A Physically Immersive Platform for Training Emergency Responders and Law Enforcement Officers

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Abstract. Training law enforcement officers and emergency responders requires significant investment in terms of time, financial resources, logistics, organization, and personnel reallocation.
In this paper, we introduce a physically immersive platform based on Virtual Reality for training enforcement and emergency personnel, and for evaluating physical and psychological stress. The proposed system is co-designed with end users to maximize the performance and outcome of training.
Moreover, the platform includes features for accelerating the development of innovative technologies, equipment, and user interfaces, by integrating the knowledge and experience of law enforcement officers and emergency responders into virtual/augmented reality design simulations.

Keywords: Physical immersion · Motion tracking · Training · Law Enforcement · Emergency Responders

1 Introduction

Training is a crucial and recurring activity for Law Enforcement Officers (LEOs) and Emergency Responders (ERs). Every year, depending on the agency and territory, they must accomplish a required minimum number of hours of training [1] for specific competences (e.g., use of force, conflict resolution), scenarios (e.g., active shooter, hazardous materials contamination), procedures (e.g., cardiopulmonary resuscitation), and equipment (e.g., lethal firearms, non-lethal Tasers). Higher ranking officers are often required to train on coordinating the intervention of multiple teams across varied departments (e.g., tactical emergency medical services) in more complex situations, such as first response or command and control [2]. An important benefit of this training is improved officer behavior in police-citizen encounters [3], a significant aspect of preventing violence escalation [4].

Among the most common forms of training are realistic simulations, which usually occur in physical spaces such as abandoned buildings or “disaster cities” where the environment is designed to match the purpose of the simulation. As this is a very expensive activity that poses logistical challenges, larger agencies and metropolitan departments have necessary financial resources and can leverage existing facilities or team up to share simulation environments. Unfortunately, the majority of departments operate in sparse communities or rural areas with limited personnel. Consequently, training results in a difficult compromise between complying with required standards, optimizing the use of available funds, and allocating human resources without disrupting necessary public safety activities. This is especially true for other types of safety workers like natural resources officers (NROs) who are deployed in rural areas and might receive less training than police [5]. When training does occur, it often takes place in classrooms where poor student engagement and lack of opportunity for simulation can lead to failure in the field.

In recent years, virtual reality (VR) simulations have been introduced to offer convenient, affordable, and reusable training programs. However, they lack physically engaging experiences and introduce habituation to what is perceived as nothing more than a video game. Moreover, VR removes most psychological and nearly all physical stress, which are crucial aspects of training. It usually supports a limited number of users at one time preventing much needed experience working in teams and with multiple stakeholders. Indeed, LEOs and ERs report that physical interaction in the environment, the presence of other people, and the risk of being shot with simunitions are key factors to delivering a realistic experience by eliciting the same cognitive and physiological reactions produced in the field.

In this paper, we introduce a novel immersive platform for providing LEOs and ERs with realistic training thanks to the incorporation of physiological and psychological dimensions.

2 Related work

[6] reviewed several systems for VR-based training for disaster preparedness and response and reports some prominent uses of in the United States' Department of Homeland Security (DHS), Centers for Disease Control and Prevention, National Institutes of Health, National Science Foundation, and other organizations relevant to the present work including police departments (PD), the Office of Emergency Management (OEM), and the Federal Emergency Management Agency (FEMA). The potential benefits of VR-based training for mitigating the effects of post-traumatic stress disorder (PTSD) are discussed in [7], which presented examples of how re-experiencing the trauma in a simulated environment can integrate and improve traditional therapy. Also, immersive reality has been utilized to predict behavior and symptoms of PTSD [8].

Being able to collaborate with other team members is an important theme in training public safety officers. [9] documents an instructional environment for team intervention and cooperation in situations that involve multi-agency coordination. In this regard, cave automatic virtual environments (CAVE) have been utilized for training purposes [10, 11, 12] in the last decade. Several studies demonstrated their effectiveness as a tool for providing users with more immersive safety simulations. Nevertheless, CAVE-based simulations suffer from high infrastructure development and maintenance costs, lack of trained technicians, limitations in terms of mobility, and concerns related to logistics. Consequently, they are usually implemented in central locations and utilized by departments that can allocate resources for this type of training. Their cost prevents them from being installed in rural areas and they are not suitable for the disassembly and reassembly necessary for frequent transport.

The system discussed in [13] introduces a mixed-reality approach to providing first responders with full-scale safety training. The system is designed to support emergency response organizations and multi-agency cooperation; however, there is no information about development status. Conversely, several research projects [14, 15] focused on the use of low-latency motion tracking systems in combination with head-mounted displays (HMDs) to deliver highly immersive training experiences. The authors of [16] present a system based on augmented virtuality for training law enforcement officers in deescalating situations. Although several focused on the use of head-mounted displays and see-through lenses, the main issue remains limited movement in space, often compensated for with the presence of treadmills or sophisticated platforms for motion detection.

Nevertheless, most systems lack the crucial physical dimension necessary for eliciting psychological and physiological responses. Thanks to recent advances in motion capture technology, zero-latency cameras enable physically immersive virtual reality (PIVR) environments in which users can freely move through physical space as part of the simulation. The authors of [17] present a PIVR system that uses a 25 square meter physical space for creating a simulation that delivers the experience of a 300 square meters space where multiple players can interact with virtual and physical objects.

3 System design

The proposed system consists of a modular hardware/software platform designed for providing LEOs, ERs, and public safety personnel with a physically immersive environment for training and testing purposes. The hardware component is an infrastructure-based motion-tracking system that captures the location and movement of users in physical space and converts them into virtual characters in the simulated environment, which players visualize using a head-mounted display. This, in turn, provides real-time rendering of a simulation scenario that maps the physical world into the virtual space and vice versa, enabling users to interact with digital objects and players, which can be either completely simulated or a virtual representation of a physical entity.

The system was co-designed with expert trainers from Police Departments, Sheriff's Offices, and other public safety organizations from a rural county with in a part of the United States with a relatively small population. Moreover, the system incorporates a situated cognition model (see Figure 1) in which scenario scaffolding enables building different simulations and different versions of the same situation to provide users with the opportunity of acquiring knowledge embedded in the specific virtual representation. For instance, the dynamics of a specific scenario (e.g., hostage situation, active shooter, fire) can be combined with a host of physical locations (e.g., office building, school, restaurant). As a result, law enforcement officers and public safety personnel can run the simulation multiple times and experience different locations, dynamics, tactics, levels of threat, and outcomes. The system is designed to be *modular* and *extensible*. New items such as equipment, weapons, furniture, and interactive objects (collectively referred to as dynamic physical elements, or DPEs, because they can all be manipulated in real time during simulations), physical or digital, can be added to the simulation by designing their virtual model and by tracking their physical counterpart. Specifically, users can interact with other players and experience the simulation knowing that there are real humans physically present in the environment. As a result, they can interact with one another and experience interpersonal dynamics that conventional VR and AR environments do not incorporate. Furthermore, the proposed system leverages physical immersion and embodied cognition to improve the performance of training: being able to deliver the same type of psychological and physical experience that occurs in a real-life scenario could be beneficial for (1) eliciting unexpected reactions (e.g., loss of visual acuity, excessive force) and identifying their root cause; (2) providing support, coaching, and additional training; and (3) repeated exposure to a scenario reducing anxiety associated with uncertainty and fear.

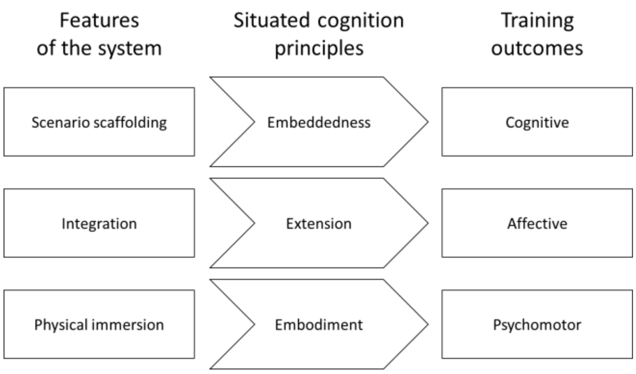

Fig. 1. The situated cognition model of the system, adapted from [18, 19].

3.1 Architecture design

The design of the proposed system follows a modular approach and its architecture consists of two main sub-systems: the hardware and software components.

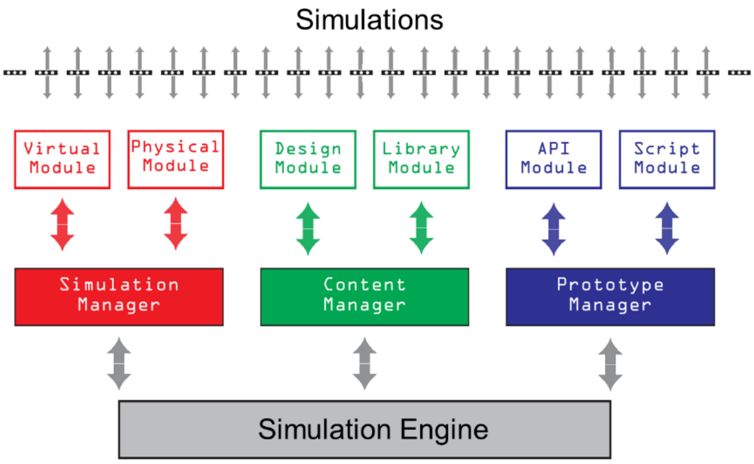

Fig. 2. The architecture of the system.

This allows for designing and testing user interfaces for a wide range of public safety environments. This, in turn, enables construction of missions and scenarios involving multiple LEOs/ERs while iteratively generating variations necessary to maintain engagement and test how users' reactions change from a physical and cognitive standpoint. The architecture also allows for potentially automating the generation of adaptive scenarios based on participant response or training goals by making use of narratively driven scripts or even AI/fuzzy logic engines.

Removing cross-communication between the manager units reduces complexity, production time, and costs. More importantly, each component is interchangeable and can therefore be developed and improved independently. Thus, the platform can be disseminated widely in an open format serving researchers and practitioners by encouraging collaborative use and avoiding the pitfalls of walled or siloed systems.

3.2 Hardware system

The hardware component of the system consists of three main elements: (1) an infrastructure for high-speed motion-tracking; (2) a wearable set of devices; and (3) physical equipment, items, and props (elements of the scenario).

The infrastructure for motion capture is based on state-of-the-art, low-latency cameras that can detect, track, and integrate into a rendered virtual/augmented reality experience relevant people, equipment, and objects, in real time. The infrastructure can integrate from a minimum of 6 up to 24 off-the-shelf zero-latency cameras that acquire and process images within milliseconds to minimize lag and to improve the responsiveness of the action-feedback loop. The platform is designed to be modular and scalable: it supports physical spaces ranging in area from 30 to 3000 square feet and need not be rectangular. Depending on the requirements of the scenario, the infrastructure can detect and track up to 40 individuals and objects (e.g., simunition weapons, furniture, and environmental items like vehicles and physical obstructions) and seamlessly integrate different DPEs in the virtual environment by using their interactive 3d model as a digital counterpart. After acquisition, the infrastructure transmits the video streams to a central node, the simulation server, where images from individual cameras are processed: relevant data points are extracted from markers and converted into position and orientation coordinates of individual elements.

The wearable component consists of a set of personal devices, including a head-mounted display and a lightweight, non-intrusive backpack that hosts a high-performance laptop computer that communicates with the simulation server and renders the environment on the HMD. The personal set includes reflective markers that are attached to specific areas of the body to enable tracking the position, orientation, and movement of users while they navigate the simulated environment.

As a third component, the physical model includes all the equipment utilized in the simulation. Several scenarios might not require any additional DPEs, as they might involve tracking users only. Other simulations might involve the use of simunitions, the presence of physical elements (e.g., fire extinguisher) and equipment (e.g., resuscitation kit) which are necessary to accomplishing the simulation. By using appropriate markers, DPEs can be tracked and added to the VR scene, so that users can interact with them. The possibility of integrating an arbitrary number of different types of physical items extends the possible applications of the system beyond training purposes. As a result, the proposed system can be utilized for evaluating how different types of weapons change the reaction of the users and the outcome of the mission. Additionally, it can be utilized for analyzing the impact of different configurations of physical elements on the performance of personnel during their operations. Low-cost material can be utilized to produce physical replicas of the actual equipment: items will appear as they are rendered in the simulation, thus, their actual appearance is less relevant. Consequently, a set of molds can be utilized for producing low-cost, actionable pieces of equipment such as simunition weapons, active items (e.g., fire extinguisher, door lock), or passive elements (e.g., doors, bricks, debris). Only mechanical parts and joints that can be manipulated in the simulation (e.g., triggers, push buttons, and handles) will be required to have higher realism. In addition, the platform includes a plugin system of hardware appliances that control environmental conditions (e.g., fans, heaters, fog machines) that can be operated by technicians or controlled by the simulation server.

The hardware component of the proposed system has several advantages. It supports up to 40 individuals and items, which makes it suitable for training of multi-team interventions over very large simulation environments. The system also enables tracking elements over an area of 50 by 50 feet of physical space, which can be expanded to a virtual space of an order of magnitude. Moreover, it allows integration of environmental conditions (e.g., smoke, heat) and terrain (e.g., mud, snow, and gravel) providing trainees realistic experiences interacting with the eccentricities of the environment itself. Consequently, it integrates the benefits of traditional realistic simulations and the advantages offered by VR in terms of affordability, reuse, and resource optimization.

Although the physical module of the system incorporates an infrastructure, it is designed to be easily disassembled and to fit in a standard NATO pallet (47.24 x 39.37 inches) so that it can be transported and shared across neighborhoods, counties, or even states at little cost. Also, it can be assembled in a relatively short time and calibrated by a non-expert using a predefined routine. The entire system can be shipped to a new location and provide training to an entire department for the same cost as sending a single trainee to a traditional training facility. Potential return on investment for cash-strapped government agencies is enormous.

3.3 Virtual module

The software module consists of a core piece of software that allows the main components of the system to communicate and share information in a timely fashion with data management capabilities.

The Simulation Manager executes the virtual and augmented reality experiences for research and training purposes through two modules: the Virtual Module, which processes the interactive scenarios for up to 12 participants in real time, and the Physical Module which processes the haptic and tactile elements of the experience. The Simulation Manager includes:

- an immersive Virtual Reality engine (built on top of industry standard 3D engines such as Unity) for deploying scenarios based on the requirements of the simulation (i.e., type of scenario, number of officers involved, environment conditions, mission objectives);
- an easy-to-use editor for designing simulation scenarios, based on a library of 3D assets, or for automatically generating new scenarios or variations using previously-recorded data;
- a set of Application Programming Interfaces that support integration of third-party software plug-ins (e.g., for recording and analyzing simulation data) as well as technology and equipment (e.g., physiological sensors, LEOs' personal data terminals).

The Content Manager allows for the design and use of adaptive, customized research/training scenarios by leveraging two important design components. The Design Module allows non-technical persons to rapidly design scenarios for use in research and training, including virtual and physical elements, without advanced training or the need for full time professional operators. The Library Module is a repository of existing scenarios, simulation datasets, and user interface prototypes created by LEOs and ERs themselves. This takes advantage of the incredibly successful formats of social design ecosystems like Thingiverse, 3D Warehouse, maker collections, etc.

The Prototype Manager operationalizes testing and deployment of new user interface systems by providing software "hooks" for connecting hardware and software without the need for customized software. The API Module provides plug-and-play integration for commercial/retail equipment that currently exists (e.g., Oculus Rift, NVIDIA graphics, Unity3D/Unreal/Godot, haptic feedback hardware). Researchers and developers inventing new equipment can use the Script Module which provides a sort of "universal translator" between the system and non-standard hardware or software. This serves the acceleration of novel tools by circumventing time consuming and costly API development through direct access to the system.

4 Discussion

The system relies on commercially-available hardware components and, thus, the platform benefits from economies of scale: individual parts can be easily replaced if damaged and alternative implementations can be realized by substituting individual devices with other commercially-available options.

As pointed out by technical experts who contributed to designing the system, the core philosophy of any type of training is to experience a particular situation several times so that when they occur in real life, LEOs and ERs will be prepared to react to it as they already went through the same scenario and evaluated the potential options and their consequences. Therefore, one of the key features of the software system is the possibility of simulating a broad range of scenarios and adding variations that can generate experiences which are likely to occur on the job. Consequently, the proposed training platform could have real-world impact for improved training resulting in faster, accurate, and predictable performance from public safety personnel. For example, ERs in rural areas would normally have no opportunities for practicing an active shooter scenario and therefore would be ill-equipped to support a metropolitan agency if they were called in to support. Moreover, it is difficult and expensive to stimulate the physical and psychological aspects of dangerous or time-sensitive situations (such as fatigue, fear, temperature, limited visibility, etc.) which can be added to the system, studied, and even controlled by the simulation manager. In addition, data can be recorded for further analysis, for track-record purposes, and for use in new simulations.

One of the main characteristics of the system is its versatility both as a software simulation and in terms of hardware configuration. For instance, the physical simulation space can be adjusted to represent a tunnel requiring responders to navigate practical obstacles such as debris, platforms, tunnels, and cars. The virtual simulation space can impose environmental conditions such as low lighting, smoke/fog, and loud sounds. Up to 12 individuals can simultaneously participate in the simulation to test user interface designs that include geolocation and hazardous chemical detection systems while training LEOs and ERs on team-based tactics for emergency response. Furthermore, the system can be utilized as a test-bed for training initiatives involving coordination of larger groups comprised of responders from multiple agencies. Personnel from different teams can be physically located in the same testing area, but virtually separated by the simulation.

5 Conclusion

In this paper, we introduced a novel platform that addresses the needs for public safety personnel training, which includes the development of innovative user interfaces and technologies. To this end, we designed a physically immersive platform that integrates motion tracking technology and VR simulations to achieve realistic and convenient simulations. The proposed system was co-designed with law enforcement officers and emergency responders, and it integrates knowledge and experience of trainers into the design of VR- and AR- based simulations.

The proposed system addresses two crucial needs of police departments, emergency management agencies, and other organizations devoted to public safety: training and evaluation of new equipment. In regard to the former, the system operates as a VR-based platform that can be utilized to meet training requirements and accomplish additional on-demand training in a cost-effective fashion. Furthermore, the proposed system integrates the possibility of supporting the development and evaluation of new equipment like user interfaces and smart devices. By using simulated environments, public safety personnel, researchers, and industry experts can collaboratively develop new technologies and simultaneously evaluate their effectiveness in a single, seamless pipeline.

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