# Beyond Ender's Game – Fusions of Simulations into Operational Interfaces

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## ABSTRACT

Advances in Augmented Reality are turning "train like you fight," into "fight like you train," where simulation and synthetic imagery can be inserted into battlefield operations to remotely operate systems with enhanced situation awareness and decision making. VR Rehab with Old Dominion University and Lockheed Martin, in collaboration with the Army's Natick Soldier Research, Development and Engineering Center (NSRDEC) have developed Fused Augmented Realities with Synthetic Vision (FAR/SV) which merges simulated terrain and graphics into operational interfaces. This paper will describe FAR/SV successful R&D investigations enhancing the situation awareness and decision making by warfighters controlling small unmanned aerial systems and small unmanned ground vehicles under OSD/NSRDEC sponsorship. This paper describes the foundational science, agile development efforts to overcome challenges, and data from empirical studies of usability and mission performance. Two successful FAR/SV innovations are presented. First, to overcome long-standing problems of 'looking through a straw' high-magnification viewing, we surround the actual live/sensor view with a correlated 3D synthetic vision wider field of view for enhanced situation awareness. Second, to overcome degraded visual conditions, we semi-transparently blend the actual live/sensor view with the underlying correlated 3D synthetic vision terrain. Additional operational benefits derive from our FAR/SV interface innovations where users perceive they are adding 2525 icons and other annotations directly to the video/sensor imagery; where 'under the hood' we are anchoring the icons and annotations persistently to our underlying correlated 3D terrain. FAR/SV supports its use as a standalone App running under Windows or Android, as well as an add-on module for existing video and sensor imagery viewing applications.

## ABOUT THE AUTHORS

**Peter Crane, PhD.** Peter Crane has over 35 years of experience in Human Factors research and practice with VRR, Inc., the Air Force Research Laboratory (AFRL), and as a Visiting Scholar at the US Air Force Academy. At VRR, Dr. Crane has been Principal Investigator for several projects for military customers involving synthetic vision/ augmented reality displays. Dr. Crane earned a Ph.D. in Experimental Psychology from Miami University.

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General Patton's assertion that, "you fight like you train," suggests warfighters will execute in combat the skills they learned in training, whether those actions are correct or not. The simulation and training community has taken this idea one step further. Live, virtual, and constructive simulations are designed so that the cues provided to the warfighter are as realistic as physics allows and the responses elicited in simulated combat will be the tactically correct on the battlefield. Simulation technologies including visual image generation, image displays, physics modeling, and networking work together to provide warfighters with high fidelity training environments. The emergence of remotely operated air and ground vehicles in battlefield operations is adding new elements to the concept of fight like you train.

In the science fiction novel *Ender's Game* by Orson Scott Card (1985), the character of Ender Wiggins trains as a commander using more and more complex simulations until he learns that his simulation final test exercise was in fact an actual battle and he was controlling real forces against a live enemy. For Ender, the simulated training environment was exactly the same as the actual warfighting environment. In our world, during battlefield operations of Small Unmanned Air Vehicles (SUAVs) and Small Unmanned Ground Vehicles (SUGVs), simulation and synthetic imagery can be inserted into live sensor imagery to enhance situation awareness and facilitate decision making. The team of VR Rehab with Old Dominion University and Lockheed Martin, in collaboration with the Army's Natick Soldier Research, Development and Engineering Center (NSRDEC) have developed Fused Augmented Realities with Synthetic Vision (FAR/SV) which merges simulated synthetic vision terrain, text, and graphics into operational interfaces. Like Ender, remote system operators will train in simulation and then bring these simulations with them into combat operations.

Synthetic Vision is a system developed by the US Air Force and NASA to provide pilots with a three-dimensional simulation of the environment in front of their aircraft. Synthetic Vision systems typically present completely simulated imagery for blind flying augmented with additional graphic cues such as a predictive Highway-in-the-Sky that extends the flight path. FAR/SV incorporates this approach together with a mixed-reality option where the narrowly focused live sensor feed from an unmanned vehicle is fused with synthetic, wide-field-of-view imagery (see Figure 1). Synthetic vision provides an intuitive visual environment where the synthetic vision display areas are always ideal viewing conditions, regardless of lighting, weather, or obscurants that accompany live camera/sensor views (see Figure 2).

A squad-level SUAV will have an estimated range of few kilometers and may be used for reconnaissance, gathering imagery, and sampling for nuclear, biological, and chemical threats. The SUAV will frequently be out of sight of the operator who will fly using an Augmented Reality, Helmet Mounted Display (AR-HMD) receiving video/sensor imagery from the vehicle. One of the operator's challenges is selecting the sensor's field of view (FOV). With a narrow FOV, the operator can see objects on the ground in great detail but often does not know where the camera is looking. Zooming the sensor's lens out to provide a wider FOV helps maintain situation awareness (SA) by providing visual context, including roads and other landmarks. The problem, however, is that with a wide FOV, the focus is too wide to complete the mission. FAR/SV adds semi-transparent synthetic vision imagery surrounding the narrow FOV active real-time views together with text and graphics for tele-operated unmanned aerial systems. FAR/SV's wider field of view and AR re-adds missing peripheral visual cues and SA context.

With FAR/SV, a soldier operating an SUAV or SUGV will be able to:

- Automatically generate the 3D synthetic vision terrain of their area of operation in seconds.
- Plan a mission using augmented, virtual reality inserting semi-transparent icons, planned routes of travel, anticipated threats, potential targets and other imagery that will support the mission.
- Rehearse the mission in virtual simulation, seeing the icons and other items inserted during mission planning accurately positioned in the virtual gaming area, with vehicle information such as heading, speed, and energy reserve on a single display.
- Execute the mission in AR using the same control interface as in mission rehearsal, seeing the same semi-transparent virtual imagery overlaid on the real-world sensor imagery from the vehicle.
- Share intel and/or conduct an after-action review, reviewing all aspects of the mission using advanced and highly versatile replay capabilities.

Using FAR's embedded training capabilities, the soldier can also learn to use FAR/SV and review vehicle control interface operation. FAR/SV is being designed to support near hands-free operation and to reduce soldier cognitive burden.


**Figure 1. FAR/SV presentation as viewed by an SUAV operator with live sensor feed in the center of the FAR/SV display with blue sky conformally fused with synthetic imagery with black sky showing the surrounding terrain and cultural features such as roads and buildings. The difference between the real-world blue sky and the synthetic vision is purposeful towards enabling intuitive visualization of the different contexts. FAR/SV provides a wider field of view visual context to the operator enhancing situation awareness while maintaining high sensor resolution for the principal area of interest.**

## HUMAN FACTORS / COGNITIVE SCIENCE BACKGROUND

FAR/SV presents the operator with an AR mixed reality display with synthetic text, graphics, and a simulated image of the real world superimposed over the forward view through an AR-HMD. Semi-transparent displays largely evolved from aircraft Head-Up Displays (HUD), which allow a pilot to watch the outside world (ground, horizon, runways, or targets) while simultaneously monitoring airspeed, attitude, altitude, and radar information. Semi-transparent displays such as HUDs allow an operator to fuse and use two sources of information at the same time. This capability is also the basis for AR, where an operator performs a task with additional graphic information superimposed using either a see-through helmet-mounted display or on a display screen. Researchers have found that adding information to an operator's visual field using HUDs or AR can improve performance in a wide range of domains beyond pilots and other warfighters. These include: air traffic control (Fürstenau et al., 2008; Fürstenau et al., 2004), vehicle maintenance (Henderson & Feiner, 2009) and anesthesiology (Liu et al., 2010). Semi-transparent displays can also aid performance by cuing an operator about events outside the current field-of-view (Livingston & Ai, 2008; Robertson et al., 2008).

**Figure 2. FAR/SV presentation as viewed by an SUAV operator with live sensor feed in the center of the FAR.SV display under degraded conditions caused by clouds and fog. Under these conditions the operator can fade the sensor image and fly using only synthetic imagery or use the surrounding synthetic imagery to support maintaining situation awareness with poor direct viewing of the environment.**

HUD and AR symbology is even more beneficial when it conforms to the outside world. Semi-transparent displays conform when, "…items in a symbology set that overlay and move in unison with similar far domain counterparts in the environment hence adhering to Gestalt grouping principles of proximity, common fate and good continuation" (Ververs & Wickens, 1998, p. 12). The artificial horizon on an aircraft HUD is an example of a conformal display. Conformal symbology helps the operator most when "…the pictorially augmented scene enables the merging of the two domains into a single environment, thereby eliminating the need to switch attention between them" (Ververs & Wickens, p. 18). With scene-linked imagery, the AR image, either a symbolic icon or realistic rendering, behaves as if part of the physical world. "Although rendered in graphics on the HUD, these "scene-linked" symbols are drawn, and move, as virtual objects in the out-the-window scene. As the aircraft moves through the world, the scene-linked symbols undergo the positional visual transformations as real objects," (Foyle et al., 1995). Foyle et al. describe scene-linked, conformal imagery as scene enhancements where the image outlines existing objects in the world. The outline of a runway or a line apparently on the field seen in televised football games are scene enhancements. In contrast, "scene augmentations represent the addition of virtual, non-real, three-dimensional objects drawn on the HUD as if they existed at a location in the real world," (Foyle et al., 1995, p. 99). Virtual targets, navigation markers, and control lines are scene augmentations. Foyle et al. found that scene-linked, conformal imagery enhanced performance by reducing attentional tunneling where operators focused their attention on the symbol rather than the real-world object it represented. In addition, Wickens and Long (1994) found that conformal, scene-linked scene augmentations reduced operator eye movements and attentional shifts.

## HOW FAR/SV WORKS

The FAR/SV system obtains the GPS position of the unmanned vehicle or soldier. The system then uses this information to obtain satellite imagery and geological data to create veridical 3D synthetic vision terrain around the vehicle's or soldier's position (see Figures 3a and 3b). By continually using GPS and other sensor data, FAR/SV updates the position of the viewport in FAR/SV virtual world to be analogous to the UV's real-world position. The user can then mark points of interest which remain consistently positioned and geo-rectified in the virtual terrain (see Figures 2 and 3).

Sensors on UAVs and UGVs often need to be at a high zoom level to examine detail of the real world. FAR/SV generates a synthetic vision terrain from satellite imagery and geological data that the pilot can view at the same time as the real sensor. Using an HMD's head tracking capabilities or other input device, the pilot can easily scan the surrounding synthetic vision terrain while reviewing the live sensor's feed. The sensor feed can also be adjusted for different levels of transparency for comparison of the real-world with the generated synthetic vision terrain. This greatly increases the operator's situation awareness and reduces the pilot's cognitive load. Similarly, when the sensor's feed is degraded due to obstructions such as smoke or clouds, the synthetic terrain can be semi-transparently blended within the live camera/sensor used to navigate the UAV/UGV. Therefore, any brownout conditions are mitigated/negated and situation awareness is enhanced with FAR/SV's synthetic vision terrain. Importantly, FAR/SV provides a complete 360-degree view of the world. Most sensors on UAV/UGVs are limited to a much smaller field of view, limiting a pilot's or sensor operator's situation awareness.

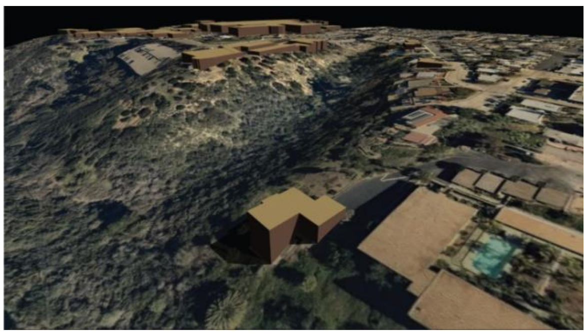

**Figure 3a. Example of Geo-rectified synthetic vision terrain generation.**


**Figure 3b. Example of Geo-rectified synthetic vision terrain generation within Android application.**

**Figure 4. Geo-rectified points of interest with simulated sensor camera not activated.**


**Figure 5. Geo-rectified points of interest with simulated sensor camera activated with minimap.**

### Fusion of Augmented Reality with Synthetic Vision User Interface Innovations

Key benefits of FAR/SV for SUAV and SUGV operators include intuitive control and visualization interactions between the real-world with AR additions plus FAR/SV's correlated 3D Synthetic Vision terrain which underlies and surrounds the live camera/sensor view window. For example, if an SUAV operator sees an enemy sniper, he or she can directly place the 2525 sniper icon into the video/sensor imagery. FAR/SV's fusion software automatically links the icon to the persistent underlying 3D synthetic vision terrain. Subsequently, whenever the operator's video/sensor views the sniper area, the semi-transparent sniper icon persists in right location and appears as if it is part of the video/sensory imagery stream. For mitigation of degraded visual conditions, FAR/SV also enables the operator to semi-transparently fade the live camera/sensor central window so that the correlated underlying 3D synthetic vision terrain can be viewed more clearly. A limitation is that only the static 3D synthetic vision terrain is visible (not moving entities like other aircraft). This function of FAR/SV enhances operator situation awareness to prevent collisions with terrain, buildings, or other cultural features that are within the 3D database.

## ARMY PLANNED USE CASES

The following use cases for drones illustrate benefits of FAR/SV for situation awareness, remote monitoring, beyond line of sight targeting, chemical, biological, radiological and nuclear detection and monitoring, site mapping, unexploded ordinance management and removal.

- Situation awareness can be enhanced as the drone is able to take off and land in degraded visual conditions, allowing for flight in conditions that would not normally be acceptable.
- Remote monitoring of locations can be improved and setup can be executed using AR during mission planning and execution.
- Beyond-line-of-sight targeting can be improved with simulation training for mission rehearsal, and AR target tagging. FAR/SV can also enable and enhance the hand-off of targeting information to the end user's device for the dismounted soldier.
- AR for chemical, biological, radiological and nuclear detection applications allows for overlays that could enable better visualization and awareness of the enhanced area and lessen cognitive burdens associated with identification and tracking of substances.
- Site mapping capabilities include terrain, urban and underground scenarios where a drone could map the environment using a variety of capabilities and then feed data back into the simulation, allowing for greatly enhanced situation awareness and planning.
- More intuitive and cost-effective AR control schemas allow for the handling of difficult objects like unexploded ordnance. Enhanced object manipulation benefit is not limited to this use case and could see benefits across a wide variety of situations.

## USER EVALUATIONS

The VRR team employed iterative usability testing processes throughout the system agile development lifecycle, including weekly quality assurance testing and quarterly user testing. The goal for user testing was to evaluate the overall usability of two early iterations of FAR/SV's mission planning and mission rehearsal tools across three devices: a Windows-based computer, a handheld Android device, and a GearVR head-mounted display. In this section, we outline our overall user testing methodology and provide a brief overview of some results that informed future software iterations. We completed two full phases of user testing in which participants accomplished simulated SUAV operation tasks using different iterations of FAR/SV's Mission Rehearsal Creator and Mission Rehearsal tools. Across all phases, participants provided verbal, written, and survey feedback and we collected performance data reflecting speed and accuracy. Results informed our rapid, targeted design updates, future user testing protocols and embedded training design. We will continue to iterate based on measures of task success, subjective opinions, and user testing to improve the usability of our software.

### Method

#### Participants

Data were collected with college student volunteers between the ages of 18 and 21. In Phase I, we collected data with eight (four women) students, including four Army ROTC students. In Phase II, data were collected with eleven college student volunteers (five women). Three students in Phase II reported one to seven years of experience with robotic devices ($M = 4$ years, $SE = 5.397$), including as a hobby or through robotics camps.

#### Equipment

The applications were hosted on a 64-bit desktop computer operating Windows 10 and a Samsung Galaxy 8+ hosting Android 7.0 as a standalone device (Figure 6) or within a GearVR headset (Figure 7). Depending on the task, participants completed their tasks with a touchscreen, mouse, keyboard, or XBox One controller.

#### Measures

Subjective system usability was measured with the System Usability Scale (SUS) (Brooke, 1996). Participants respond to ten questions related to positive and negative system traits using a five-point Likert-type scale (1 = strongly disagree; 5 = strongly agree). Answers were converted to a raw score that falls between 0 and 100 and high scores indicate high usability. Sauro (2011) suggests that an SUS score of 68 indicates average usability, so we applied 68 as an acceptability threshold. To assess performance, we measured mission planning and rehearsal task completion times, and coded common errors.

**Procedure**

Participants reviewed a detailed video outlining the usability testing procedure, task information, and software controls and features. Participants completed tasks in a virtual environment that simulated buildings surrounding a parking lot. First, they used the mission planning tool to plan a simulated drone flight path by placing waypoints to observe the parking lot. Second, they used the mission rehearsal tool to fly a simulated drone along their chosen path, search the parking lot for threats, record video, and label targets using 2525 icons. Following each scenario, participants completed the SUS and provided written and verbal feedback.

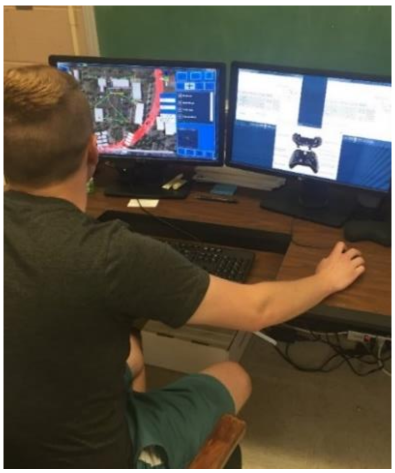

**Figure 6. Participant creating waypoints using the Windows version of Mission Rehearsal Creato**r.

**Figure 7. Participant completing a Mission Rehearsal task with the GearVR and Xbox One controller.**

**User Testing Phase I Results**

Group mean differences between the different implementations of FAR/SV, Windows, Android, or Gear-VR head-mounted display described below were not statistically significant, $p > .05$. Figures 3 and 4 illustrate performance and SUS scores across applications.

**Performance**

Participants created a mission plan in an average of 500.00 seconds (*SE* = 110.00 seconds) and rehearsed their mission in an average of 330.00 seconds (*SE* = 97.00 seconds) across applications (see Figure 8). Participants generally took more time to plan their mission with the Android application than with the Windows application. There was wide variability across participants for mission planning time. For example, male ROTC participants spent significantly longer than females planning their mission and re-checking their waypoint placement. Common errors included difficulty placing waypoints during mission planning and the inability to place 2525 icons at their intended location during mission rehearsal. All participants completed all scenarios successfully and improved flying performance across tasks.

**Subjective System Usability**

System Usability Scale (SUS) scores reached or approached the recommended 68-point criteria for acceptability for the mission planning tool (Windows: 68.75; Android: 67.50) (see Figure 9). Across applications, participants generally reported that they imagined most people would learn to use the mission planning tool very quickly. For mission rehearsal, SUS scores fell just below the threshold for usability (Windows = 65.00; Android = 57.50; GearVR = 64.50), so the system required some additional design improvements to be "usable." Across applications, participants reported that they found the mission rehearsal tool functions to be well integrated and easy to use. They reported being confident and would like to use this system frequently.

**Summary**
Based on an in-depth analysis of user testing data, the research team provided specific design guidance and worked alongside the software development team to make targeted design changes to each application. Design changes included improvements to the usability of the graphical user interface to reduce cognitive burden for learning and remembering how to interact with the application. A variety of A/B testing of features was also performed to validate or invalidate the usefulness of the application features. For example, we determined that radial menus were often more efficient for users than table-like or drop-down menus, particularly in the HMD. A second example of a design change involves a virtual skybox. In early versions of the application, a sky image in the background of the virtual terrain was confusing to users. Following testing, the software development team removed this sky image in favor of a black background to enhance operator situation awareness and visual perceptual processing.

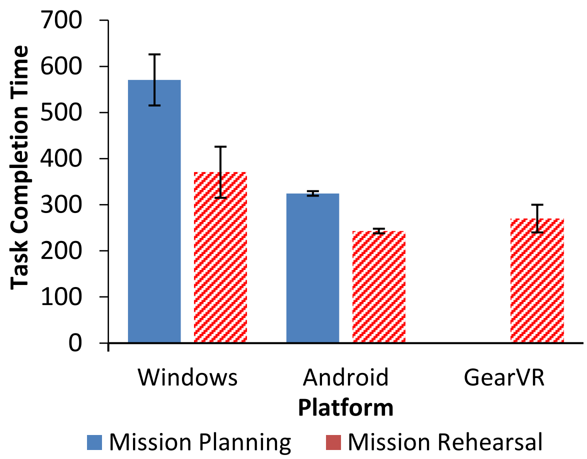


**Figure 8. Phase I task completion time (seconds) and standard errors for Mission Planning and Rehearsal.**

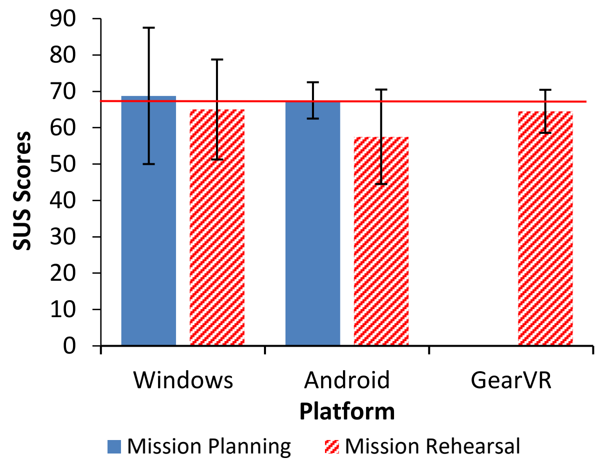


**Figure 9. Phase I SUS scores and standard errors for Mission Planning and Rehearsal. Usability acceptability threshold indicated with red line.**

**User Testing Phase II Results**

Group mean differences between the different implementations of FAR/SV, Windows, Android, or Gear-VR head-mounted display described below were not statistically significant, $p > .05$. Figures 5 and 6 illustrate performance and SUS scores across applications.

**Performance**
Participants performed substantially faster with fewer errors and less individual variability during mission planning during Phase II (see Figure 10). Participants created a mission plan in an average of 188.40 seconds (*SE* = 28.79 seconds) and rehearsed their mission in an average of 183.30 seconds (*SE* = 103.18 seconds) across applications.

**Subjective System Usability**
System Usability Scale (SUS) scores improved for Windows and GearVR mission rehearsal. Scores for the Android version of mission planning improved in this phase and exceeded usability acceptability ratings with a score of 77.50 (see Figure 11).

**Summary**
The software development team carried out a full user interface redesign to address most negative system traits discovered during early iteration quality assurance testing and user testing phases (see Figures 12 and 13). Preliminary findings during testing indicated that specific features such as radial menus reduced confusion, while the virtual skybox caused visual perception decrements. The second phase of testing indicated these design changes improved overall user performance and preference. The performance and subjective usability improvement may be due to a combination of factors: negative system traits were effectively addressed; participants in this phase of testing reported more experience with robotic devices and game controllers; and we made improvements to training protocol.

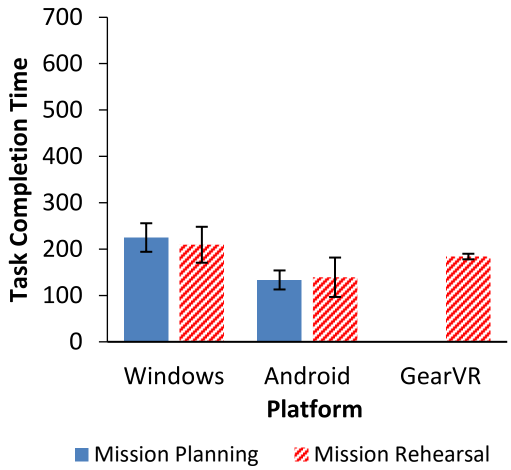


**Figure 10. Phase II task completion time (seconds) and standard errors for Mission Planning and Rehearsal.**

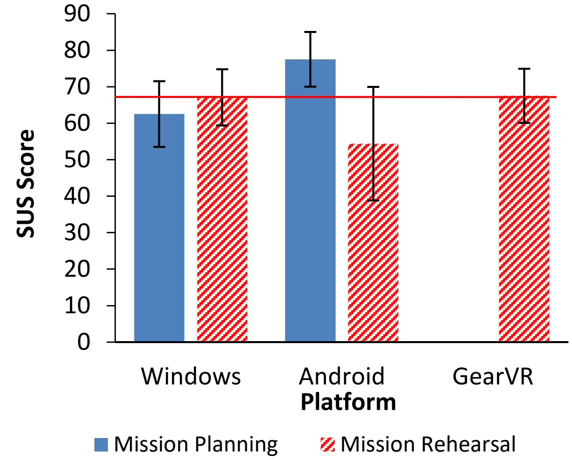


**Figure 11. Phase II SUS scores and standard errors for Mission Planning and Rehearsal. Usability acceptability threshold indicated with red line**

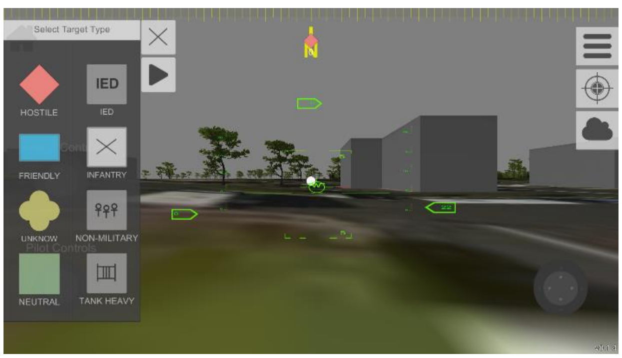


**Figure 12. Menu design for 2525 marker placement in FAR/SV Mission Rehearsal; pre-testing iteration.**

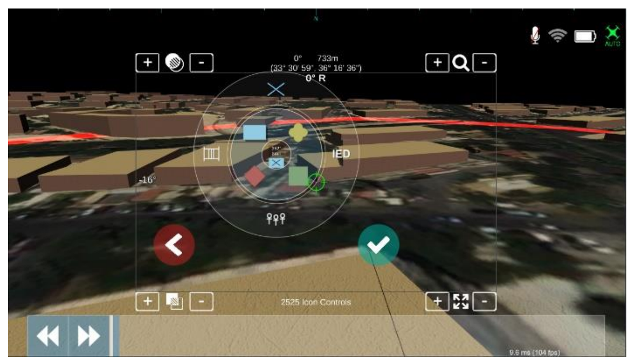


**Figure 13. Menu design for 2525 marker placement in FAR/SV Mission Rehearsal; post-testing iteration.**

## SUMMARY AND CONCLUSIONS

The goal of FAR/SV is to provide operators of small, battlefield unmanned vehicles with a mixed-reality user interface that integrates real-world, vehicle-based sensor views with a wide FOV three-dimensional, geo-referenced simulation of the world. The integrated image also incorporates scene enhancements such as target indicators and scene augmentations such as a navigation path. Like the fictional Ender Wiggins, the unmanned vehicle operator can plan and rehearse using the actual mission equipment but with simulated imagery augmented with synthetic cues. During actual missions, the operator will fly with the same cues over real-world imagery from the vehicle's sensor. In addition, the simulated imagery will be available to the operator as synthetic vision augmentation to enhance situation awareness under sensor high magnification or degraded visual conditions. FAR/SV blurs the distinction between simulation for training and the operational environment. By bringing simulation into theater, the operator can function in a familiar environment and enjoy reduced cognitive demands. Technical developments are being continually checked in our human factors laboratory to ensure usability and to identify positive and negative interface design components early in the process. Future developments will focus on non-military applications such as search-and-rescue or wildland fires. Just as Ender transitioned smoothly from training to operations, warfighters and emergency responders will be able to take their training environment into action with them.

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