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Towards Immersive Skill Training for First Responders With Biosensor-Based Assessment of Situation Awareness

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ABSTRACT

First responders engage in highly stressful situations at the emergency site. Maintaining cognitive control under these circumstances is a necessary condition to perform efficient decision making for the purpose of own health and to pursue mission objectives. We are eventually aiming at developing biosensor-based decision support for risk stratification on cognitive readiness of first responders at the mission site. A fundamental prerequisite for efficient decision-making is situation awareness (SA). We envision to reliably predict levels of SA from bio-sensing in the field in the future. We propose as an important preparatory stage the assessment of SA during skill execution within an immersive environment, using biosensors that are mountable in the field. The Virtual Reality (VR)-based experience should enable to study biosensing in the context of SA in detail. In this paper, we describe the immersive research environment that will - as a research tool - enable both training and assessment of SA during characteristic task execution of a firefighter squad leader. The research concept, the system architecture with treadmill and biosensors, including analytical software components, as well as the study plan for future research studies are outlined.

Keywords: Human systems integration, Extended reality, Situation awareness, Biosensors

INTRODUCTION

First responders engage highly stressful situations at the emergency site that may induce stress, fear, panic and a collapse of clear thinking (Putnam, 1995). However, their physiological and cognitive readiness is of highest importance to enable appropriate decision-making (Frye & Wearing, 2014). A major aspect for keeping control of the situation is that first responders should always maintain SA. Training of the first responders' routines improves resilience towards stressors in severe hazard conditions. Advanced training of first responders, in particular, the use of VR-based environments for the training of SA and stress-resilient decision-making behaviour is one of the upcoming challenges of the near future.

A VR-based environment was developed with a typical firefighter scenario to train and to evaluate the SA of squad leaders (Figure 1). The operator has two major tasks, (i) searching for pocket of embers on the ground by using an

Figure 1: First responder in the treadmill with biosensor evaluation kit for the VR-based study of SA in critical situations (credit: L. Paletta, JOANNEUM RESEARCH DIGITAL).

infrared camera and whenever detected to call for a team member to work on it, (ii) to survey the team of 5 first responders for their visible presence as well as for their health condition and consequently to react in proper time instants whenever team members would be injured or disappear. The movement of the team members within a predefined skill-oriented territory is activated by an AI-driven method.

A wearable multisensory non-invasive measurement suite is mounted on the operator including VR-in-built eye tracking, biosensors for cardiovascular, electro-dermal and temperature data capture, to report by means of digital human factors analytics. From the sensor data-stream we intend to deduce psychological constructs, such as, SA (Paletta et al., 2022), physiological strain, cognitive-emotional stress, and fatigue. This paper describes the system architecture as well as the features of the VR-based skill evaluation system (VR with eye tracking, biosensors, treadmill, dashboard).

IMMERSIVE SYSTEMS FOR FIRST RESPONDER TRAINING

VR-based training in disaster management has been recognized as an important additional modality to traditional real-life skill training (Freeman et al., 2001). The increased realism in the practice enables first responders to reinforce their individual performance, in particular, to execute tasks appropriately under stress and apply decision making under conditions close to reality. Mills et al. (2019) estimated that a mass casualty triage training of paramedic students in a real-world simulation is about 13 times more expensive than in VR, while the simulation efficacy has been found nearly identical. Recent research (Koutitas et al., 2020) has even indicated superior performance in simple search tasks following VR- and AR-based training of first responders as opposed to traditional classroom and real world training. The use of wearable sensor-based monitoring systems offers life-saving opportunities for advanced health care solutions for stress analysis. By means of a wearable biomonitoring platform, Rodrigues et al. (2018) demonstrated that an increase in the stress levels decreased the cognitive performance of firefighters. Meina et al. (2020) showed that psychophysiological measurements are reliable indicators of stress even in ecological settings and appear promising for chronic stress monitoring in high-risk jobs, such as firefighting. Wildland firefighters often have to make tactical decisions under stressful conditions in order to bring a fire under control. These decisions can be hindered by human factors such as insufficient knowledge of surroundings and conditions, lack of experience, overextension of resources or loss of situational awareness (Fryer et al., 2015). SA should be kept high even during simple exercises (Paletta et al., 2022).

ASSESSMENT OF SITUATION AWARENESS

The concept of Situation Awareness (SA). SA has been suggested to directly affect human decision-making and performance in human–machine environments. Building on her definition of situation awareness, Endsley (1995) designed a model to describe information processing errors in complex systems. The model allows identification of errors that can 'lead to accidents in complex systems', such as, a team-supported firefighting operation. Depending on the phase of information processing, errors are expected in (1) perception processes, (2) the understanding and interpretation of the situation, and (3) in the projection of the system state into the future/anticipation. Without the perception of important information, the risk of creating a false picture of the situation increases (level 1 SA). However, in addition to perceiving stimuli, it is also necessary to combine, integrate, and store them. Information from several different sources must be integrated and interpreted in relation to personal or general goals (level 2 SA). The highest level of SA represents the ability to project current events onto anticipated future events (level 3 SA; Peissl, 2016).

Measures of Situation Awareness. To address the limitations of freeze-probe methods, alternative assessment formats have also been developed. In particular, self- and observer-rating techniques using questionnaires are also considered as direct SA measurements. The SA rating technique (SART; Taylor, 1990; Salas et al., 2018) and the SA behavioural rating scale (SABARS; Matthews & Beal, 2002) are two commonly used rating techniques. For example, after an experimental trial is completed, the SART assessment method asks participants to rate their awareness using a seven-point scale on the following dimensions: situation familiarity, attentional focus, information quantity and quality, situation instability, attention concentration, situation complexity, situation variability, arousal, and spare mental capacity (Salas et al., 2018). In contrast to the SART, another self-rating technique, the SABARS, is an observer-based rating method that relies on the observation of domain experts on participant behaviours. Specifically, it is a five-point rating scale on 28 observable SA behaviours of the participant (Matthews & Beal, 2002).

Measurement of Situation Awareness in VR. Ehrlich et al. (1997) reported that Virtual Environment (VE) technology, which uses position tracking and real-time update of visual, auditory, and other displays (e.g., tactile) in response to the user's motions to give the user the sense of being 'in' the environment, has the potential to improve simulation-based training for dismounted soldiers. One challenging area of research is matching U.S. Army training requirements with current and projected future VE capabilities. VE technologies were identified to be highly suitable to train particularly members of small dismounted units to acquire and maintain SA. Kaber et al. (2017) evaluated the efficacy of a computer-based SA measurement system for training dismounted infantry SA in an urban terrain VR-based simulation. The SA behaviour and communication ratings revealed differences among squads, which trended with experience.

Measures of SA were also consistent across the test scenario as a result of similar mission types and task difficulties.

Physiological Measures of SA. With respect to physiological measurement techniques, a recent systematic review by Zhang et al. (2020) reported that eye tracking was most commonly used for assessing SA.

Several studies associated SA with indirect cardiovascular activity measured by heart rate (HR) or heart rate variability (HRV). Three different studies used measurements related to EEG brain activity. Finally, one study used electro-dermal activity (EDA) and one used respiratory rate (RE). Among all articles, only one used multiple physiological measures.

Progress of presented work. The specific progress targeted in the presented research work is achieved by (i) proposing a very specific skill training that is at the same time particularly suited for SA training, and (ii) applying psycho-physiological measurements from wearable / portable sensors, in real-time. This work is based on previous results on biosensor-based estimation of situation awareness (Paletta et al., 2022) and will be performed applying pilot studies in the Human Factors Lab[1] of Joanneum Research, Austria.

Human Factors Lab. The Human Factors Lab combines state-of-the-art human-centred digital measuring technologies with AI-enabled software for behaviour-based analytics and assessment of psychological constructs in digital systems, such as, for digital cognitive biomarkers for cognitive screening in dementia, or, for estimating SA scores (Dini et al., 2017; Paletta et al., 2022). It analyses human stress as well as cognitive, affective, and motivational state by means of mobile and wearable technologies applied at work or at home. The infrastructure is equipped to investigate psychologically relevant parameters in real-time including a wearable biosensor and Neuro-ergonomics (fNIRS, EEG) workplace as well as VR/AR-based technologies, eye tracking (stationary, mobile, wearable) and high precision motion capture devices, furthermore, a treadmill, social robots and software libraries for gaze based analytics. The Human Factors Lab has access to various IoT software libraries for permanent data acquisition for various sensors and gateways to set up wireless sensing network.

[1] http://www.joanneum.at/humanfactors

AI-BASED IMMERSIVE SKILL-TRAINING SYSTEM

In this Section, we introduce the overall rationale for the implementation of the immersive training system. Then we present the system architecture that enables to perform a specific skill-oriented mission as well as to monitor specific aspects of the team behaviour and cognitive-emotional as well as SA-based parameters.

Overall Concept. A VR-based environment was developed with a typical firefighter scenario to train and to evaluate the SA of squad leaders. The operator has two major tasks, (i) searching for pocket of embers on the ground by using an infrared camera and whenever detected to call for a team member to work on it, (ii) to survey her team of 5 first responders for their visible presence as well as for their health condition and consequently to react in proper time instants whenever team members would be injured or disappear. The movement of the team members within a predefined skill-oriented territory is activated by an AI-driven method.

System Architecture. A schematic sketch of the overall hardware and software setup is depicted in Figure 2. From the input sensor devices, i.e., the eye tracking and VR-based event monitor, as well as the bio-signals from the BIOPAC system, data are received and analysed with respect to informative features in the Feature Fusion component (centre). The results are then visualized in real-time in dashboards on nearby displays (top).

Figure 3 provides a sketch of the system architecture of the VR-based skill training system. From the system architecture in Figure 3 we can depict that there are basically two relevant configuration inputs, providing static and dynamic parameters into the system. The I/O handler from Unity is responsible to control the XR aspects in the system. The render pipeline provides control over the rendering of the application, including, in particular, the individual virtual cameras, such as the thermal imaging camera.

The Application Logic and Manager component implements the control loop and decision-making in the system. Control signals are then fed to the individual scoring, visualisation and user interaction modules (Cognitive Computing & Visualisation). Output data are fed in real-time to the logger as well as to the dashboard and the display in general (top).

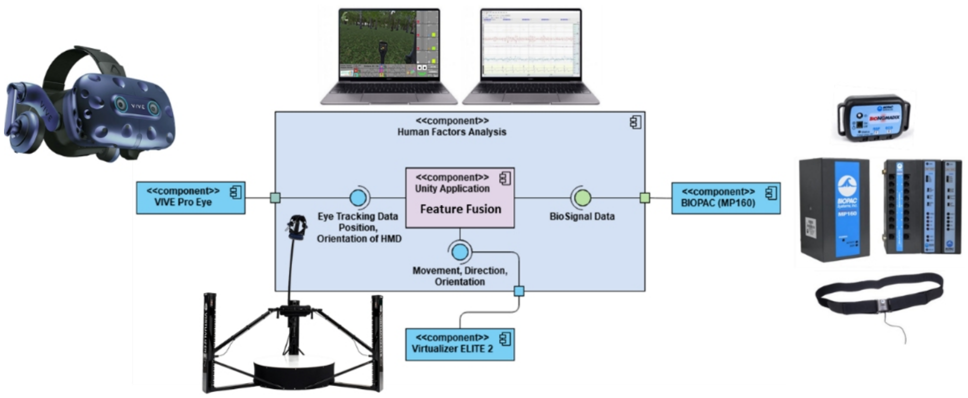

Figure 2: A schematic sketch of the overall hardware and software setup of the human factors analysis system, primarily based on the 'Virtualizer' treadmill (bottom).

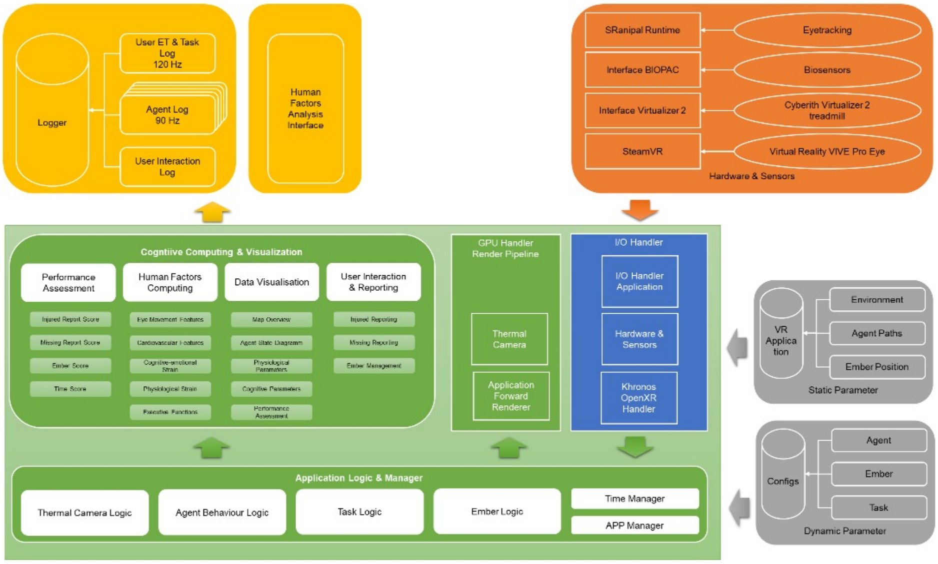

Figure 3: Schematic sketch of the system architecture of the VR-based system for SA assessment in the project SIXTHSENSE (Bijelic et al., 2022).

System Components. The Vive Pro Eye Headset is used for the study, which records the eye tracking data with 120 Hz. Cyberith Virtualizer 2 is used for locomotion, which transmits the walking speed and direction of the participant. The biometric data is transmitted bi-directionally over the network between AcqKnowledge BIOPAC and the VR application. The application (made with Unity) records the data of the participant, the instructions of the participant and the current behaviour of the five AIs in each frame.

Virtual Test Environment. The environment spans an area of size 100 × 100 meters^2 in which 64 pocket of embers are randomly distributed. The participant operates as a squad leader starting in the area centre. She has a certain amount of time available to find the pocket of embers and provide orders to team members to extinguish them. There are five virtual team members designed as AI-based agents that are located in this area, progressing on predefined pathways within the area, and ready to serve to extinguish pocket embers that are located on their pathways. The objective of the mission is a dual-task optimisation problem within a predefined interval of time, i.e., (1) to find and extinguish as many embers as possible and at the same time (2) to monitor the five team members and their state of health and presence as well as instruct them if an ember had to be extinguished. Figure 5 visualises the various tasks of the squad leader and the team members.

Behaviour Trees. A behaviour tree (Colledanchise et al., 2017) refers to a mathematical model of plan execution used in computer science, robotics, control systems and video games, and therefore is of high importance for VR-based environments as well. They describe switchings between a finite set of tasks in a modular fashion. Their strength comes from their ability to create very complex tasks composed of simple tasks, without worrying how the simple tasks are implemented. Behaviour trees present some similarities to hierarchical state machines with the key difference that the main building block of a behaviour is a task rather than a state. Its ease of human understanding make behaviour trees less error prone and very popular in the game developer community. Behaviour trees have been shown to generalize several other control architectures.

AI-based Agent Wayfinding and Team Behaviour. In the presented work, an A* search algorithm (Zeng and Church, 2009; Russell, 2018) was applied for wayfinding within the graph of potential way trajectories of the virtual team members. A* is a graph traversal and path search algorithm, which is used in many fields of computer science due to its completeness, optimality, and optimal efficiency. Figure 4 depicts the behaviour tree defining the behaviour of the virtual team members in the immersive training environment that cooperate with the user in a specific way to serve by extinguishing the pocket of embers but also disappear or get injured a predefined number of time within a certain mission task.

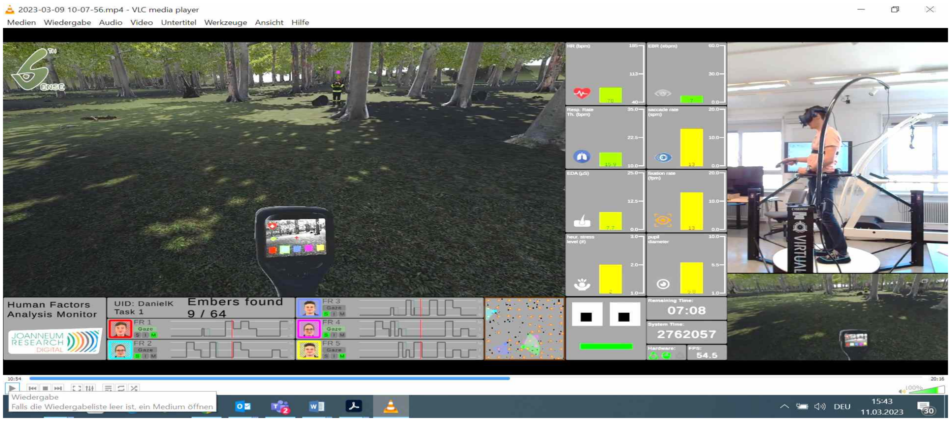

Figure 4: The human factors analysis monitor for research and development applying real-time and posterior study insight into relevant features. Left: egocentric view on virtual environment, including the virtual IR camera to detect pocket of embers. Below: overview on status (present, injured, missing) of team members. Mid right: human factors measurements. Right: live view of VR user.

In Figure 6 the behaviours, such as, TaskPatrol, TaskExtinguish, and TasgGoEmber, are depicted as well as the decision points in the tree that discriminate about further onset of behaviours. Specific parameters are configured that define how often these five agents or team members are injured or disappeared which makes the complete mission controllable and comparable between different study participants. Finally, the AI was configured on the following four decision points: “patrol”, “extinguish founded embers on command”, and “get injured” (e.g., physiological breakdown), disappear (e.g., fallen down the ravine).

(a) Pocket ember detected in IR camera (b) Close-up of an FR avatar

(b) Selecting a FR to operate (d) Surveillance of remote FRs

Figure 5: Typical situations in the VR-based skill training. (a) Detection of a pocket of embers (orange) in the display of the virtual, mobile IR camera. (b) Close-up of a female FR being active in the "patrol" mode. (c) Selection menu to activate an FR to extinguish a pocket of embers. (d) Surveillance of the health status and presence of remotely distributed FRs (marked by blue and yellow).

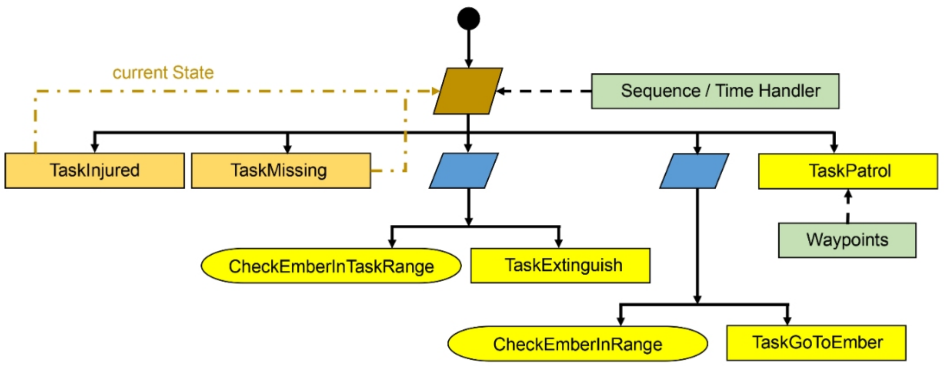

Figure 6: The behaviour tree the AI-based agent and team behaviour is based upon represented as control node logic.

STUDY PLAN

A pilot study is planned with N = 20 students, with pre-and post-study cognitive tests, such as, Determination Test (Schuhfried, 1987) and Psychomotor Vigilance Test (PVT; Dinges & Powell, 1985), furthermore the Situation Awareness Rating Technique (SART; Taylor, 1990). With respect to the SART we will research for situation awareness-specific digital cognitive biomarkers by means of correlation analysis. This multi-tasking configuration including the mission to remove pockets of embers as well as to monitor the presence and health status of a complete mission team will enable to measure (a) executive functions, such as, cognitive flexibility, and (b) level 1, 2 and 3 situation awareness by gaze-driven virtual events, such as, viewing first responder avatars, as well as digital activities, the response time to virtual events, such as, team members getting injured or missing.

CONCLUSION

Conclusion: Advanced training of first responders and emergency staff with typical operation scenarios is one of the upcoming challenges of the near future. First results motivate the use of VR environments for the training of situation aware and stress-resilient decision-making behaviour of firefighters. A study with N = 20 participants is planned to take place in 2023 to generate the expected digital cognitive biomarkers, in particular, the estimation of situation awareness scores from digital virtual events as well as digital biosensor measurements.

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