after impact, and is caused by the nanoparticles forming tiny clusters inside the fluid. The particles jam up forming a log jam structure that prevents things from penetrating through them.

Magnetorheological fluids are made up of nanoparticles of iron in a thick oil or syrup suspension. When a magnetic field is applied, the iron particles align and the fluid becomes extremely stiff. The degree of stiffness varies depending on the strength of the field applied. It would be possible to wear comfortable, flexible armour that would become rigid at the flick of a switch.

This type of materials can achieve the following parametres:

- use dense fabrics (2 m / 8 kg), coated,
- combine with aerogels in fabric, inflatable parts,
- switchable fabrics with molecular actuators,
- small cooling (thermocouples, heat-exchangers,
- temperature-sensitive materials).
- combine with T and humidity sensors.

Nanofibers as the bulletproof materials are tested and they become to be used as the elements of model bulletproof vests. For instance, US Global firm produces the nanofibers as G-Lam bulletproof materials. The nanofibers are produced on the base of polibenzoxazol and polierylenobistiazol and other chemical compounds [5].

The different kinds of nanofibers [1] are presented in Figure 6.



Fig. 6. The examples of different types of nanofibers for using as a layers for ventilation / insulation suit

One of the new technology of producing of nanofibers is electrospinning (Fig. 7, 8) as a cheap and relatively simple technique to produce nanofibers [1]. The technique is very old but has regained interest since it enables the production of cheap nanostructures. The process simply consists of:

1. blowing a polymer solution through a small nozzle,
2. applying a high voltage (25÷50 kV) over nozzle and substrate to reduce the fiber, diameter electrostatically down nanoscale,
3. recollect the nonwoven nanofiber mat from the substrate.

Other characteristics of these produced nanofibers are:

1. typical fiber diameters are in the range of 50÷200 nm,
2. long fibers: typically cm range,
3. also suited to produce ceramic, metaloxide and carbon,
4. nanofibers high throughput.

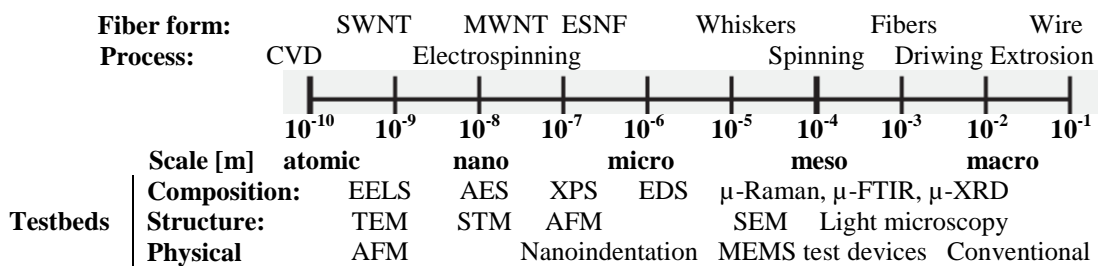


Fig. 7. The different type of technology and measures means in dependence on scale

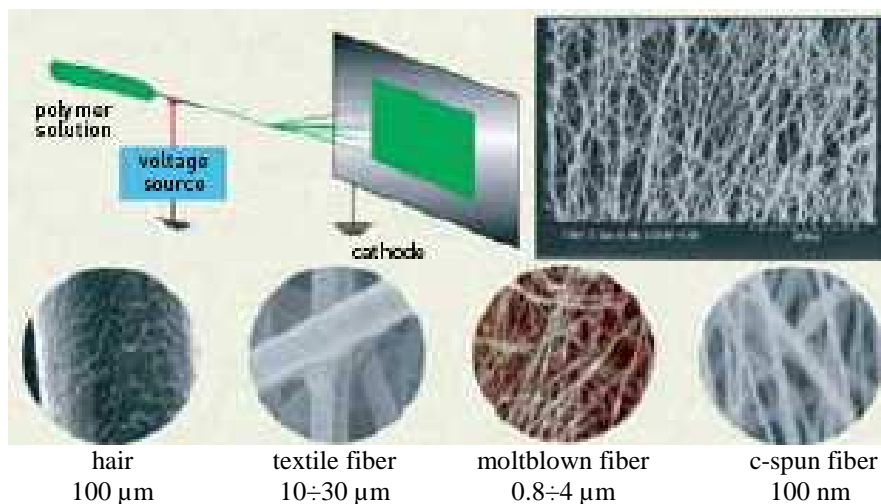


Fig. 8. High throughput electrospinning of nanofibers (Tandec, USA)

Nanofibers can be used in nonwoven mats but can also be spun into yarn. The following applications are in development:

1. nanofiltration and absorption (eSpin, USA),
2. catalytic breakdown (catalytic active nanofiber, or nanofibers with a catalytic coating, BC breakdown),
3. sensors, thanks to the large surface area sensitive to absorption and subsequent change in e.g. electrical resistance (polymer conductive nanofiber) to be investigated:
 - structural applications, reinforcement fiber, e.g. for antiballistics,
 - insulation,
 - selective gas permeation (breathing, BC protective fabric),
 - carbon nanotube polymer composite fiber (high strength).

Texas Tech Researchers Make Chemical Warfare Protective Nanofibers (in 2006) may have discovered a polyurethane nanofiber technique (nanofibers are tiny about 1,000 times smaller than microfibrils) that can save lives. The honeycomb polyurethane nanofabric is produced by using electrospinning. The nanofabric, created by exposing polyurethane to high voltage, can not only trap toxic chemicals, but also be used in a hazardous material suit. This can be a very efficient filter against toxic chemicals (warfare agents), as well as a membrane for protecting people as a chemical protective clothing.

The tensile strength of nanofibers has not been researched much. First experiments with nonwoven mats indicate that the tensile strength increases significantly with reduction of the fiber diameter: e.g. going from a 6 μm fiber to a 60 nm fiber resulting in a 10-fold tensile strength. These CNT fibers and other nanofibers have a theoretical strength of 130÷180 GPa.

The increase is expected to originate from:

1. increase in number fiber-to-fiber bonds,
2. orientation of the polymeric molecules in the fiber-length direction.

A new inorganic fullerene-like nanostructure (IF) is a material produced by the Weizmann Group [6] and instead of carbon, it's made of tungsten disulfide (Fig. 9) [7, 8]. Unlike carbon based organic fullerenes (are highly toxic), IF is easier and less expensive to produce, is chemically stable, less reactive and less flammable, while IF materials have been fully tested and deemed safe.

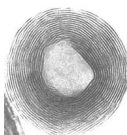


Fig. 9. IF nanostructure as the basis for future nanoarmour

One of the most interesting new IF properties discovered is its extremely high degree of shock absorbing ability. The new Tungsten-based IF material has up to twice the strength of the best impact resistant materials currently used in protective armour such as boron carbide and silicon carbide. It's over 5 times stronger than steel. Mixing IF with elastic materials could lead to new compounds which are both shock absorbing and flexible – perfect for ballistic armour.

Nanotechnology for the soldier is directly related to new functionalities in his typical suit (Fig. 2) and called smart uniform (Fig. 10), typical helmet (Fig. 11) and smart helmet (Fig. 12) or other portable equipment. Technologies with potential use for the soldier are:

1. integrated sensors (RFID+) and actuator arrays: body, health and environmental monitoring, and wound treatment,
2. directed RF tracking-tracing-identification,
3. anti-ballistic protection (flexible, lightweight),
4. BC-sensing and protection,
5. adaptive: switchable insulation, adaptive insulation and ventilation in suit, camouflage.



Fig. 10. Smart uniform with the different type of sensors

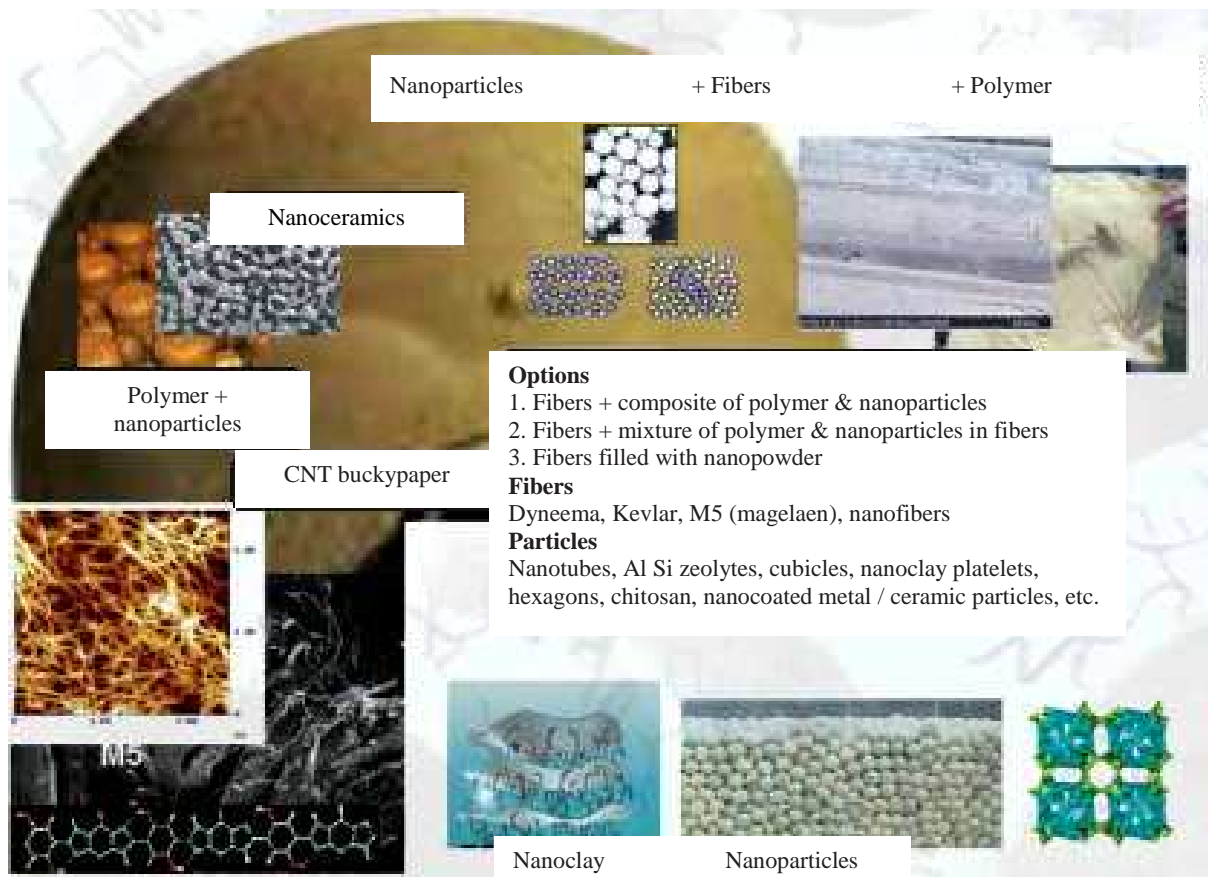


Fig. 11. Anti-ballistic materials for helmet



Fig. 12. Smart helmet with antenna sensor array (ASA)

3. Bio for soldiers

The nano-bio fusion is a booming area with high expectations that major steps in health treatment, body repair and body improvement can be made. It is regarded as the most innovative domain of this moment. Developments are in the field of:

- nanomedicine: targeted drug delivery by medically functionalized nanoparticles, for rapid cure without side effects or human stimulation,
- regenerative medicine: DNA programmed tissue engineering for quick and efficient wound healing, rebuilding of organs and other body parts,
- smart implants: biocompatible implants that can sense and actuate in order to repair or enhance a body function.

The elements of biotechnology for soldiers are presented in Figure 13, 14 [1].

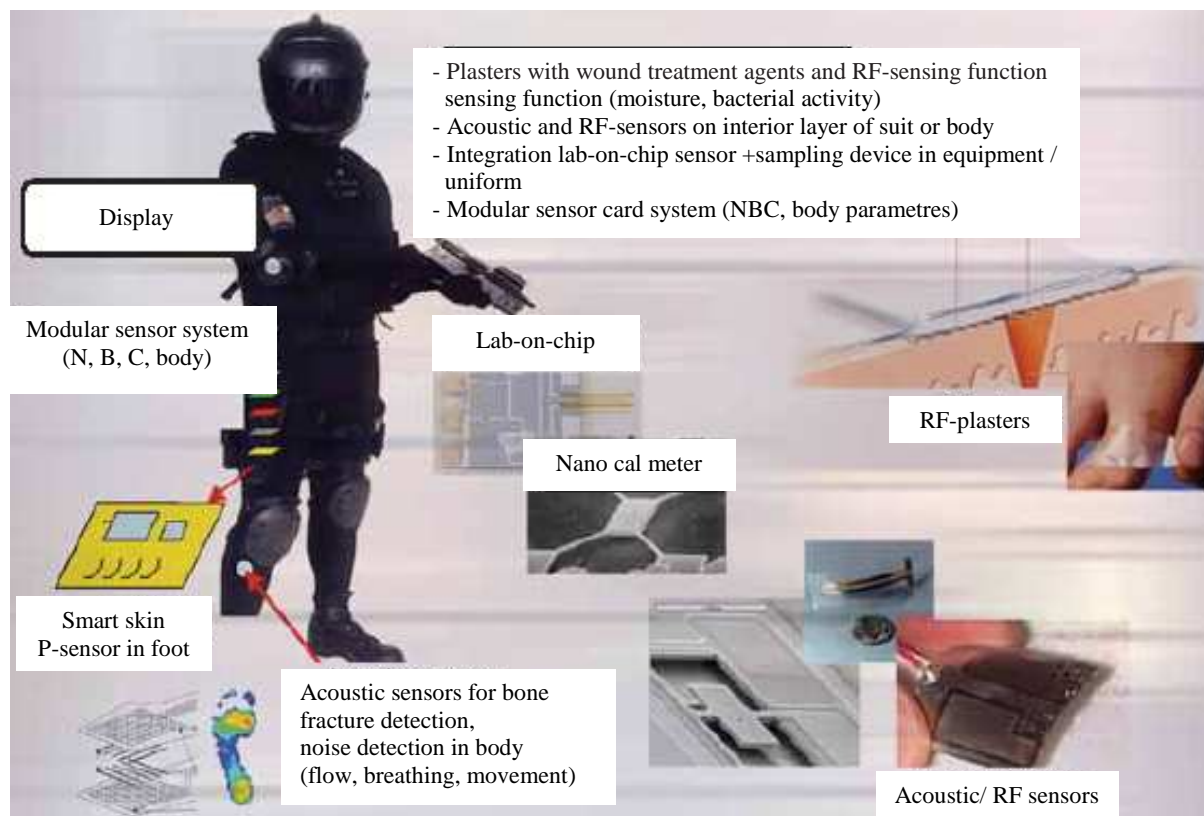


Fig. 13. Health monitoring and wound treatment

The functions of the 2010 Future Force Warrior system will provide an overall physiological picture of how the soldier is performing on the battle space, continuously monitoring key parametres such as body core temperature, heart rate, and how much water the soldier has drunk [9]. A medic who can be miles away will be able to diagnose a soldier (Fig. 15) who is about to have a sunstroke or suffer another medical problem, and if necessary the computer will immediately drop down a map to direct the soldier where to find medical assistance.

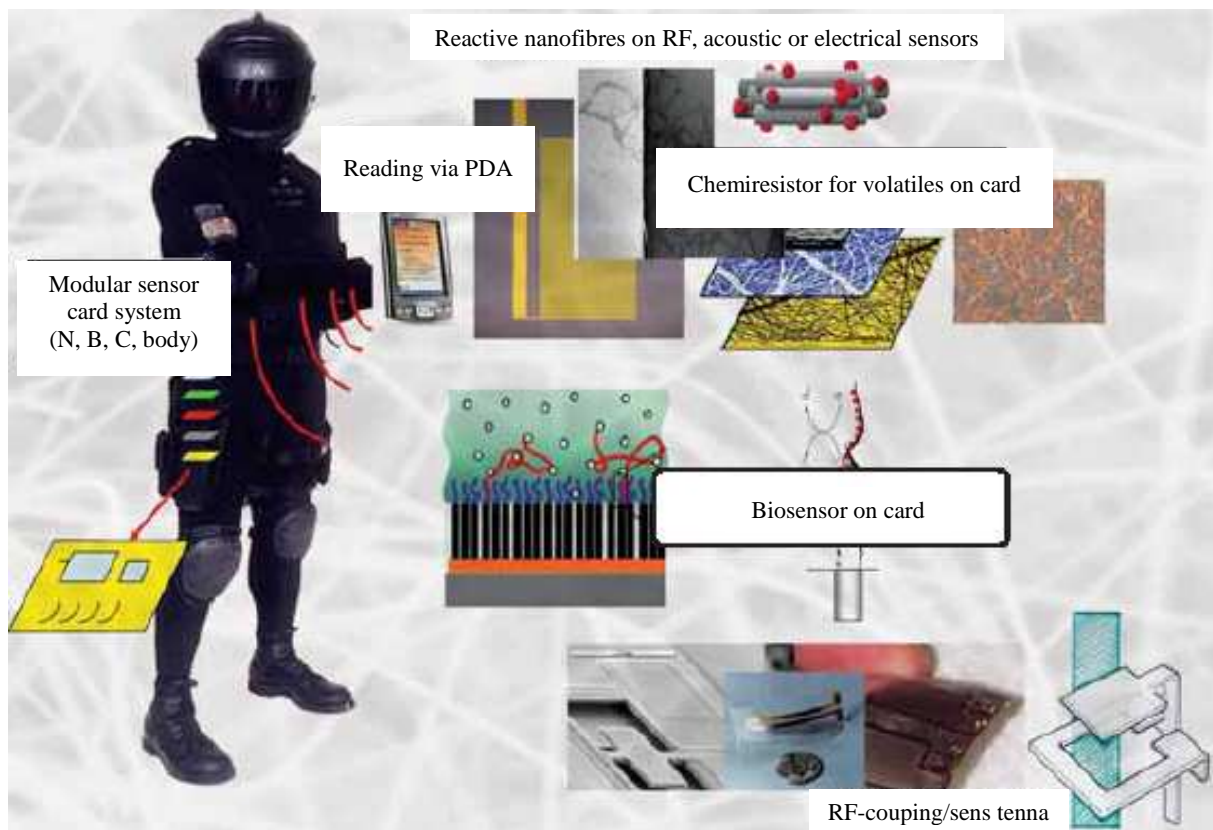


Fig. 14. BC sensing and health monitoring in suit

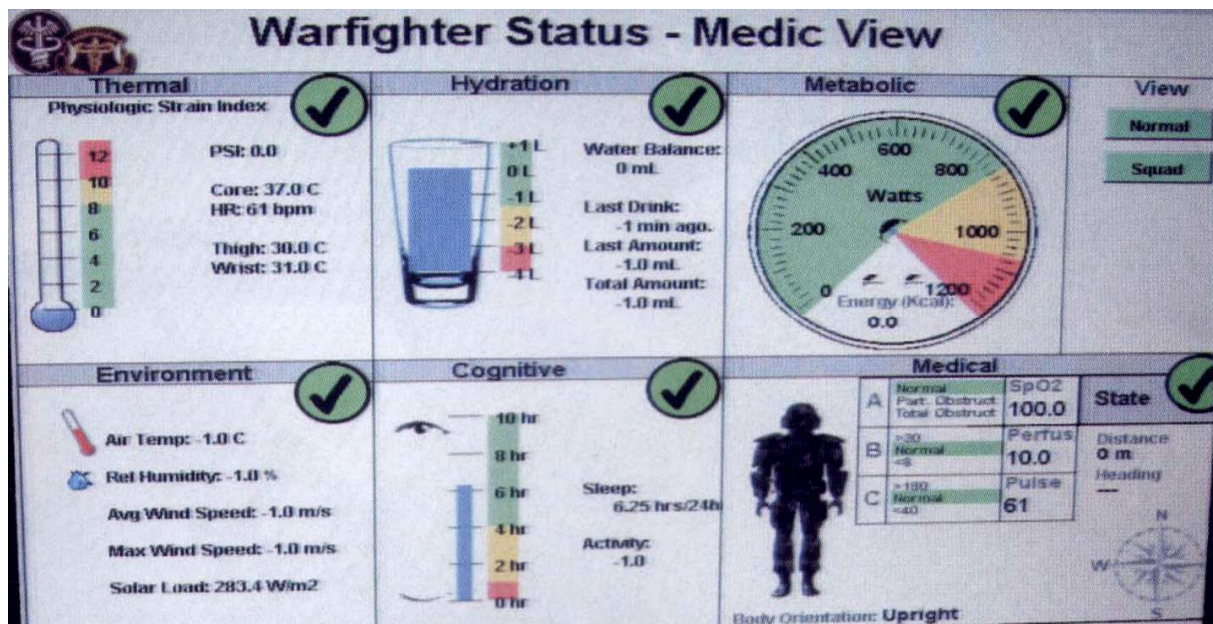


Fig. 15. The example of DEMO monitor presentation of the different parameters of Future Force Warrior as: thermal, hydration, metabolic, environment, cognitive medical

An Israeli company has recently tested one of the most shock-resistant materials known to man [4]. Five times stronger than steel and at least twice as strong as any impact-resistant material currently in use as protective gear, the new nano-based material is on its way to becoming the armour of the future.

4. Conclusions

All directions of development of means of the soldier body protection are concentrated to gain the following:

1. High protection ability of light materials with the use of:
 - nanolayers and /or
 - nanoparticles as:
 - stiff solid bodies– helmet, inserts for bulletproof vests,
 - elastic fibers – uniforms, bulletproof vests,
2. High quality equipment as sensors, mounted on helmets, enabling optical and acoustic observation, communication and telecommunication, etc.
3. Sensors and equipment, enabling monitoring of soldier biological parameters, detecting threat of N, B, C type and making easy his functioning as a result of uniform ventilation, etc.
4. Parts of uniform – especially bulletproof vests, changing their stiffness from very soft during regular exploitation to extremely stiff when impacted by a projectile or a knife, etc.

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