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Vital Analysis: Field Validation of a Framework for Annotating Biological Signals of First Responders in Action*

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***Abstract*— First responders are professionals that are exposed to extreme stress and fatigue during extended periods of time. That is why it is necessary to research and develop technological solutions based on wearable sensors that can continuously monitor the health of these professionals in action, namely their stress and fatigue levels. In this paper we present the Vital Analysis smartphone-based framework, integrated into the broader Vital Responder project, that allows the annotation and contextualization of the signals collected during real action. After a contextual study we have implemented and deployed this framework in a firefighter team with 5 elements, from where we have collected over 3300 hours of annotations during 174 days, covering 382 different events. Results are analysed and discussed, validating the framework as a useful and usable tool for annotating biological signals of first responders in action.**

I. Introduction

Certain professional groups, such as Firefighters (FF), work in dangerous and extreme environments, in which they are exposed to unquantifiable stress and fatigue levels during extended periods of time [1]. It is yet unknown how these exposures, being short or long, affect them. Nevertheless, it is known that these professionals present the highest occupational fatality rates in the U. S. [2] and a possible reason is that these exposures lead to serious cardiovascular problems [2], and, in the worst cases, death [3]. This motivates the need for systems and technologies capable of monitoring, during real work conditions, the biological signals and behaviour of these professionals, allowing the management of stress and fatigue levels and helping the prevention or detection of possible accidents that can jeopardize their physical condition.

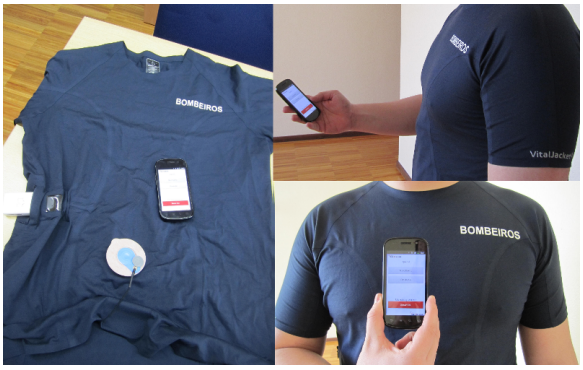

Fig. 1. Images of a version of the Vital Jacket®, specially made for the firefighters, and the Vital Analysis framework running on a smartphone.

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To meet those needs, the "Vital Responder" project (http://www.vitalresponder.pt/) was created. It is based on a wearable shirt (Vital Jacket®) [4] (in Fig. 1) that can collect electrocardiogram (ECG), accelerometer and GPS signals and then transmit them to a base station capable to infer the stress and fatigue levels of each individual using this collected data. In order to address these research questions effectively, we need not only to collect a significant amount of data from real situations, but also contextualize it with adequate annotation. This has motivated the main contribution of this paper, which is the creation, deployment and field validation of a framework capable of annotating biological signals of first responders in action.

Being able to acquire annotations during a real event in extreme conditions is clearly a non-trivial challenge for the individuals undergoing highly stressful and dangerous situations, given that they do not have the time or mindset to do it themselves, and it is not feasible to have a team of observers with them, constantly annotating what is going on, mainly due to safety reasons. Nevertheless, it is possible to find projects that perform annotation of biological signals in real scenarios in real time, by external observers [5] or even by the users themselves [6], although these examples are not as demanding and uncontrolled as with first responders, allowing the users to have time to do the annotation or to have cameras filming the event. The only studies with annotation during first responders events [7] were tested during simulations or trainings.

In this paper, in Section II, we will describe the Vital Analysis Framework. In Section III we will present our results and will discuss them, and in Section IV we will present our conclusions.

II. Vital Analysis Framework

Given the nature of a firefighter's work our framework needs to collect a reasonable variety of information which will enable us to label and contextualize the biological data gathered. This includes not only information about official events encountered, but also: information about work being done inside the fire station; information about anomalies or difficulties that appear during an event; and their subjective self assessment of their levels of stress and fatigue in the beginning of the day, after such events, and in the end of a work day. In this paper we will use the FF definition for event, which is a specific emergency situation for which they are call to intervene.

A. Contextual Study

To understand the routines of firefighters in the largest possible variety of situations, inside the fire station and during real events, two contextual studies were performed:

- 3 full days in real situations: we have stayed with a team during 3 full days and followed them to every possible event. During those days we were able to see them in action during: pre-hospital assistance; vehicular accidents; small fires; and forest fires, which, despite the fact that we were observing from a safety distance, we were always in contact with the commanding officer, giving us the opportunity to understand the workflow of the event and at the same time question the commander about it;
- 3 weeks of training situation:, in which we attended theoretical classes about specific event methodologies and procedures, and some training exercises (see Fig. 2) such as: vehicular accidents with several different extrication requirements; rescuing inside buildings in fire and in other extreme scenarios, such as mountain and river; and forest fires.

Fig. 2. Images of a vehicular extrication and a rescue in a river scenario exercises, taken live during the contextual studies.

During these days we have gathered enough information to understand the daily routine of a firefighter inside the fire station and the methodologies and procedures used and required during most of the possible events. This information should be understood as requirements for the final framework, where the most important are:

- *the focus during the event*: during an event, it is normal to think that their focus is only in the task at hand, which is true from what we have observed. The only exception is the sound of the walkie-talkie, everything else that can distract them is rejected. We have concluded that **during the event itself it would be very hard to have annotation**. But before and after, they have time.
- *size of the team*: there are no events where a firefighter goes alone. There is always a team, and in the most important events they always have, at least, five elements. Therefore, **to have information about an event we only need one of them to have time to do it**.
- *roles during the event*: in every event, we have a team of firefighters completely focused on the event itself, and ignoring what is around them. Nevertheless, we have observed that for each specific event, each firefighter has a different role. Despite the fact that all of them are important, there is one that is less focus demanding, which is the driver. In every event observed, **the driver had time to understand the big picture of the event, and is more relaxed than the other team mates**. This role is not given to the same firefighter every time, but **could be an opportunity to have annotation during the event**.
- *the trip to the event, and back home*: we have noticed that **outside the event itself, during the trips, the firefighters have time and patience to perform some actions** outside their normal behaviour, therefore, just like the driver during the event, **this can be a good place to try to get extra information**.
- *voice over anything else*: we noticed that the firefighters are used to have to report what is happening by voice, even if the situation is getting out of control. Therefore **we should try to use voice annotation to collect information**, since it is a normal thing for them to do.
- *actions are rarely predictable*: the methodologies and procedures for each event are very well defined, but we have observed that in a chaotic environment they are forced to change this routine and adapt to each specific situation. This means that **our framework needs some sort of "break the glass" mechanism that can override the typical annotation action flow**.
- *each event has a different impact in each firefighter*: to be **able to allow each user to perform a subjective self assessment** can give us extra information about how stressful and fatigue the event was to each subject, allowing us to handle this observed inter-person variability.

All this information will be reflected in all the decisions presented in the next subsections, because with them we can have a realistic approach to the problem at hand.

B. Conceptual Model

Taking in consideration the requirements identified in the contextual studies, it became obvious that our conceptual model would need to have three annotation methodologies:

*1) **Stress Annotation Methodology (StA)**:* The StA has the goal of recording a self assessment of psychological and physical stress in the daily routine of firefighters. The meaning of stress is ambiguous [8]. And to address it, we approached a team of psychologists, from the Faculdade de Psicologia e Ciências da Educação do Porto, Portugal, to provide us with standard questionnaires from which it could be possible to know if a work day was stressful or not, and to know if the specific events along the day were stressful.

These questionnaires are divided into four different categories. The first category, translated and adapted to Portuguese from Zuckerman (1994, pag. 389–392), regards to a firefighters personal information and is only done once. The second and third categories, adapted and translated by Pais Ribeiro and Rodrigues (2009) from Carver (BRIEF-COPE 1997) are the first questionnaires that interpret the meaning of stress. These questionnaires are done at the beginning and the end of every work day. Comparing the results from both provides a rich understanding of the mental and physical

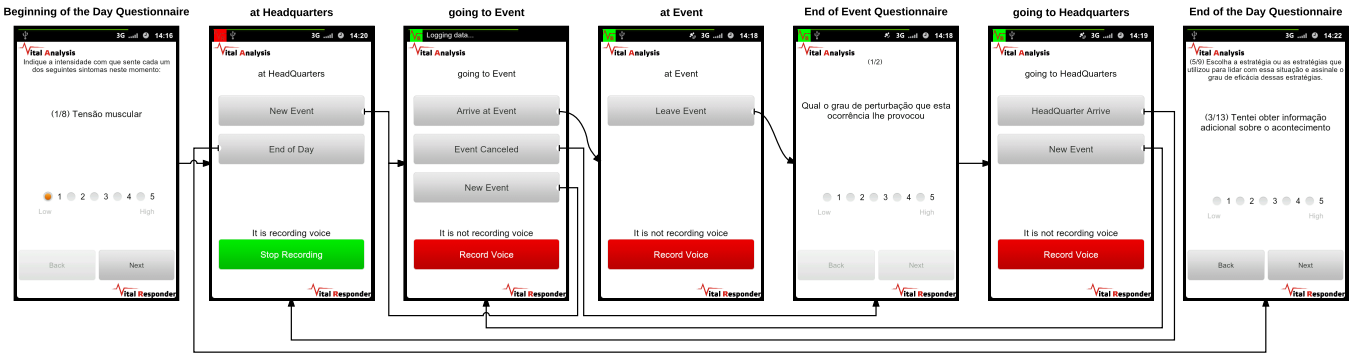

Fig. 3. System Image of the Vital Analysis application with real screenshots.

capacities that were put to test daily, and minimizes the effect of the intra-person variation. The final and more specific one is the event questionnaire, created by the psychologist team. The answers that we can obtain at the end of an event, being it a fire, vehicle extrication or any other, lets us better understand the difficulties the firefighters had to face regarding their own limits within that event.

*2) **Event-driven Annotation Methodology (EdA)**:* The EdA gives us the possibility to detail an event by dividing it into several predefined stages, allowing us to evaluate and quantify the collected biological signals differently for each. This predefined stages, are the basic stages for every single event, and are usually consecutive:

- *at Headquarters*: The firefighters are in the headquarters waiting for a new call for an event. When they receive it, they head to the theatre of operations, starting the next stage.
- *going to Event*: During this trip we can gather data on how the biological signals are influenced by the pre-event stage. Upon arriving at the event, the third stage starts.
- *at Event*: In the event itself the data acquired is bound to be rich. Taking into account the StA and even the VoA (see section II-B.3), the data collected can be intertwined to recognize the capability of each firefighter to overcome their own boundaries regarding stress.
- *going to Headquarters*: the last stage starts with the trip back to headquarters.

Despite this simple workflow, our methodology also contemplates all the other possible official actions during an event: higher priority call, cancellation of the event, and new call for another event when returning to headquarters.

The conceptual model can be seen in Fig. 3, applied in the system image, where all the main four stages are represented.

*3) **Voice Annotation Methodology (VoA)**:* Motivated by the unpredictability of all types of events we have design the VoA. This methodology will be our ”break the glass” mechanism, and a positive transfer from their own already established methodologies, allowing that at least one of the firefighters can report activities that are not expected during an event. This way it is possible to obtain rich and expressive contributions on what is happening in any given moment, especially when compared to event-only annotation.

This methodology is also used to allow the user to add annotation whenever he thinks is necessary, giving us extra information during an event, or during the daily internal routines, extending the EdA, and also supporting the StA.

C. Implementation and Deployment

After the contextual design, we address the implementation phase. We have chosen to implement our framework in the Android OS due to the knowledge that the team already had about the platform. The next step was to choose a robust smart phone that could survive in extreme environments, with good battery life, and being small and light but at the same time with a sufficient large screen (see Fig 1). The choice fell on the Samsung I5500 Galaxy 5, with dimensions 108x56x12.3 mm, weight of 102 g, a 2.8 inches capacitive touchscreen, and a Li-Ion 1200 mAh battery.

The first process was to design a system image (see Fig. 3). We had to design a simple button interface with all the actions possible to do in each stage, considering affordance (easily recognize buttons that are distinct from informative labels), mapping (clear text was chosen over more attractive icons), visibility (smallest amount of information possible per screen) and feedback (explicitly say to the user what is happening). As can be seen in figure 3, the VoA is present during almost all the system, allowing the user to enrich the data collected as he sees necessary. Notice that each action done in the system, produces a special tag that is logged with a timestamp, that allow us to understand what was clicked and when. These timestamps also allow us to know what was the duration of each event, questionnaire and voice annotation.

After the implementation and the laboratory tests, we have deployed the application within a five men team to use it during their daily work, which has been used since July of 2011. The usability results acquired from this deployment are shown, explained and discussed in the next sections of this paper.

III. Results and Discussion

From all the data gathered with the Vital Analysis framework we chose a dataset collected from 11-07-2011 until 18-01-2012 and we have compared it to the official reports,

TABLE I

RESULTS COMPILED FROM THE DATASET COLLECTED FROM THE FIREFIGHTERS (FF). WE HAVE ANALYSED ALL THE EVENTS (TOTAL), WHEN ONLY A SPECIFIC AMOUNT OF FF WHERE PRESENT (1FF..5FF), AND WHEN MORE THAN A SPECIFIC AMOUNT WAS PRESENT (>1FF..>3FF)

	Total	**1FF**	**2FF**	**3FF**	**4FF**	**5FF**	**>1FF**	**>2FF**	**>3FF**
No. of Events:	382	213	138	23	5	3	169	31	8
% of Annotations:	52,4%	36,2%	69,6%	87,0%	80,0%	100,0%	72,8%	87,1%	87,5%
% of good Annotations:	68,5%	66,2%	67,7%	80,0%	50,0%	100,0%	69,9%	77,8%	71,4%
% of incomplete Annotations:	8,5%	5,2%	11,5%	5,0%	25,0%	0,0%	10,6%	7,4%	14,3%
No. of Events with audio:	20	8	7	3	1	1	12	5	2

mandatory by law, in which firefighters have to store the beginning and end time of each event. We have collected, from the five firefighters, a total of 3343 hours of Vital Analysis data. These are distributed over 174 days, covering 382 different events.

In order to analyse this massive amount of data, we have extracted an extended set of metrics with a strong emphasis on usefulness and usability. Although other analyses are possible from such a rich dataset, for the purpose of this paper we are interested in answering two questions:

- Do firefighters use the prototype correctly? (usability)
- Are events annotated correctly? (usefulness)

The first set of metrics is summarized in Table I. Where we can observe the percentage of annotated events, good and incomplete annotations, mapped not only for all the events but also for a varying number of participating firefighters, using the framework, per event. We define that an event is annotated if it has timestamps of all the actions done during the event, as explained in subsection II-B.2; that an annotation is good if none of those consecutive timestamps has a time difference smaller than 1 minute, since it is near impossible to change the stage of the event inside that time; and that an annotation is incomplete when it does not have all the necessary timestamps to define an event. As can be seen in Table I, looking at the events of the headquarters, we have 382 events during the usage of the framework, in which 52.4% (200 events) where annotated, and from these ones 68.5% (137 events) had a good annotation. If we compare the timestamps with the official times in the event reports, we have that the median times are: 08:52 minutes for the beginning time and -01:03 minutes for the end time, which supports that most of the annotations were made inside the event itself and are thus correct. We also noticed that our application had some crashes during events, which made us lose information on 8.5% (21 events) of the annotations (the incomplete annotations in Table I). This problem was identified as a memory management problem of other applications running on the smartphone, which is now fixed.

Other result that is interesting for our analysis are the 20 events in which FF have used the VoA. This number looks insignificant when compared to the 200 events annotated, but we have noticed that these annotations were made during the events that they considered most stressful, given their answers to the questionnaires. Although this observation needs to be confirmed by a full psychology analysis of the dataset, it strengthens our belief that we are gathering VoA precisely when it can be more useful.

Table I also shows the mapping of these metrics for a varying amount of FF per event. Notice the steady increase in the quantity of annotations as the number of FF grows, confirming our contextual study results. More FF increases the odds that the driver stays in the car or that a field element is idle enough to perform annotations.

IV. CONCLUSIONS

In this paper we have presented a new framework for annotation biological signals of first responders in action. Results from over 3300 hours of field deployment in a real FF team confirm that Vital Analysis exhibits good usability and was easily accepted and integrated by FF in their daily routine. This creates a unique new window for researchers to understand how our biological signals are affected by extreme fatigue and stress situations.

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