Switchable Vision Blocks: The Missing Link for Embedded Training

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ABSTRACT

The provision of Embedded Training (ET) capabilities is written in the requirements documents for future manned ground fighting vehicles as well as for upgrades to current force fighting vehicles including the Stryker, the Abrams and in the Marine Expeditionary Fighting Vehicle (EFV). ET allows vehicle crew members to train anywhere, anytime.

Manned Ground Vehicles (MGV) crewmen use optical vision blocks as a safe means to see the world outside. This paper describes an electro-optical Switchable Vision Block (SVB) that not only allows the crew to see the world outside, but also serves as a visual interface to virtual environments for embedded training. Other components for embedded training systems are already in place, including collective simulation systems like CCTT and "drive by wire" systems that allow soldiers to use the vehicle controls either for operations or for training. The SVB is the missing link between current and evolving simulation-based training systems and the soldier.

This paper describes the design and development of SVB prototype technology. Three prototypes were created that represent tradeoffs for the multi-dimensional design space. The key challenges for this design were the integration of an optical out-the-window view with high-resolution, collimated views of virtual environments in a way that:

- Did not degrade operational performance, including transmissivity for the optical view and luminance for the virtual view,
- Met form and fit restrictions representative of future and current force vehicles
- Met stringent weight and overall size restrictions
- Provided a fail-safe configuration that ensured a working optical path view for the full range of failure modes, including ballistic integrity.

ABOUT THE AUTHORS

R. Jorge Montoya is a senior research electrical engineer with RTI International. Over the last 3 years he led the IPT that first developed Switchable Vision Block (SVB) concepts, then designed and implemented three SVB prototypes. He received an MS in Electrical Engineering from North Carolina State University.

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Joseph White is a senior research electrical engineer with RTI International. He contributed to design and implementation of the electronics subsystem for the SVB prototypes. Mr. White holds an MS in Electrical Engineering from North Carolina State University.

Isaac V. McKissick is a graduate of the US Military Academy, with a BS in General Engineering. He earned an MS Engineering Management and MA Applied Economics and Finance from University of Detroit. He has six years of service in Light Infantry and Armor Units. At General Dynamics Land Systems (GDLS), he is the contracts liaison for FCS Embedded Training and Program Manager for Switchable Vision Blocks.

Glen Cornell is a Software Engineer at GDLS. Mr. Cornell is presently managing the training content development team in support of the Manned Ground Vehicles in the Future Combat Systems program. Mr. Cornell holds a BS in Computer Engineering from the University of Central Florida.

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INTRODUCTION

The provision of Embedded Training (ET) capabilities is written in the requirements documents for future manned ground fighting vehicles as well as for upgrades to current force fighting vehicles including the Stryker, Abrams, Bradley, and the Marine Expeditionary Fighting Vehicle (EFV). ET allows vehicle crew members to train anywhere anytime without a dedicated training simulator and with minimal training-unique hardware.

EMBEDDED TRAINING WITH VISION BLOCKS

Embedded Training Requirements

Embedded Training (ET) is an objective requirement of current and planned force vehicles. Embedded training uses resources integrated into the vehicles that provide a common look and feel for soldiers and leaders to gain and sustain proficiency at the individual, crew, leader, and collective levels anywhere, anytime. In particular, the goal for embedded training is to have no training-unique components in the vehicles.

Vision Blocks for Embedded Training

A visual interface is an essential element of an ET system. Physical constraints (weight, size, power, etc.) in the interior of combat systems and training doctrine dictate the sharing of as many resources as possible. Current force vehicles use unity power optical vision blocks as a safe way for the vehicle crew to see the world outside.

One way to obtain an ET capability for manned ground vehicles is to extend the functionality of the vision blocks to provide the crew with a common visual interface for operation of the vehicle and for embedded training. This common viewer, which we call a Switchable Vision Block (SVB), is the final interface between the soldier, the environment, and the training system that enables soldiers to 'train as they fight.' As such, the SVB is the missing link between current and evolving simulation-based training systems and the soldier.

The insertion of SVB technology also enhances the crew's battlefield situational awareness by displaying overlay information on the external view rather than solely displaying it on the map. SVB technology has the potential to support a blended view mode in which synthetic information, e.g., from maps or sensors, could be overlaid onto the real world view to enhance the crew's battlefield situational awareness.

ARMORED VEHICLE VISION BLOCKS

Armored vehicle vision blocks are solid, periscope-like devices made of either glass or acrylic in a metallic case. A system of mirrors (typically an upper mirror and a lower mirror) is configured to allow the crew member to look outside the vehicle over some specified field of view (both horizontal and vertical) at a given distance from the exit window of the vision block. Figure 1 depicts a generic vision block and identifies its component parts.

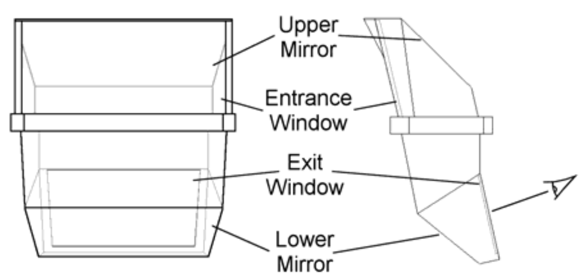


Figure 1. Generic Vision Block Form Factor

Vision Block Functional Requirements

The function of a vision block is to allow the vehicle crew to accomplish the following tasks in a tactical environment:

- Maintain vehicle position and orientation on the battlefield during day and night operations.
- Maintain vehicle orientation relative to friendly vehicles within the platoon or company during day and night operations.
- Detect close-in vehicles or troops from within the turret environment and activity.

Training objectives, instructional doctrine, and environmental (weight, size, etc.) constraints require that the crew of the fighting vehicles interface to the embedded training display by means of the vehicle vision blocks. On the other hand, combat and normal vehicle operations require maintaining the integrity of the vision blocks.

Vision Block Form and Fit Requirements

Vision blocks are installed through a hole in the vehicle armor. This hole is a possible weak spot in the protection for the vehicle crew, and is carefully designed. Vision blocks differ from one fighting vehicle to another as well as between different stations of the same vehicle. For example, the Stryker ICV has two different form factors for the vision blocks used in the driver's station and the commander's station. Different form factors require different strategies for folding the optical path and positioning the electronics and connectors.

Training with Existing Vision Blocks

Most current Army vehicle designs incorporate umbilical training capability including external electrical and data interfaces to vehicle systems and optical and electronic interfaces into the High Power Sights (HPS). However, because of the physical and optical complexity of the vision block, these embedded training systems require the installation of bulky displays on the outside of the vehicle in order to emulate the field of view of the passive vision blocks in a training, non-operational mode. This umbilical training requires significant set-up and alignment required to configure the vehicle for training. The external displays are another training unique device that the unit has to manage logistically.

SWITCHABLE VISION BLOCKS

A switchable vision block, self-contained within the vehicle, provides the vehicle crew with a common visual interface for operation of and training within the vehicle. This allows the vehicle crew to "train as it fights." The insertion of SVB technology as a tactical tool will enhance the crewmember's ability to effectively perform the tasks outlined above with greater accuracy and efficiency in areas such as battlefield situational awareness relative to terrain, friendly and enemy activity, and other sources of potential hazard. Insertion of the SVB concept will also prompt an adjustment to existing doctrine for crew coordination on the battlefield allowing each crewmember to expand areas of responsibility as battlefield workload allows.

SVB Functional Requirements

As originally conceived, the SVB has two constructive functional requirements, support for direct and indirect view modes. The SVB also has one objective functional requirement, support for a blended view mode. These view modes are described below.

Direct View Mode

Real-world scene as viewed through an optical path through vision block. Support for this mode is a requirement. Figure 2 illustrates the direct view mode.

Figure 2. Direct View Mode

Indirect View Mode for Embedded Training

For embedded training, a digital video scene generated by an image generator is viewed through the vision block, and the image generator is linked to a training simulation for individual, crew, or collective training. Figure 3 illustrates the indirect view mode being used for embedded training.

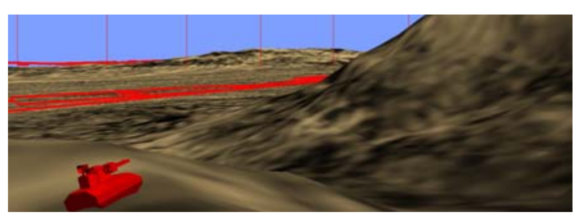


Figure 3. Indirect View Mode for Training

Indirect View Mode for Sensor Display

The SVB provides additional operational capabilities beyond those of a purely optical vision block, since the source driving the SVB display may be live sensor data, such as FLIR or a video camera, as illustrated in Figure 4. The image processor or image generator may blend sensor data from multiple sensors, but this is still viewed as indirect view mode from the SVB perspective. The SVB provides an attractive alternative to Night Vision Goggles, which are the primary viewing mechanism for night operations.

Figure 4. Indirect View Mode for Sensor Display

Blended View Mode

A further benefit of Virtual objects or cues is that they can be registered and overlaid on real-world scenes. Figure 5 illustrates blended mode where a red box cue is overlaid on the direct view mode. The cue is registered to be aligned with and highlight the aircraft on the right side of the image. This mode was not considered a requirement for this study, but a desirable mode. Note that much of functionality of blended view mode can be achieved through digital image processing of camera or sensor feeds and use of the SVB in indirect view mode.

Figure 5. Blended View Mode

SWITCHABLE VISION BLOCK REQUIREMENTS

Visual Requirements

Design of the SVB required innovative solutions to both operational visual requirements as well training visual requirements (Montoya et al., 2005).

Operational Visual Requirements

The operational visual requirements included Field of View (FOV), transmissivity of natural light through the optical system, luminance of the virtual display, and avoidance of geometric and chromatic distortion.

The horizontal FOV (or HFOV) is dependent on the number and configuration of vision blocks at each of the crew stations; fewer vision blocks require a wider HFOV, more vision blocks allow a narrower HFOV. The vision blocks must be positioned so that HFOV overlap and avoid blind spots in the operator's vision outside the vehicle. The structural integrity of the armor encourages fewer vision blocks, but different vehicles have different solutions.

The transmissivity of the SVB is an essential design requirement. Natural light is attenuated as it travels from the outside world through the optics of the basic vision block. The additional elements introduced in the optical path of the SVB design cannot overly detract from the visibility available with a traditional vision block.

Training Visual Requirements

One of the most notable design challenges for embedding a display in a vision block is the design of an optical system that will make the interface to embedded training human factors friendly, i.e., that it will support prolonged training periods with little or no eye fatigue and support quick eye accommodation from direct view to training view and back. Since the direct view through the vision block is just like looking out the window at a distant scene, for effective training, it is necessary to present the simulated scene visually far away, even though the image source may be very close. To accomplish this, a collimated[1] optical system is needed to provide an image that will appear to be at an optically infinite distance from the viewer.

Collimated optical systems are used for simulated Out The Window (OTW) displays in a wide range of flight simulators and driver simulators. The same technology is also used in an aircraft Heads-Up Display (HUD) where the displayed symbology must be visible to the pilot while he is focused on distant objects. In most of these applications, the optical system is a large addition to the exterior of the vehicle model. Such an implementation approach is not possible in fighting vehicles.

[1] Collimated light is light whose rays are parallel and focused at infinity.

The luminance of the display element of the SVB is an essential design requirement for indirect mode viewing. The display must be bright enough to provide the operator with visibility of the virtual environment that is consistent with optical visibility of the actual world outside the vehicle.

Geometric distortion is a result of the engineering compromises required to provide collimated displays. Geometric distortion can make it difficult for the operator to accurately judge distances. Geometric distortion also influences the configuration of the mirrors, lenses, and the display. If the optics are optimized for on-axis viewing (i.e., viewing of the center of the field of view), then distortions will occur in off-axis viewing.

Chromatic distortion in lenses is due to the effect of imperfection on different wavelengths of light. This causes the viewed object to be smeared with different colors at different angles from the eye.

Form Factor Requirements

The physical dimensions of the SVB are a major concern in terms of the viability of the SVB for installation in current and future vehicles. The physical dimension constraints will vary from one current force vehicle to another. The essential tradeoff is how to achieve the maximum optical path for the SVB while meeting the space constraints of the vehicle crew station. The form factor requirements can be summarized as follows:

- The SVB envelope (basic vision block plus necessary space to implement the functional extensions that define the SVB) must stay within the Armor Envelope.
- The SVB envelope cannot block the View of Tactical Displays: Most current force vehicles already have tactical displays already installed. Installation of SVB's should not impact this display.
- Keep the same eye point as the current vision block for current force vehicle upgrades. Also ensure that the Indirect Mode Viewpoint is the same at the Direct Mode Viewpoint. This is an ergonomic requirement that facilitates transition from one SVB view mode to the other.
- Allow positioning of two adjacent SVB at 45 degree angle. It is assumed that in the general case, eight SVBs must be configurable to support a HFOV of 360 degrees with no blind spots and minimal columns between adjacent SVBs.

SWITCHABLE VISION BLOCK SOLUTIONS

Three SVB prototypes were constructed to explore the tradeoffs between simplicity of implementation and quality of the human factors for embedded training. Figure 6 depicts the space of tradeoffs considered in developing this design.

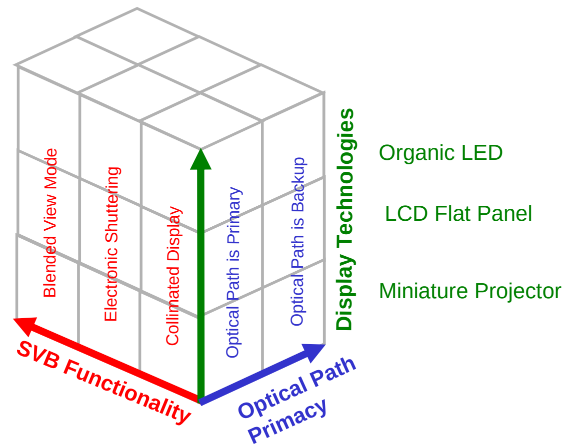


Figure 6. Tradeoff Space for Switchable Vision Block Designs

Discussions with vision block users quickly established that the optical path had to be the primary and fail-safe viewing mode. LCD flat panels emerged as the display technology for the prototypes, since organic LED technology was not available in the form and with the standard interfaces required. Miniature projectors were too bulky given the stringent form-factor constraints of current and future force armored vehicles. The three prototypes represented three approaches to the SVB functionality tradeoff. Electronic shuttering refers to the control mechanisms needed to shift between modes. The metric used for evaluating collimation was the length of the optical path in the indirect view mode.

The simplest SVB has one moving part (lower mirror) and one linear actuator. It has no optical amplification and the training products are presented in a 7" x 5" XVGA LCD display at a distance of 10 inches from the user with no collimation.

The second SVB has two moving parts and two actuators. It lengthens the optical path to 16 inches by the use of a Fresnel lens viewer temporarily placed behind the operator window of the SVB in the indirect view mode. Again, the training products are presented in a 7" x 5" XVGA display.

The third SVB, shown in Figure 7, is the most complex of the three. It has five carefully-shaped optical

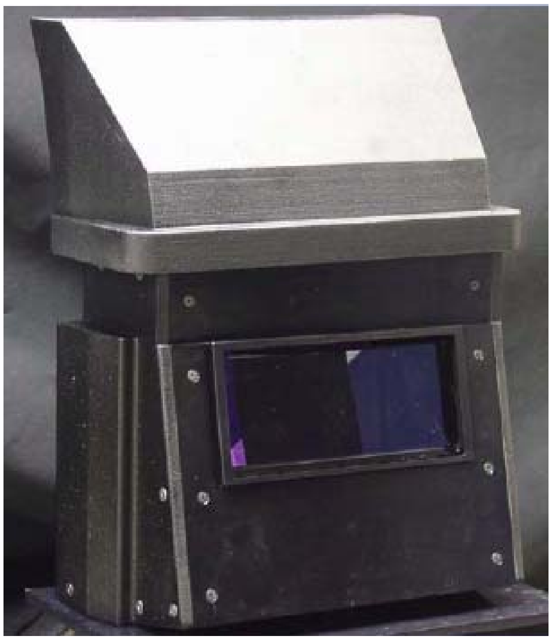


Figure 7. Switchable Vision Block with a Collimated Display

elements that provide a sharp and undistorted view of the training scene. These articulated parts are moved in and out of the respective optical path by two pneumatic actuators. The resulting optical path is infinite providing a collimated display with parallax correction. Even though the scene is presented in a small display (3.3" x 2.6" VGA display) within the vision block housing, the scene looks like it is far in the distance, making it more realistic and also more comfortable for long training sessions.

All three prototypes have solid upper sections for ballistic integrity and hollow lower sections to accommodate the articulation of parts necessary to switch between viewing modes. All three prototypes also fail safe (revert to direct view mode) under power failure conditions. An interface box, customized to each of the prototypes, was implemented to manage interactions between the SVB and the vehicle computer (control signals), image generator (video) and power source. Video scene management has been designed into the interface functionality to support the selection of the appropriate segment of the training video scene in a crew station with a multiple SVB configuration.

Concept of Operation

The dual purpose visual interface to an ET system described in this paper can be applied to a variety of training scenarios including driver training, both individual and convoy, and crew training (commander, gunner, driver) to include mission rehearsal.

The potential for displaying sensor-derived, properly registered, overlay information on the real world view through the blended view mode, either synthetically or direct, provides crew access to enhanced situational awareness and gives the SVB a value add for vehicle operations.

Direct View Mode Operation

The tracing of light through the SVB in direct view mode is shown in Figure 8. Light from the world outside the vehicle flows through the entrance window and is reflected down through the armor by the upper mirror. It is reflected through the exit window to the eyes of the operator by the lower mirror. This is the fail-safe configuration of the SVB; in the event of a power failure, the SVB will revert to this configuration.

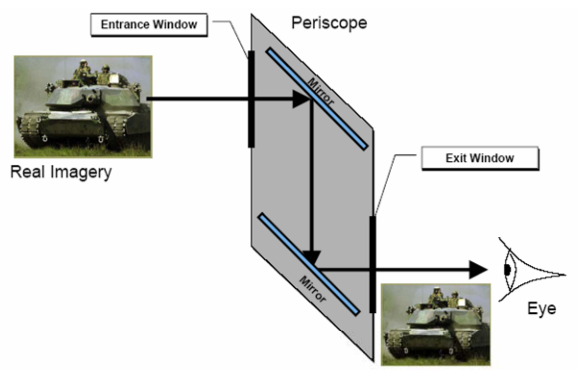


Figure 8. Concept of Operation for Direct View Mode

Indirect View Mode Operation

The tracing of light through the SVB during indirect view mode is shown in Figure 9. In this mode, the source of light is a display of synthetic imagery. The entrance window is shuttered so that no light gets in from the outside world. The lower mirror switches from reflecting the light hitting the upper mirror to transparently and translucently allowing the light from the display to go directly to the operator eye point. Light that is absorbed as it passes through the lower mirror can be compensated by driving the display at higher than normal luminance. This conceptual diagram does not show the configuration of lenses and/or mirrors needed to ensure that the display of synthetic imagery is collimated.

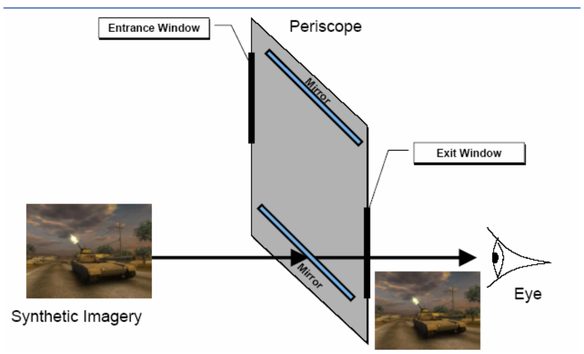
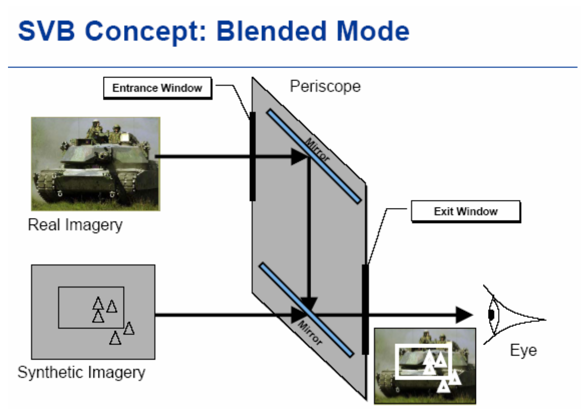


Figure 9. Concept of Operation for Indirect View Mode

Blended View Mode Operation
The tracing of light through the SVB during blended view mode is shown in Figure 10. In this mode, the source of light to the viewer is a combination (blend) of external imagery and display of synthetic imagery. The lower mirror is controlled into a partially transmitting, partially reflective state which allows light from the different sources to be blended in proportion to environmental conditions. The functionality of both individual view modes is proportionally maintained. This conceptual diagram does not show the configuration of lenses and/or mirrors needed to ensure that the display of synthetic imagery is collimated.

Figure 10. Concept of Operation for Blended View Mode

LESSONS LEARNED



Lessons learned from the prototype development activity identified the following risks:

1. Embedded training capability alone will not justify inserting an SVB into a future or current vehicle. Each SVB must justify its costs (fiscal, weight, power, reliability, etc) by adding operational value.
2. A true blended view mode (symbology and overlays registered to the real world or direct view mode) has operational value. This capability will allow sensor data and/or command and control information to be blended with the "out-the-window" view for the vehicle crew.
3. An SVB prototype must be proven in a current force vehicle to minimize the technology risk.
4. The SVB prototype must have a simple switching mechanism with minimal or no moving parts for maximum reliability and ease of maintenance.
5. The SVB prototype must provide motion parallax correction to support accurate registration of overlays as needed for operational requirements such as mission rehearsal.
6. The SVB system has to interface with the vehicle command and control system (e.g., FBCB2).

REMAINING CHALLENGES

Although the SVB prototypes meet the operational requirements identified at the beginning of the project, several challenges remain to graduate the SVB to a constructive requirement in upgrades to current and future force fighting vehicles. They are:

- Reducing or eliminating the number of moving parts in the view mode switching mechanism (reliability and maintainability issues)
- Fully integrating the virtual view and the out-the-window view in a true blended mode capability.
- Getting enough of an embedded training system into a current force vehicle.
- Getting the bandwidth into current force vehicles to support collaborative training via the network

CONCLUSIONS

The project described in this paper demonstrates that it is possible to implement a dual purpose visual interface based on the vision blocks of current and planned fighting vehicles. Enhancement of the indirect view mode with a collimated display provides an optimal ET visual environment that supports prolonged periods of training comfortably without a need to refocus when switching from one view mode to the other. Newly developed SVB concepts address reliability issues by achieving view mode switching without moving parts and extend the functional capabilities of the SVB by supporting a true blended view mode that enables the presentation of sensor-derived information to the crew for enhanced situational awareness.

ACKNOWLEDGEMENTS

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