Modular Adaptive Simulation and Test Environment for Responders (MASTER)

Submitted by John Kelly / Symstemics / 050117

Solution description – The Modular Adaptive Simulation and Test Environment for Responders (MASTER) system exploits a novel combination of high technology readiness level (TRL) sensors with currently available commercial off the shelf (COTS) components to enable a **uniquely adaptive mobile instrumented wearable solution** suitable for any responder group that can be worn under/on top of existing field gear and with existing and actual responder equipment, enabling full environmental and object realism during simulation and test in any environment for any responder class at any facility or real-world location in real time (true "train as you work, work as you train" conditions for evaluation).

Key to the MASTER solution is the use of **see-through augmented reality (AR) enabled in real time** for each participant in which objects and other elements may be injected as an overlay in the existing real world environment and interacted with for further task and execution realism. The AR injects use-case specific object presence images, and audio and visual based environmental effects (blurred/fogged vision, sounds of fire, etc.) to the participant and enables interactivity of virtualized or real (selected) objects (doors, switches, device controls). The AR additionally can inject hazards such as fires or shooters and emulate specific victim or event conditions into the field of view and hearing of the participant's visual and aural space. The AR is provided in a **compact dual eye glasses solution with wearable point of view (POV) camera** suitable for facemask and helmet wear and integrated with orientation and camera sensors, while the audio is provided via headset and mic.

A second key is the **use of smartphones** as the basis for the wearable processor and data/device and communications interface device which additional enables core body inertial and location measurements, initial photo and video capture, and even select environmental data such as temperature to be captured. **Existing wireless and/or cellular supported infrastructures can be exploited or expanded** to create multi-participant communications and exchanges including form/document, photographic, audio file, and other media and data. Data interfaces and protocols are standardized for easy exchange. Existing tactical communications systems may be interfaced as well.

Selected accessories and sensors including uniquely developed tactile/haptic and body pose sensors augment the self-worn MASTER system and are self powered and interconnected, creating an easily donned instrumentation system suitable for collection and exchange of location, orientation, body position, object tracking, physiological, visual/aural, and other data. **Additional accessories** such as portable flash rigs, smoke pots, and simulated equipment may be selectively added to the system if desired.

A **rapidly deployable portable command center (C2)** core element maintained on a portable laptop includes software to enter mapping of the selected real-world area, and to develop and serve selected AR-based object material such as use-case required debris, furniture, blockages, victims, tools, controls, etc. to the participants via client applications hosted on their smartphones. Software based on open source ARToolkit elements and the Unity game engine are used to enable real time environmental condition (fog, rain) visual and audio effects injected to the self-worn MASTER wearable system as well as to monitor both interactivity of AR enabled objects (including proximity alerts, action state, and presence) and collect and exchange ongoing data throughout any operational event.

The C2 additionally may be extended to exploit existing tactical communications by the inclusion of existing COTS tac-comm to VoIP or cell bridge systems, enabling participants to fully operate with their existing C2 equipment.

A system overview of the primary subsystems and benefits of the MASTER system is shown below and described in more detail further in this document:

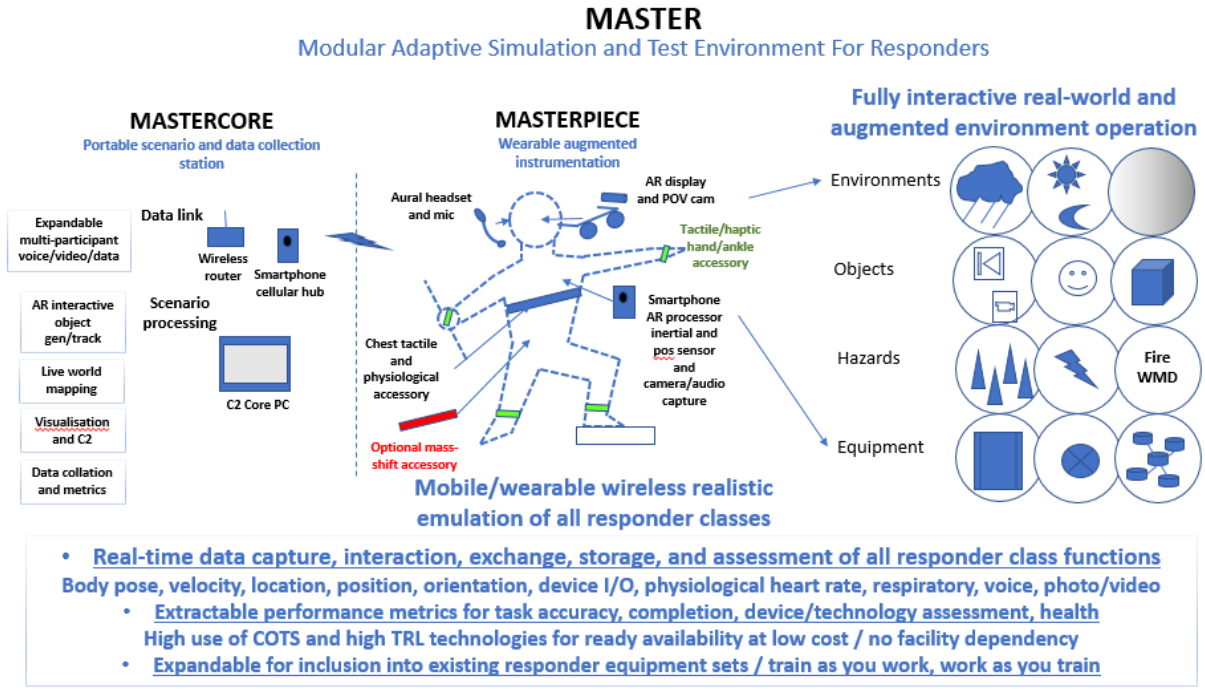

Figure 1 – The Modular Adaptive Simulation and Test Environment for Responders utilizes high COTS/high TRL/low cost solutions and a highly customizable and realistic augmented reality (AR) audio/visual and tactile solution to enable a mobile test and validation and training solution for any responder class or scenario use case in any real-world location with real time data collection and analysis. The MASTER system may be integrated with existing equipment for additional realism and future performance enhancing complete integration into current-day responder operations.

Key value propositions – By virtue of instrumenting the user (rather than a fixed site location) and enabling augmented injection of objects, hazards, and environmentals interactively to a real-world overlay of any real-world environment, **the MASTER system may be used literally anywhere**, making any facility (existing or otherwise) a valid test and evaluation or training site with full instrumentation to evaluate task execution, technologies, and performance in a safe and repeatable manner.

By enabling software-modifiable visual/aural and tactile/haptic environmentals, **any weather and hazard condition can be safely emulated regardless of location or time of day in any location**.

By use of non-equipment conflicting force-feedback and thermal elements included in the MASTER accessories**, realistic impact, heat, and other feedback while using actual user equipment is provided and actual process/methods and actions are utilized**.

The MASTER may be **infinitely customized for any responder user group or use case** through software-based selection of objects, use case scenarios, tasks and task order, and other tailoring while maintaining standardized metrics and data capture through the use of the MASTER core system and its accessories.

By enabling manual or scanned blueprint facility location entry, **any site location may be easily entered and registered** within the MASTER system for coordination and use.

By ensuring standardized data interfacing and use of commonly available protocols such as TCP/IP, MP3, MPEG, Bluetooth/LowPower, WiFi, 4G cellular, Shapefiles, XML, and VR exchange formats, **any additional technologies and equipment (as well as existing test facilities and other simulation equipment or stand-alone trainers) can be easily integrated** and data exchanged amongst all MASTER participants in the future.

Lastly, the MASTER may be **scaled for numerous users** through the expansion of the proposed wireless/cellular LAN element and C2 elements using emplaceable wireless routers and/or cellular hubs.

Self-description and development methodology – The MASTER system solution was architected and designed from 20+ years of wearable system and distributed sensor system analysis and design. The viability of success is very high with a majority of the system derived from existing COTS products and approaches and high TRL availability of the select proposed unique technologies for the MASTER accessories.

Problem discussion and Most Important Requirements – From the stated goal of the effort, a system is requested for test and validation of various technologies and product solutions to be used with and by various groups of first responders. This can be extended to include interests in training and a desire to provide simulated conditions suitable for near-realistic operation in various environments with diverse equipment and utilizing disparate methods. The desired solution should have a physical and a virtual element in order to enable a variety of simulated conditions, many of which may require the presence of hazards not normally considered safe or repeatable in their presentation and interaction.

For the purpose of test and evaluation of systems and personnel, it is **critical** to enable the collection, storage, and assessment of various data to develop metrics of performance usable for said evaluation. This is often achieved by instrumenting a fixed facility with various sensors including motion and video. Additional instrumentation such as acoustic and contact sensors can be applied as well to provide further resolution to the tracking of activities and actions within a set space.

Many such solutions currently exist each with a similar **dependency of being in a fixed site or facility** developed or modified for the express purpose of test and evaluation via embedded data collection. This approach **limits flexibility** of users due to geographic proximity, limits to size of facility/number of participants, and sheer cost of development, logistics, and use. Furthermore, such site-based solutions often are either **too tailored** to the expressed environs of a particular user group (example: police search and clear rooms with target practice sites) or **too genericized** (example: military MOUT concrete buildings) to offer sufficient detail, modification, or realism. Lastly, site-specific instrumentation solutions **lack scalability** to expand to other platforms such as vehicles or ships or aircraft, limiting their realism of effect.

Certain additions can aid from a realism perspective via special effects (or "gigs") including acoustic speakers, blast pots, fire lines and outputs, flash bang emitters, strobe lights, and even wall and floor shakers. Further environmental aids such as water cannons, fog and snow emitters, and thermal heat or cold blowers exist to customize any such solution, with the similar limitations of high additional cost for acquisition and operation impacting the overall broad use of such solutions.

The breadth of use cases presented for consideration in this effort includes significant differences in methods, functionality, capabilities desired, and operations. One example is the potential for mobile transport emulation as well as static/fixed building entry/exit. A second is the consideration of a significant area search/monitor/control scenario suggesting several acres of area. A third is the potential for highly differentiated discrete clothing and equipment utilized by each user group.

An additional observation to the above is that **many users must modify their typical operational profile** (wear, equipment, process, methods) to the constraints of the test and validation facility, rather than the other way around. **A significant benefit is seen if a solution can be developed to accommodate the desired user without undo modification to their operational gear/equipment and methods of use.**

Users and use cases: Specific to this effort six (6) classes of first responders were identified to include: Fire, Police, EMS, Search/Rescue/Recovery, Explosives/XO, and HAZMAT. Each class includes specific **environmental needs** and implied clothing/equipment/process and method differences and **actions**.

For environmental needs, the following **variables to enable** were extracted from the use case data:

Realism / Environmental Dimension Variables			
Dimension	**Type**	**Variables desired**	**Potential solution approach**
E1	Light	Change of source, intensity, shadowing, fluctuation	Visual modification
E2	Weather	Snow, rain, fog, wind, cold, heat	Visual modification, aural aiding, haptic/thermal aiding, ext. FX aid
E3	Aural	Fire, wind, water, traffic, people/single/crowd, C2/comms, victim, participants	Sound injection to system audio
E4	Physical	Vibratory, motion, instability, shifting foundation, water effects	Visual modification, aural aiding, tactile feedback, haptic vest FX aid

For actions, within each responder class, use cases were identified with desired actions and capabilities described. In normalized universal modeling language (UML) architectures, the participants are defined as "actors" with associated "capabilities" (related actions intended for each scenario) typically decomposed into functions that normalize the large disparity of actions into quantifiable elements to help prove the system can in fact accommodate the range of use cases and additional cases as well.

A summary of extracted responder **classes and primary actions** from the provided use cases was performed to aid a specific functional needs examination to derive the system solution:

Responder Classes		
Class	Type	Key action(s)
C1	Fire	Motion, climb, crawl, carry, drive, directed object (hose, tools), contact (victim), data entry, communication
C2	Police	Motion, climb, carry, drive, directed object (weapon, light), swim, run, contact (arrest), data entry, communication
C3	EMS	Motion, climb, carry, drive, directed object (medical equip), contact (victim), data entry, communication
C4	S/R	Motion, climb, carry, drive, other platforms, control (UAV, UGV), swim, data entry, communication
C5	XO	Motion, search/identify, move, climb, crawl, carry, drive, cover/remove, contact (item/WMD), directed object (tools), data entry, communication
C6	HAZMAT	Motion, search/identify, move, climb, crawl, carry, drive, cover/remove, contact (item/explosive), directed object (tools), data entry, communication

An **assignment of responder user classes, use cases, actions, and composed functions** (for the MASTER system solution to address and validate its ability to emulate) was performed and is shown in the following matrix used to develop the MASTER system:

MASTER Responder Use Case Capability to Function Decomposition																																									
		Functions to enable (by Class)																																							
Use Class	Use Case	Physical									Object Interaction											Environment					Actions, Unique														
		Move	Walk	Run	Bend	Crawl	Climb	Swim	Ladder	Vehicle	Touch	Identify	Mark	Locate	Avoid	Block	Move Obj	Alert	Pickup	Activate	Open/Close	Emulate	Modify	Map	Navigate	Location	Drive	Control	Visualize	Handcuff	Hose	Tools	Equipment	Photograph	Communicate	Transport	Enter/Exit	Edit	Exchange	Data entry	Assessment
Fire	Public Building	x	x	x	x	x	x	(x)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		x	x	x	x	x	x	x	x	x	x	x
	Private Home	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		x	x	x	x	x	x	x	x	x	x	x
	Site Investigation	x	x		x	x	x		x	(x)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)	x			x	x	x	x		x	x	x	x	x
Police	Traffic Stop	x	x	(x)	x					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)	x	x		x	x	x	x	x	x	x	x	x	x
	Pubic Event	x	x	(x)	x		(x)	(x)	(x)	(x)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)		x	x	(x)	x	x	x	x	x	x	x	x	x	x
	Crime Scene Walkthrough	x	x	x	x	x	x	(x)	x	(x)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)	(x)	x			x	x	x	x		x	x	x	x	x
	Scene Documentation	x	x	x	x	x	x	(x)	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)	(x)	x			x	x	x	x		x	x	x	x	x
EMS	Accident Response	x	x	x	x	x	x	(x)	(x)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x			x	x	x	x	x	x	x	x	x	x
	Car Crash Triage	x	x	x	x	x	x	(x)	(x)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		(x)	x	x	x	x	x	x	x	x	x	x
	Heart Attack/Restaurant	x	x	x	x	(x)	(x)			(x)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)		x			x	x	x	x	x	x	x	x	x	x
S&R	Disaster Response	x	x	x	x	x	x	(x)	(x)	(x)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)		x			x	x	(x)	x	(x)	x	x	x	x	x
	UAV	x	x	x	x	x	x	(x)	(x)	(x)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)	x	x			x	x	(x)	x	(x)	x	x	x	x	x
	Lost Hiker	x	x	x	x	x	x	(x)	(x)	(x)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)		x			x	x	(x)	x	(x)	x	x	x	x	x
	Terrestrial	x	x	x	x	x	x	(x)	(x)	(x)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)		x			x	x	(x)	x	(x)	x	x	x	x	x
	Maritime	x	x	x	x	x	x	x	(x)	(x)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)		x			x	x	(x)	x	(x)	x	x	x	x	x
XO	UGV Robots	x	x	x	x	x	x	(x)	(x)	(x)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)	x	x			x	x	(x)	x	(x)	x	x	x	x	x
HAZMAT	WMD Search	x	x	x	x	x	x	(x)	x	(x)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)	(x)	x			x	x	x	x	x	x	x	x	x	x

Lastly, **the initial system requirements** were extracted from the provided description:

System key functions (NIST derived)	
#	Function desired
1	Real time communications (receive/transmit), multiple participants
2	Real time capture of select data (action completion, location, photo, video, environmental)
3	Timing of participants and functions
4	Ability to identify assets, objects, tasks, and risks
5	Ability to enable equipment failures or injuries to participants in tasking
6	Provision of live video chats
7	Provision of data sharing amongst participants

From the above, the following key performance parameters (KPPs) for the MASTER fully compliant solution can be determined as identified below:

System KPPs	
KPP1	Address all use cases for all responders to include the following six (6) classes: Fire, Police, EMS, Search/Rescue/Recovery, Explosives/XO, and HAZMAT.
KPP2	Provide required functions to support defined use cases (see Use Case extraction matrix)
KPP3	Enable realistic environments to be simulated in the following four (4) dimensions: light, weather, aural, physical
KPP4	Enable capture and exchange of selected measurement data sufficient to address following four (4) classes of performance metrics : time, accuracy, efficiency, action states
KPP5	Support multiple (>2) participants including centralized control and monitoring with access for data / visuals for same
KPP6	Enable integration and use of select technologies (see NIST Technology List) and additional simulation/factility/equipment interfaces

Solution details, by subsystem/area – The MASTER system is composed of two (2) primary subsystems: (1) an enabling core subsystem (MASTERCORE) that functions both as the augmented reality simulation and environment generator as well as the central communications/data exchange and command and control element; and (2) an individualized sensor and display/control/communications operation element (MASTERPIECE) worn by each participant. The following describes each subsystem in detail.

MASTERCORE - The MASTERCORE subsystem is composed of the following: (a) a laptop hosting the scenario processing and data hub/command status and storage unit; (b) mapping software hosted on the laptop for generating 2D and 3D facility overlays; (c) augmented object overlay generation server and companion client application software; and (d) a communications hub unit customized for wireless interoperation (WiFi router or cellular hot spot) and extendable for integration with existing tactical radio systems.

Initial operation of the MASTER system utilizes a general map of the intended testing area created using existing COTS floorplan rendering software (in 2D) or shapefile generation 3D maps (such as that provided by 3D Spaces). The map may be manually entered or as a future capability derived in live action through the storage and tracking of the participants moving through the facility or area. The mapped area is used for georegistration of both participants and objects of interest for every scenario and aids in the ongoing geolocation of both during operation as well.

The **primary enabling function** of the MASTER system is the use of an augmented reality overlay software-based capability derived at a hostable server device working in conjunction with an environment software-generating game engine able to render objects and features such as visual and hazard effects. Objects and hazards and interactive elements are generated using 3D rendering and effects tools such as the open source ARToolkit which can derive elements such as furniture to block progress/move aside, blankets to pick up/cover objects with, movable doors, victims/other personnel, and light and device switches and controls. When joined with an environmental rendering game engine (such as the Unity Technologies' Unity) and the area map created previously, the generated objects may be superimposed into the point of view of each participant using a separately controllable client software component hosted on each participant's smartphone (similar to Apple's Augment app) to coordinate and unify presented events/actions and object interactions as if existing in the real environment on which they are overlayed.

The participant's orientation, body pose, location, and other data to inform the core element of where exactly to place the augmented overlaying objects is provided by body-worn inertial and orientation sensors and location sensors (GPS) hosted natively within the smartphone core used as the wearable participant's central processor and controller. Additional inertial elements (similar to the InterSense InertiaCube 4) enabling pitch/roll/yaw/velocity/orientation estimations are provided at the head (integrated with the augmented display unit), the chest (integrated with the heart rate and respiratory sensors), and at each hand and foot (integrated with companion tactile and haptic/thermal effects devices) described further. By combining multiple separate inertial sensors located at key motion anchors of the participant (head, chest/torso, hands, feet/ankles), **a fully rendered estimate of the actual body pose can be correlated** (with separately derived location) by the MASTERCORE to accurately place augmented objects at the correct proximity of the participant in real time.

For scenario development, a separate task-focused software element is utilized to generate both a waypoint-based timeline of events and a series of decision points or aids to enable flexibility of the scenario when executed. Task completions and guidance may be interchanged between participants and the C2 operator with modifications occurring in real time. Data such as body pose, action status, task status, photos, audio captured, video, and entered form data is created both passively and actively by the participant's wearable system and their actions and interchanged with other participants and the MASTERCORE C2 element using standardized data formats and protocols (MP3, MPEG, XML and select ASCII, HTML).

The specific scenario task summaries, benchmark and schedule planning, task and performance capture, decision aid suggestions, data capture, and select display shell for operations is intended to be developed within an HTML5 based web application specific to the MASTER system needs. This incorporates the ARToolkit, Unity, and related smartphone / communication software development kits (SDKs) with scalable HTML/Javascript, creating a simplified and extendable application solution.

Communications including voice and data (form entered, discrete measurement, and photographic and video and environmental sound data) are provide by the inherent wireless and cellular capabilities of a companion smartphone similar to those worn by the individual participants. For wireless operation, a cellular hot spot may be created sufficient for establishing wireless communications. For cellular operation, existing 3G/4G operations via the smartphones can be leveraged simply. For areas without cellular operation, COTS-provided cellular hub elements (such as those by Qualcomm) may be deployed to create a localized cell network, with companion wireless routers utilized to extend coverage throughout the area as needed.

A unique but common (to the responder community) effort with MASTER is to additionally enable existing tactical communications equipment interfacing via bridging systems common to the Responder community (such as those provided by Trident or Codan/Daniels) that enable voice and data repeating and interface from HF/VHF/other communications systems into TCP/IP based VoIP and networked operations.

MASTERPIECE – The MASTERPIECE wearable system is composed of the following: (a) a smartphone hosting client application software capable of real time augmented scenario-specific object rendering (similar to the Samsung Android S6 or higher) with self-contained power, photo and video camera capability, audio communications, data capture/exchange/storage/entry, and user interface and control; (b) a dual eye augmented/AR overlay display (similar to Vuzix AR3000) capable heads up display (HUD) worn as glasses and integrated with a separate inertial sensor capability for head tracking of orientation and a point of view (POV) camera; (c) an audio headset element with at least one (1) earpiece and microphone, with this and the AR glasses both connected to the smartphone element; (d) separately arrayed wirelessly connected (via low power Bluetooth) tactile and haptic feedback sensors at the hands and feet, each with an integrated power supply and inertial sensor; (e) an integrated tactile, inertial, and heart rate and respiration sensor chest-mounted element that may include a separately described unique shifting mass effect element (to emulate specific scenarios desiring body pitch/shifting floor approximations).

The core of the capability is provided via a current smartphone (such as Samsung's S6 and S8) which includes multiple wireless and wired interfaces for the additional wearable equipment to connect. Additionally, the phone is utilized for data acquisition and storage and exchange via the existing wireless/WiFi and/or cellular capabilities selected by the participants for inter-participant and inter-C2 exchange. The phone additionally includes GPS and wireless / cellular triangulation location capability, enabling self locating of the participant autonomously.

Visual data is derived via use of the ARToolkit-generated client application and the ARToolkit-Unity served environmental software at the MASTERCORE C2 element for display via the AR glasses element. The AR glasses display element can be enabled using waveguide optics to present augmented overlay data and information within the field of view of a participant using a see-through optical path (no blockage to the real world to the eye), enabling a true environmental fusion of simulatable objects/hazards/actions and existing facility/area elements.

Audio data specific to the scenario environment (additional voices, sounds of objects and weather, etc.) is additionally generated and passed from MASTERCORE to MASTERPIECE for injection to the audio stream and mixed with inter-participant/C2 audio for presentation to the headset. Environmental audio data is captured by the headset and smartphone microphone for collection. Sensor data (inertials, body worn physiologicals, step/velocity interpolations, body pose/orientation/pointing/location, task actions/completions, device evaluation data, etc.) are stored at the MASTERPIECE smartphone and can be relayed between participants and downloaded for MASTERCORE storage and analysis as well.

Unique to MASTER is the proposition of <u>separately worn tactile/haptic elements at the hands and ankles to emulate additional realism</u>. The units are composed of an inertial sensor, a tactile sensor (to create patterned vibrations), and a thermal generating element and separate power source. The components are assembled to a linear Velcro-enabled strap and worn at the hands and ankles to enable body pose measurement for object orientation and to provide unique vibratory and thermal feedback. During scenario operation, the participant can receive select hazard area alerts (danger: vibration), equipment feedback (operation of motor: vibration), or other hazard (increasing heat from thermal element if close to hot fire/doorknob) through the setting of pre-existing hazard ranges or operator control. The chest sensor element includes physiological sensors and (future growth) environmental sensors (temperature) as well as similarly separate inertial and tactile elements.

An **additional novel implementation** includes the use of a shifting metal mass encased in a smooth compartment and operated on by two (2) electromagnets at opposing sides of the lower back in an extension of the chest element or as a separately worn accessory across the lower back. When programmed, the electromagnets may operate in sequence to cycle the mass side to side, **providing the direct sensation of a pitching floor or water** by shifting the wearer's mass and thus balance impression.

Solution setup/deployment and installation – The design of the MASTER system is intentionally modular, compact, and mobile such that deployment to operation should be <1hr at any site location. Specifically, the MASTERCORE C2 element laptop and communications equipment aids may be deployed from a single Pelican ™ rugged case by one individual.

The MASTERPIECE wearable systems comprised of AR glasses/camera/sensors, smartphone/mount, and hand/ankle and optional chest/torso sensor/tactile elements may be assembled on a single participant within 15 minutes. Existing user equipment and tools are again available for use with the system.

Prior to deployment, the generation of a site-specific/use case-specific scenario is performed using a scanned or manually entered estimation of the location map captured in a registrable 2D/3D shapefile. Specific objects, victims, virtual participants, and interactive options and decision aids are selected from a pre-developed library or uniquely generated in ARTools for use in the Unity server and client applications to present the correct augmented reality environment and actions.

Operation of the MASTER system is conducted via simple execution of the AR scenario with real-time data exchange, voice, video, and action status occurring between the MASTERPIECE-equipped participants and the MASTERCORE C2. Real-time task execution scoring, device performance evaluation, and additional monitoring/modification and evaluation may be performed at either the MASTERCORE C2 or by an evaluator wearing a separate MASTERPIECE system as well.

Storage of all collected data at the wearable and deployed systems may be collected post-scenario for after action assessment, data pattern collection and analysis, and further performance metric extraction.

How the solution meets key needs in technology evaluation, test, validation – The MASTER system provides the following enabling benefits for successfully technology evaluation, testing, and validation:

Wide range of use cases: The MASTER system's wearable-based portability and real-world deployment enables anywhere/anytime/any scenario utilization with actual equipment and no dependencies or limits due to site/facility constraints. The MASTER system's use of augmented reality interactive object overlays and centrally coordinated task and data collection enables infinite scenario creation capabilities and a wide array of capturable measurements.

Physical equipment handling: Due to the MASTER's use of wearable instrumentation and virtualized/augmented interactions, existing user equipment may be used to increase test/training realism.

Interfaces and data exchange: The use of communalized data protocols and interfaces enables any device integration with the MASTER core elements for specific testing and future upgrading.

Metrics: The capture of unified real-time based inertial, orientation, physiological, position/location, specific body pose, voice, photo/video, and augmented interactive action completions enables the MASTER system to extrapolate significant performance metrics including time to task completions, estimates of accuracy in performance, opportunities to assess physical state/exhaustion, and successful administration of medical or other specific process functions.

The MASTER system measurement base includes extractable time and location/ georegistered/ orientation and body pose-marked sensor measurement and action state elements which are **sufficient to derive all classes and metrics of performance** as stated by NIST for this effort (below):

Measurements and metrics of performance		
Class	Metric	Measurement
M1	Time	Task execution, data entry, data exchange, assess/decide/act cycle timing, setup, specific object actions (locate, administer, extract, etc.)
M2	Accuracy	Task success/measure, mistake tracking, location/orientation precision, object identification, data entry/correctness, visual coverage/quality, task benchmarking
M3	Efficiency	Data scope/scale/amount required for optimum result, reattempt (impatience) rates, interactivity/conversations/data exchanges, decision aid results vs time/accuracy
M4	Actions	Object manipulation, data acquisition/storage/access/exchange, visual editing, equipment donning/doffing/use/interference with other equipment

Scoring discussion by category – The MASTER system **meets and exceeds all previously extracted system requirements and KPPS defined** earlier in this document and **rates very high for every scoring category and responder class** provided for consideration as shown below:

MASTER Capability Benefits and Summary		
Category	Approach and benefit	Rating
Realism	The MASTER's use of augmented interactive object overlays and selectively worn tactile/haptic units enables full environmental simulation and opportunity to utilize actual equipment/clothing and tools within any real-world location.	Very High
Availability	The MASTER system's high use of COTS and simple high TRL based accessories combined with a low cost wearable architecture enables easy availability of the design. Use of augmented reality and wearable instrumentation enables any-where availability of deployment and use.	Very High
Versatility	The use of augmented interactive object overlays and wearable mobile systems enable multiple responder equipment configurations to be used with actual real world locations including mobile platforms.	Very High
Metrics	The MASTER system collects numerous live data elements for object tracking/action state, physiologicals of participants, and significant body pose/orientation/location to enable highly accurate augmented real world operation and high-order extrapolated performance estimations.	Very High
Replicability	The MASTER system's simple architecture, COTS/high TRL wearable low cost enablement, and straighforward design implementation enable highly accurate regeneration of systems.	Very High
Repeatability	The MASTER system's enhanced body pose inertial recording and uniform wearable solution enables highly accuracte and repeatable actions by multiple participants.	Very High
Interoperability	The MASTER utilizes commonalized data and interface protocols (WiFi, Cellular 3G/4G, BTE, HTML5, AR shapefile, Javascript, XML/select ASCII) to enable rapid device integration and intra and inter-system interoperability with the wearable, deployed core, and external systems.	Very High
Safety	The MASTER's use of augmented environments (Visual/audio injections) creates realistic yet safe operational execution for hazards and exposure to elements. The addition of tactile and haptic/thermal accessories creates additional realism of equipment use and environmental exposure without exposure to actual and uncontrolable elements. The wearable solution enables use of existing protective clothing and equipment during test and evaluation as well. The extension of captured measurement monitoring such as body movement/respiration/etc. can aid monitoring of real-time performance and health as well.	Very High

Above/beyond – The MASTER system is a **paradigm-shifting solution** for test and validation of responder equipment and future technologies by rejecting the current-state instrumented fixed site solution limitations and **proposing a highly mobile/easily deployable/real-world-operable/any-time emulatable/and infinitely customizable solution for any responder anywhere in true train as you work-work as you train fashion.** The MASTER system is extendable through use of communalized interfacing and modular architecture of design using low cost high COTS/high TRL solution elements.

Cost assessment and BOM/Purchase order list – The estimate of cost for a minimally deployable system (2 wearable units plus support C2 system) is **$14,440.00.** The specific per-system components and estimates are as follows:

	Wearable MASTERPIECE system				
#	Item	Type	Cost est	Qty	Total cost
1	AR Glasses	Vuzix AR3000	3000	1	3000
2	Smartphone	Samsung S8	750	1	750
3	Hand Tac Unit	InterSense4/custom	250	2	500
4	Leg Tac Unit	InterSense4/custom	250	2	500
5	Chest Tac Unit	InterSense4/custom	350	1	350
6	Headset	Panasonic	75	1	75
				System	5175
			Two systems total cost		**10350**
	Deployable MASTERCORE C2 system				
#	Item	Type	Cost est	Qty	Total cost
1	PC unit	HP MultiCore	3500	1	3500
2	Wireless router	Belkin	100	1	100
3	Unity software	Unity	0	1	0
4	ARToolkit	ART	0	1	0
5	Mapping software	3D Systems	250	1	250
6	Data analytics	Various	0	1	0
7	Case	Pelican	200	1	200
				System	**4050**
		Minimal MASTER system total cost			**14400**

The above includes custom work to develop the tactile/haptic hand and leg units to include small thermal element, tactile element, and inertial and power elements. Estimates for software include known availability pricings or open source availability and does not include time of development.

The above does not include potential work for the proposed shifting weight mass unit if desired to mimic/emulate sliding floor or rocking boat scenarios.

Competitive follow-up on design percentage performable by self – 80%. The proposed MASTER system may be developed primarily in-house by the proposed designer. The high COTS percentage of core hardware may be purchased (smartphones, AR headset, audio headsets, PC, communications equipment). The uniquely described tactile/haptic accessories may be developed simply from purchased equipment and assembled by hand. The AR server and client elements may require additional outside assistance for coding and scenario building using the provided SDK interfaces to develop a stand-alone MASTER application (40% of software development; 20% total system).

Limitations to current design - While compact, novel, low cost, infinitely customizable, and specifically usable anywhere within the real world, the MASTER system contains potential areas for expansion including : (a) opportunity to include olfactory generation (smell of smoke, etc.) via specific device integration and control (similar to Sensoryco.ts solutions), (b) additional thermal panel inclusion to expand the “feel” of heat (or cooling panels for cold) deployable within the specified areas, (c) additional wireless streaming cameras placed within the specified area to extend field of view coverage, and (d) integrated power system for the wearable MASTERPIECE systems (minimizing individual device recharging/replacement/logistics).

Follow ons – The MASTER system's use of common data interfaces and protocols and scalable software architecture elements provides significant "future proofing" to enable the addition of new solutions and modification of functions going forward. Some select areas identified for near-term integration and enhancement are likely including: (a) additional location/indoor focused position aids such as beaconing to enhance localization accuracies, (b) expanded tactile/haptic unit number and placement on wearer's body to expand realism, (c) additional voice and gesture control elements to further simplify/make more realistic the control and use of the MASTER system, (d) further equipment integration to minimize the MASTER system elements and enable simpler deployment and use.

The primary follow on for MASTER is in the potential for the system to become fully integrated into the daily operations of first responders to enhance current process and methodologies at a low cost.

Summary – The MASTER modular wearable measurement collection and evaluation system provides a unique paradigm shift away from the static site-based instrumentation facility approach to new technology test and validation as well as affording real-world realism and safety for actual equipment-based train as you work/work as you train operations, with the opportunity to become a fully operational real-time enhancement to daily first responder equipment at a low cost.

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John Kelly / Symstemics