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Smart TextILEs in Defence: looking at the soldiers of the future (STILE)

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1. INTRODUCTION

Smart Textiles are a new generation of materials and systems with very interesting multifunctional properties (camouflage, moisture management, electronics integrated in textiles, etc.). These properties, together with the possibility of integrating the materials and systems in uniforms and platforms, have drawn the attention of the defence stakeholders.

In this context, the European Defence Agency (EDA) has incorporated the Smart Textiles to the Strategy Research Agenda (SRA) of the CapTech Materials & Structures; in addition, a Technology Building Block (TBB) is devoted to this technology. Furthermore, other EDA CapTechs, such as the CapTech CBRN and Human Factors and the CapTech Ground Systems have performed initiatives related to "Smart Textiles".

Throughout 2018, EDA launched an OB study dedicated to "Smart textiles in defence: looking at the soldiers of the future". This study, entitled as STILE Project, was assigned to the consortium led by the Spanish Textile Research Institute (AITEX), in collaboration with the Centro Tecnológico das Indústrias Têxtil e do Vestuário de Portugal (CITEVE) and Instituto de Ciência e Inovaçao em Engenharia Mecânica e Engenharia Industrial (INEGI).

STILE project has the objective of laying the foundation for a European Multifunctional Smart Textile focusing on defence and, in particular, of tackling aspects of functionality, integration, comfort and light weight.

The first phase of the project was focused on two main objectives. The first one was the development of a credible roadmap, with the final goal of establishing how to pass from the current state of the art to a full system that integrates several functionalities in a textile substrate. The second objective was devoted to the fabrication of a proof of concept, integrating various functionalities, namely:

- signature management
- monitoring of environmental parameters and CBR threats
- improved mobility
- flame retardancy, water and dirt repellence and anti-mosquito solution
- physiological monitoring, temperature regulation
- communication and wireless exchanging data.

Aiming at making the most of the results achieved during the first phase of the project, the design of the proof of concept and the depth of the simulation formerly developed were refined throughout the second phase. A full testing campaign of the proof of concept was carried out, considering different parameters in both controlled (laboratory conditions) and non-controlled (real conditions) environments.

Additionally, the IFAST International Forum was organized, in order to disseminate and promote the results of the STILE Project among the widest audience, gathering different stakeholders related to the field of multifunctional smart textiles and raising awareness among them about the importance of the research in this field.

2. OPEN ACTIONS COMING FROM THE FIRST PHASE

At the end of the first phase of the STILE Project, the following six open actions were identified, with the objective to be tackled during the second phase:

- Encryption of data during the transmission to the external server,
- Improvement of colour fastness to light,
- Upgrading the proof of concept with a system able to adapt the temperature regulation solution as function of the environmental temperature,
- Improvement of the protection of the smartphone pocket against heat and flame,
- Addition of a sixth sensor, in order to use the full 3 pairs of sensor ports,
- Development of numerical models to simulate materials thermal protection behaviour in the proof of concept and increase the results confidence.

3. SIMULATION

The STILE concept was designed carrying out extensive simulation activities. Two simulation models were developed to evaluate the main aspects regarding the thermal protection capacity of the garment and the thermal signature under different ambient conditions.

A FEM (Finite Element Method) model was developed to study the thermal protection capacity of the clothing assembly. Three exposure scenarios were defined and simulated to evaluate the fire protection capacity by analysing the skin burning degree. In addition, three ambient exposure scenarios were defined and simulated in order to analyse the thermal signature of the garment under different body metabolic rates.

The obtained results showed the good heat insulation performance of the STILE proof of concept to protect the body against external threats. The proposed finite element model demonstrated to be capable of describing the thermal behaviour of the garment interaction with the human body and the surrounding ambient conditions.

Experimental validation tests were performed in controlled temperature ambient conditions; the results were compared to the outcome of the numerical simulations using the proposed model, obtaining a good correspondence for the different garment sections. This demonstrates the capability of the proposed numerical model to estimate the thermal protection and signature under different ambient conditions.

This study showed how numerical simulations can be highly efficient and effective in the textile design process. The added value is particularly evident when the textile material integrates very complex systems, which implies the need to arrive to the fabrication phase with a high level of confidence related to the expected results (e.g. thermal and signature management), in order to optimise the experimental cost associated to the design and fabrication processes.

4. TESTING OF THE PROOF OF CONCEPT

Fabrication of key open actions.

Out of the list of open actions coming at the end of the first phase of the project, three of them were regarded as “key open actions” and were tackled at the beginning of the second phase of the project:

- Upgrading the thermoregulation system

- Improvement of colour fastness to light
- Protection of the smartphone pocket against heat and flame.

With regards to the upgrade of the thermoregulation system, a thermometer with specific requirements was incorporated into the combat shirt to provide precise information about the thermal comfort experienced by soldiers. A thermistor was selected as the most suitable device to be used as thermometer in these conditions. With this new design, the thermoregulation solution acquires intelligent features. The management system is now capable of automatically activating and changing the heating and cooling levels, according to a predefined configuration associated with the environmental temperature.

Regarding the improvement of colour fastness to light, new formulations involving thermochromic pigments were developed and an optimization study of the multi-functional fabric was carried out.

In relation to the protection of the smartphone pocket against heat and flame, protective flaps composed by the camouflaged multi-functional fabric were added, in order to cover the "window" of the pocket, and thus providing protection against heat and flame. The "windows" were made of transparent films, and placed in the smartphone and battery pockets, providing easy reading of the corresponding displays.

Initial testing campaign

Ergonomics and fitting assessment by wearer trial were planned and performed with a group of users of variable ages, height and weight. A total of 17 movements/tests were evaluated by the wearers of the STILE system in two parts, one with only the STILE system and other wearing the STILE system and the body armour, considering two environmental conditions (cold and hot environments).

Additionally, different tests were conducted on the software, e.g. communication, wireless exchanging data and electronic systems, aiming at detecting the existence of usability problems, issues related to the energy management of the system, difficulties associated with the interface of the smartphone application, interferences among different subsystems.

Analysis of the initial testing campaign

Throughout the development of the initial testing campaign, various issues were detected, mainly related to the following aspects:

- number, length and positioning of the cables
- performance of the heating and cooling systems
- positioning of the battery
- potential improvement in the comfort and freedom of movement of the proof of concept
- enhancement of the functionality of the electronic system
- and the smartphone application interface.

Design improvement

The gathered data coming from the analysis of the initial testing campaign of the second project phase were used to identify different areas of improvement in the design of the STILE proof of concept.

Improvements on the design of the proof of concept coming from the first phase of the project were envisioned to increase ergonomics and fitting aspects, as well as the impact of STILE thermal regulation system on the user. Besides some changes in the underwear shirt (inner layer), the main changes resided in the combat uniform (outer layer), more specifically the combat shirt, especially in the fans cable placement and CBR sensoring system. Accordingly, instead of a connectors belt, a

removable pocket containing the control box and battery was attached to either the combat belt or ballistic vest via the MOLLE system.

In addition, the realization of tests on the software, communication, wireless exchanging data and electronic systems enabled the detection of potential areas of improvement related to usability problems, issues related to the energy management of the system, difficulties associated with the interface of the smartphone application and interferences among different subsystems.

Improved proof of concept fabrication

With the objective of achieving an enhanced version of the combat system, an improvement of the previous design was carried out and the corresponding modifications and adjustments in the fabrication process of the global solution were implemented.

The main improvements implemented on the proof of concept concern in the combat shirt, specifically in:

- Fans cables. A new placement was envisioned and both cables (front and back) were oriented up and then horizontally to the lateral seam.
- CBR system cable. The placement of the CBR cable continues to be along the lateral seam but ending at the same point of the fan cables. At this point, all the 4 cable wirings are joined in one single cable with the connector to match the counterpart connector of the removable "pocket".

A sixth sensor was included in the CBR threats monitoring solution adopted at the end of the first STILE project phase, making the proof of concept capable of monitoring six different chemicals: CO, H_2S, Cl_2, NO_2, SO_2 and NH_3.

The data sending protocol was improved to ensure the communication process, using an AES (Advanced Encryption Standard) encryption system.

The system was also improved solving specific issues related to the thermal inertia of the heating system, the performance of the fans, the interferences between the GPRS and GPS systems, the Time to First Fix (time required for the device to get and process satellite signals, in order to provide an accurate GPS position), and other issues associated with the smartphone application.

Full testing in controlled environment

The full testing campaign in controlled environment was carried out, conducting a battery of tests on the improved and enhanced version of the STILE multifunctional smart combat system.

In relation to the electronic, communication and wireless exchanging solutions, the improved version of the STILE combat system showed a better performance of the different sub-systems related to these functionalities. Regarding the signature management, improved mobility and flame retardancy, as well as water, dirt and anti-mosquito solutions, the improved version of the STILE multifunctional smart combat system showed, in general, that the results were considered as approved, according to each respective standard orientation. Overall, these technical improvements also translated into better results of the ergonomic, fitting, and impact of the thermal regulation system assessments. The ergonomic and fitting assessment performed with the users indicated a clear enhancement as compared to the first version, both wearing only the STILE model and wearing the STILE model and the ballistic armour. As for the impact of the new thermal regulation system assessed with the same group of users, an improvement was also observed.

Full testing in non-controlled environment

The full testing campaign in non-controlled environment was carried out with the participation of CINAMIL (Centro de Investigação, Inovação e Desenvolvimento da Academia Militar / Military Academy Research Centre in Portugal), as a subcontractor. The inputs coming from CINAMIL MRLab (Military Readiness Lab) were used to assess and evaluate, not only the comfort and fitting, but also the physiological effects of the STILE proof of concept. To that effect, special attention was given to the following aspects of the STILE equipment:

- Physiological monitoring: a series of sensors were used to assess internal and external temperature, heart rate variations and respiratory alterations
- Temperature regulation: information was collected from internal and external sensors
- Comfort and fitting: besides ergonomics and comfort, parameters such as flexibility, weight distribution and freedom of movement were assessed.

Final adjustments in the fabrication

The technical remarks and the suggestions provided by CINAMIL were analysed and considered, with the objective of making some final adjustments in the proof of concept developed throughout the STILE project.

An improved version of the proof of concept was achieved including modifications related to the inclusion of ventilation openings in the control system box and the textile pocket, the shortening and integration of the cable, the integration of ventilation openings in the top part of the combat shirt to promote increased air circulation, and the inclusion of an elastic band around the chest area of the underwear shirt, in order to tight the fit.

5. IFAST INTERNATIONAL FORUM

The dissemination campaign at the end of the project was meant to reach out stakeholders involved in the field of advanced smart textiles in the civilian and military domains. In this context, the International Forum on Advanced and digitalised Smart Textiles (IFAST) was organized online on 15 and 16 June 2021. The event showed two main aspects of the multifunctional smart textiles: their added value to respond to capability needs and their dual use properties, which makes this technology a relevant example of “dual use by design”, which is expected to be an advanced technology transfer mechanism more and more relevant in the future EU dual use ecosystem.

IFAST was organised in an Exhibition area, where industries, academia and research organisations presented their products, services and projects in the field of smart, advanced and digitalised textiles, and a Conference area. The latter hosted several keynote speeches and the presentation of the results of the STILE Project. In addition, two panels were organised, with the title “Foresight on advanced and digitalised smart textiles in the European defence sector” and “Visualising a European dual use programme for multifunctional smart textiles”.

The event had a broad participation of relevant stakeholders coming from governmental defence bodies, industry, academia and R&T communities, as well as European institutions and organizations.

The contributions to the IFAST Conference and Exhibition are published in a book of abstracts (ISBN pdf 978-92-95075-58-0, ISBN paper 978-92-95075-59-7).