Multipurpose Switchable Vision Blocks: Enabling Embedded Training in Combat Vehicles

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ABSTRACT

Embedded Training (ET) is an objective requirement of current and future force fighting vehicles. The goal of ET is to allow vehicle crew members to train anywhere at anytime with little or no training-unique components in the vehicles. Switchable Vision Blocks (SVBs) are a key technology for "train-as-you-fight" ET. Applied research during the past five years has established the feasibility of using SVBs as a visual interface for ET (Montoya et al., 2007). However, SVBs must compete with other technologies to earn their way into tactical armored vehicles, such as the Stryker family of vehicles and the Abrams family of tanks.

This paper describes the results of additional developments to transform the basic SVB into a multi-modal viewing device that can earn its place in tactical armored vehicles. This new SVB design is a multidimensional viewing device that supports the following three functions: 1) the conventional vision block function, 2) an ET function, and 3) an enhanced operational and situational awareness function, particularly for displaying night-vision systems video products, as well as for overlaying displays of symbology.

This paper also describes efforts to adapt the technology for use in the driver station of several current force fighting vehicles, including the Abrams, the Bradley, and the Stryker. After examining the physical environment of these three classes, the Stryker Infantry Carrier Vehicle was selected as the vehicle of choice. The target application of the SVB is embedded driver training and the presentation of night-vision systems video products. The ability of the SVB to rapidly switch modes without moving parts makes it an attractive alternative to night-vision goggles, particularly in environments with disruptive changes in lighting.

ABOUT THE AUTHORS

R. Jorge Montoya is a Senior Research Electrical Engineer at RTI International[1]. Over the past five years, he has served as the Program Manager for SVB research and development (R&D) at RTI. He led the Integrated Product Team (IPT) that first developed SVB concepts, and then designed and implemented three SVB prototypes. He is currently working on a U.S. Army Small Business Innovation Research (SBIR) project that seeks to extend the results of SVB R&D into Embedded Virtual Driver Training Technologies. He earned his M.S. degree in Electrical Engineering from North Carolina State University.

Paul Weissman, who is President of Optical Resolutions, Inc., is an expert optical system designer with more than 30 years of practical experience. He was a member of the IPT that developed the original SVB prototypes and is currently leading the Army SBIR investigating the application of the SVB to Embedded Virtual Driver Training Technologies. Mr. Weissman earned his B.S. degree in Ophthalmic Dispensing from New York City Technical College.

Dr. Geoffrey Frank, who is a Principal Scientist at RTI, performed the systems analysis and training analysis for the original SVB study. He received his Ph.D. in Computer Science from the University of North Carolina at Chapel Hill.

[1] RTI International is a trade name of Research Triangle Institute.

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INTRODUCTION

Embedded Training Requirements

The provision of Embedded Training (ET) capabilities is written in the requirements documents for future manned, force fighting vehicles, as well as for upgrades to current force fighting vehicles, including the Stryker, the Abrams, the Bradley, and the Marine Expeditionary Fighting Vehicle (EFV). ET requires that vehicle crew members can train anywhere and at anytime without a dedicated training simulator and with minimal training-unique hardware. ET also requires that crews "train as they fight," using the same visual interfaces and controls for operations and for training.

Embedded Training Systems for Manned Ground Vehicles

For manned ground fighting vehicles, the primary visual interface to the outside world is the vision block (VB). In general, an ET system consists of a training software server, an intra-vehicle network, an inter-vehicle network capability, and a visual interface for the crew member. Marshall and Green (2003) identified design and integration issues associated with using ET systems in fighting vehicles. As advances in digital, networking, and sensor technologies make their ways into upgrades to existing fighting vehicles, ET systems become more feasible. Although there have been ET demonstrations on current force fighting vehicles using thermal sights as the visual interface to computer-generated training imagery, the visual interface remains a technological challenge for ET implementation. This is especially true for the drivers because of the lack of general purpose displays in and the severe space constraints of the driver stations.

Embedded 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. However, because of the physical and optical complexity of visual ET systems, implementation requires the installation of bulky displays on the outside of the vehicle to emulate the field of view of the passive VBs in a training, non-operational mode. This umbilical training requires significant setup and alignment, which are required to configure the vehicle for training. The external displays are another training-unique device that the unit has to manage logistically.

Vision Blocks

Current force fighting vehicles use VBs as a safe way for the crew to observe the outside world. VBs are solid (glass or plastic) optical devices with a wide instantaneous field of view and an even wider field of regard. Figure 1 shows a generic VB.

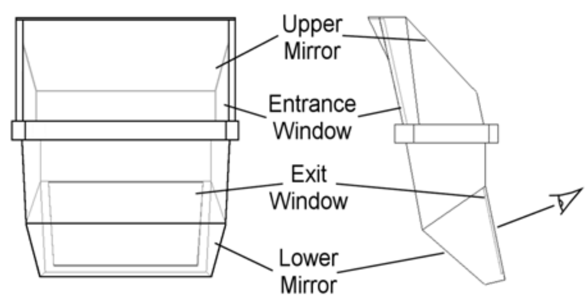

Figure 1. Generic Vision Block

Switchable Vision Blocks for Embedded Training

One way of realizing the visual interface of ET systems with minimum additional weight and size is to extend the functionality of the vehicle's VBs to serve as a display system for ET products. Such an extension is called a Switchable Vision Block (SVB), and research and development (R&D) team members RTI International and Optical Resolutions, Inc. have been conducting R&D efforts in this area over the past five years. Figure 2 shows a concept of operations for the SVB as the visualization component that switches between the Direct View Mode for operational use and the Indirect View Mode for ET.

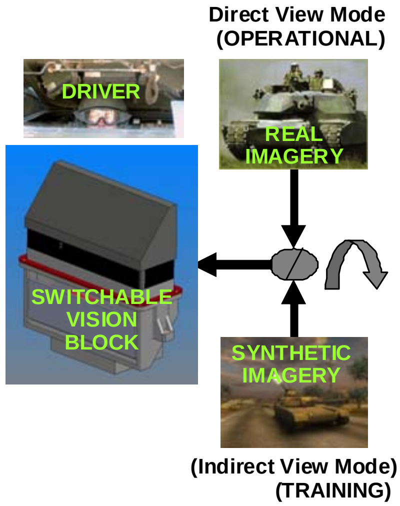

Figure 2. Concept of Operations for the SVB as a Visualization System

An SVB, which is self-contained within the vehicle, provides the vehicle's crew with a common visual interface for operation of and training in the vehicle. This allows the vehicle's crew to "train as it fights." The SVB changes from an operational device to a training device with the flick of a switch, as opposed to the extended setup and alignment times for umbilical training devices. This means that scenario-based training is available to the soldier even for short periods of time, with little advanced planning required. It also avoids the logistical issues associated with umbilical training devices because the training capabilities are built into the fighting vehicles.

During the past five years, significant R&D efforts have been dedicated to developing SVB concepts (Montoya et al., 2005, 2006). A previous Interservice/Industry Training, Simulation, and Education Conference paper (Montoya et al., 2007) described in detail the development and implementation of three SVB prototypes for evolving crew station configurations of the manned vehicles of the Future Combat Systems (FCS) Program. The main conclusions derived from this work were the following:

- The SVB must add operational value to the vehicle's crew beyond that of a visual interface to the ET system to justify its place in the vehicle and its additional costs (e.g., fiscal, weight, power, reliability).
- The SVB must have a simple View-Mode switching mechanism with minimal or no moving parts to maximize reliability and ease of maintenance.
- The SVB must be proven in a current force fighting vehicle to minimize the technology risk.

AN SVB DESIGN WITH OPERATIONAL BENEFITS

The R&D team is currently working with the U.S Army Research Development and Engineering Command Simulation and Training Technology Center (RDECOM–STTC) on a Small Business Innovation Research (SBIR) project to develop an SVB. The overall objective of this SBIR is to develop and demonstrate a prototype visual-imaging solution for low-cost, virtual, fully embedded vehicle driver training that is focused on current force fighting vehicle VBs and night-driving sources.

This SBIR effort will include several deliverables, such as an engineering prototype, a technical data package, and a Final Report that includes a commercialization plan. As part of the acceptance of the prototype, government human factors and Stryker driver Subject Matter Experts (SMEs) will evaluate the SVB with respect to usability and training effectiveness. Evaluation methodology and criteria will be developed during the later stages of Phase II of the SBIR project.

Enhanced SVB Design Goals

The SVB system currently under development includes several enhancements over previous SVB prototypes to include the following:

- A collimated (i.e., infinity focus) display system for ET that reduces eye strain and allows for extended training scenarios
- An electro-optical (static) View Mode switch that can rapidly switch between the sensors and the direct View Mode
- A presentation of the video products from the vehicle's sensors, particularly the night-vision systems
- A blended (real and synthetic) View Mode to support the overlay of situational awareness and vehicle operational data and to support the presentation of the video products from the night-vision systems.

Collimated Display for Embedded Training

One of the most notable design challenges for an SVB is the design of an optical system that will make the interface to ET human-factors friendly. That is, a display system that will support prolonged training periods with little or no eye strain and support quick eye accommodation from direct view to training view and back. Because the direct view through the VB is identical to looking out of the window at a distant scene, for effective training, it is necessary to visually present the simulated scene far away, even though the image source may be close. To accomplish this, a collimated[2] optical system is needed because it provides an image that will appear to be at an optically infinite distance from the viewer.

Sensor Video Display

After a video interface has been developed to a synthetic image source for ET, the same technology can be used as a multipurpose video display device. This device must be capable of presenting video products from a variety of sources to the driver and, eventually, to other crew members of force fighting vehicles. These video products may include image intensification, forward-looking infrared (FLIR), or millimeter wave radar (MMWR). Using the SVB as the display mechanism provides visual continuity for the driver, who is using the same visual interface for daytime driving, nighttime driving, and driving in other reduced visibility conditions, such as fog, sandstorms, or rain.

Night Vision with the SVB

The desired operational benefit is to reduce night blindness. The Army Readiness Center has documented an increase in driving accidents in Iraq and Afghanistan (Frank et al., 2007), and problems with using night-vision technology in mixed rural and urban driving have been noted in lessons learned that were reported from the field. A problem occurs when light enhancement (i.e., image intensification) technology is used in a dark environment and a significant light source, such as an oncoming vehicle's headlights, is suddenly introduced into the field of view. The sensor and the driver can be temporarily blinded for several minutes, which is extremely dangerous. The SVB offers the opportunity to use a low-light sensor in the dark but quickly switch to another sensor (or an unenhanced optical view), thereby significantly reducing night blindness.

Figure 3 shows a concept of operations for the enhanced-capability SVB, which includes an interface to on-board night-vision systems as a means of earning its way into the vehicle. In Figure 3, the enhanced capability of the SVB allows switching between different video sources, including both the ET synthetic view and sensor video, such as from a low-light sensor or a FLIR sensor. The challenges for this mode of operation are the following:

- Selecting sensor data to be presented in the multiple SVBs in a driver's compartment
- Providing a consistent point of view for the driver as he or she switches from the out-of-the-window view to various sensor views.

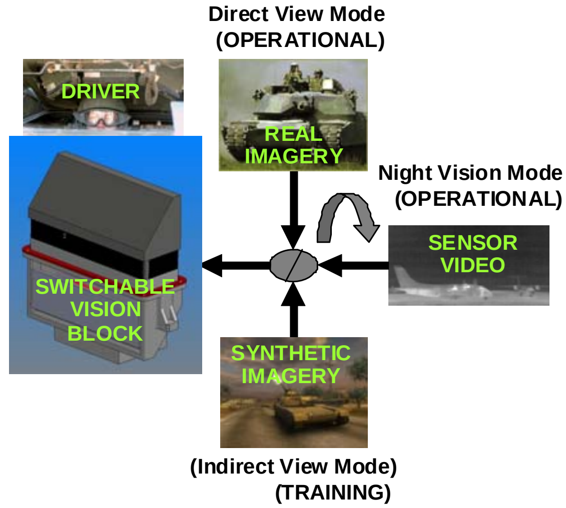

Figure 3. Concept of Operations for the Enhanced SVB Supporting Visualization of the Night Vision

Blended Mode Displays

A true blended View Mode (i.e., 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-of-the-window" view for the vehicle's crew. The current method for displaying the common operational picture is through maps and overlays on command and control systems, such as the Force XXI Battle Command Brigade and Below (FBCB2) system. Providing a visual link between the direct view of the real world and information on a map has operational value in terms of reducing the cognitive load on the driver.

DEVELOPMENT APPROACH

To achieve these enhanced SVB objectives, the R&D team explored recent developments in optical, display, projection, and View-Mode-switching technologies. The R&D team also explored manufacturing techniques that would support the integration of these technologies into a system that is capable of providing, upon demand, the Direct View Mode functionality of an existing VB, a visual interface to the driver virtual-training database, and the display of the video products from image intensification or thermal night-vision sensors.

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

Selecting a Fighting Vehicle for SVB Insertion

The R&D team considered the driver compartments and the associated VBs of the Abrams M1 tank, the Bradley M2/M3 Fighting Vehicle, and the Stryker Infantry Carrier Vehicle (ICV) as potential environments for the application of the multipurpose visual-imaging solution under development.

Discriminators for the selection of a specific driver compartment as the environment to host the SVB application were that 1) there was sufficient *space available underneath and behind* the native VBs and 2) the *additional volume* required to implement the SVB would *not occlude* any head-down display used by the driver. The R&D team examined virtual models of the driver compartments of the Abrams M1 tank and the Bradley M2/M3 Fighting Vehicle available from the Training Group at RTI and inspected the real Stryker ICV driver compartment.

The Abrams driver station is located at the center front of the tank and is equipped with a monitoring panel that shows the condition of vehicle's fluid levels, batteries, and electrical equipment. The Abrams driver compartment has three VBs.

The Bradley M2/M3 Fighting Vehicle's driver station is located on the left front side of the vehicle. As shown in Figure 4, the station is equipped with three forward periscopes plus one periscope to the left. There is also a full instrument panel directly in front of the driver. The Bradley driver's compartment presents a challenge for installing an SVB due to limited space available underneath the exit window for SVB electronics. Installing an SVB in the Bradley may prevent the driver from seeing the instrument panel.

Figure 4. Bradley Fighting Vehicle Driver's Compartment

The Stryker ICV driver station is located on the left front side of the vehicle. As shown in Figure 5, it is equipped with a control panel on the left of the driver and a Driver's Vision Enhancement (DVE) monitor in front of the driver. The Stryker ICV driver compartment provides additional space below the current VB exit window and above the DVE monitor that can be used for the SVB electronics and optics.

Figure 5. Stryker ICV Driver's Compartment

The Stryker driver station uses the M17E4 periscope, which is a solid VB. That is, the periscope is a laminate that is filled with an optical medium from the entrance window to the exit window. The entrance window is displaced from the exit window with two rhomboid-shaped folds with upper and lower fold mirrors. Between these two mirrors, embedded within the lamination, is a glass section. This arrangement provides a unity power optical device through which the driver can view the outside world.

After comparing the three environments, the Stryker ICV driver compartment was selected as the application environment, and the M17E4 VB was chosen as the basis for implementing the SVB. This decision was based on the availability of space in the Stryker driver station, which was compatible with the ongoing SVB optical designs.

Making SVB Design Decisions

To properly address the requirements of the advanced SVB and include the capability to introduce technological advances as they become available, the R&D team partitioned the development of SVB concepts into the following subsystems: optical, View Mode switching, image source, interface, and housing.

The *optical subsystem* consists of mirrors, lenses, and specialized optical components that are arranged in a way that meets the optical performance requirements of the SVB. The *View Mode switching* subsystem is a special electro-optical device that controls the light path through the SVB depending on the desired viewing state (i.e., VB, ET, or blended) for the SVB. The *image source* subsystem consists of a display that provides light for the training and blended View Modes, as well as its associated control and environmental modules. The *interface* subsystem manages the interactions between the vehicle's sources of power, video, and control signals and the SVB. It consists of video, control, and power modules. The *housing* subsystem is the element that encapsulates all other subsystems into the final SVB.

Optical Subsystem Tradeoffs

The basic function of the SVB optical subsystem is to collimate the display while minimizing chromatic and geometric distortions. In addition, the optical subsystem must preserve the optical characteristics (unity power and fields of view) of the basic VB while in the Direct View Mode. Practically, these issues translate into the following design questions:

- Where do we place the collimating mirror within the confines of the SVB?
- Where do we place the image source and how do we direct the image to the collimating element?
- What is the extent of aberrations that result from the physical arrangement of the optical elements and how can they be corrected?
- How do we switch the optical elements to accommodate the various view modes?

Several optical subsystems were designed and analyzed. Comparing the SVB concepts that emerged based on the various optical subsystems led to the selection of the SVB shown in Figure 6. This SVB has a minimum number of optical elements, it does not require a distortion corrector, and it images the largest image source. It also requires the minimum additional volume for implementation.

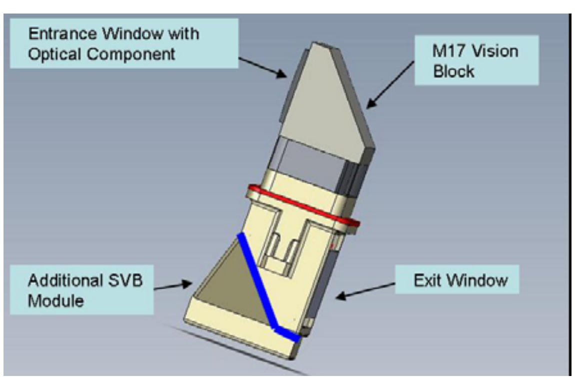

Figure 6. Optical and Physical SVB

The SVB housing will consist of a replica of the basic M17 VB used in the Stryker ICV driver compartment plus an additional module to be attached to the lower portion of the VB. The M17 form factor and the means of installation in the vehicle will be preserved and the optical elements of the recommended optical subsystem will be integrated into the block of glass (or acrylic) that constitutes the optical medium of the VB inside the housing. The additional module, which houses the image source and the SVB electronic interface subsystems, will be pinned and bolted to the M17 VB as shown conceptually in Figure 6. The blue line delineates the location of the additional module needed to extend the M17 VB into a Stryker SVB.

Electrical Fail-Safe View Mode Switching

View Mode switching is accomplished by means of a specially designed mirror whose reflectance and transmittance are adjusted electronically to the values required by the corresponding View Mode. This is accomplished while the mirror is mechanically static.

This approach makes the implementation of the SVB more reliable and ensures that if a power failure occurs, the SVB reverts to the Direct View Mode configuration, thus providing a fail-safe configuration. This approach represents a significant improvement from the collimated SVB prototype previously developed (Montoya et al., 2007) which depended on a mechanical (pneumatically actuated) View Mode switching mechanism.

Although the baseline SVB performed well during tests, the mechanical switching mechanism, along with the movement of the optical components in and out of the direct line of sight, were considered reliability and maintainability risks. These would reduce the likelihood of the SVB being incorporated into a current force fighting vehicle. The current approach switches view modes without moving parts and supports a true blended View Mode for mixing real and synthetic imagery.

Image Source Technologies

In previously reported work (Montoya et al., 2006), RTI investigated the applicability of flat-panel displays (including both liquid crystal displays [LCDs] and organic light-emitting diode [OLED] displays) and micro-projection technology to the SVB concepts. That study recommended the LCD flat-panel display as the image source for the SVB based on product maturity, range of sizes and resolution, and high commercial demand that typically foretells continued product development, higher performance, and lower cost. At that time, LCD brightness and ambient temperature sensitivity were concerns; however, in the current project, the R&D team has identified two miniature LCD panels that have the necessary characteristics (i.e., size, resolution, brightness, and contrast ratio) for the SVB application.

Vehicle System Interface Design

The M17 VB is a passive optical device that does not require electrical inputs from the vehicle. However, the SVB will require power, data, and control signals from and to the vehicle. The active elements of the SVB include the electronically controlled mirror (to switch between view modes) and the LCD panel with its associated modules (i.e., control board and heater). The active elements will derive their power from the vehicle's power source. The LCD panel will receive its video from the vehicle's ET computer, and/or the night-vision systems, and/or sensors, and/or other video sources. To power and control the active components of the SVB, the R&D team has devised an electronics interface as shown conceptually in Figure 7.

The interface contains video, control, and power modules. As shown in Figure 7, the video module receives its input from the vehicle's computer and/or any other source of video in the vehicle and drives the LCD. A key function of the video module is scene management because this ensures that the correct segment of the overall image is routed to the appropriate SVB in a multiple SVB application (as shown by the orange arrow in Figure 7). The control module receives commands for the adjustment of display characteristics and sends functional requests and SVB status information back to the vehicle computer via a USB connection as shown in Figure 7. The power module receives power from the vehicle's power source and converts it into the various voltages that are necessary to power the LCD, the LCD heating element, and the electrically switched optical elements.

In addition, the interface may be required to handle inputs from the vehicle's night-vision systems and other potential sources of video. For the SBIR application, the source for night-vision video is the Stryker's DVE AN/VAS-5 that outputs its video to a 10.4-inch flat-panel display with an 800- x 600-pixel active matrix LCD (DRS Technologies, 2008). If this resolution matches that of the LCD display, then the DVE video may be fed directly into the LCD through the interface display module. Otherwise, the DVE video must be routed through the vehicle's ET computer where the video would be properly scaled to match the SVB LCD's characteristics and compensated for the effects of the optical subsystem. These alternatives also apply to other video sources.

Proposed Integration into Stryker

The SVB will be implemented in two parts: a VB that replicates the form factor of the original M17 VB and an additional module that houses the display subsystem

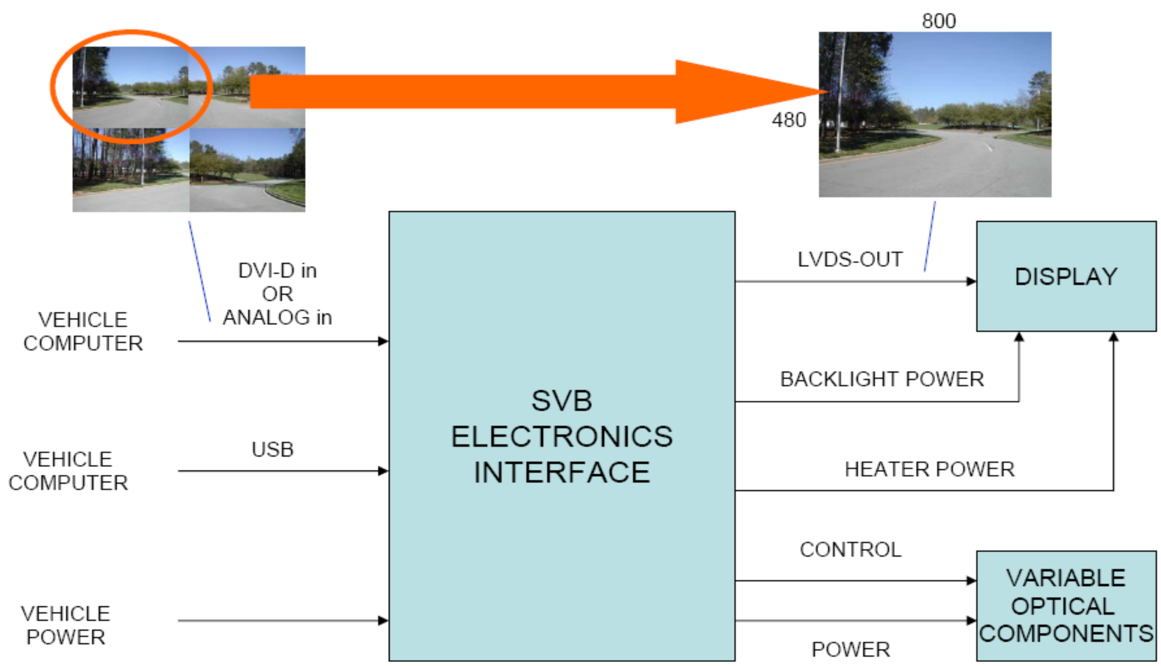

Figure 7. Conceptual Block Diagram of SVB to Vehicle Interface

and the electronics interface between the SVB and the vehicle's computer and power. The SVB will be installable in a manner similar to the current installation method (i.e., clamping into the hole allocated for it in the vehicle's armor). The additional module will be pinned and bolted to the bottom of the VB. A flexible cable will connect the vehicle's computer and power sources to the electronic interface of each of the three SVBs. The cable will travel along the cable shown in the hatch of the driver compartment and will be designed with enough flexibility and slack to withstand the opening of the hatch. This arrangement is shown conceptually in Figure 8. During Phase II of this SBIR project, the R&D team will investigate the feasibility and applicability of a wireless interface between the SVB and vehicle's sources of power, video, or both.

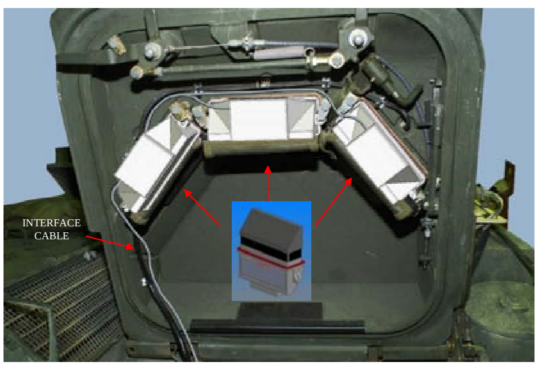

Figure 8. Design for Integration of SVBs into the Stryker ICV Driver Compartment

BLENDED MODE CAPABILITIES

The optical and electrical design of the SVB described in this paper allows the overlay of information from a variety of sources on the out-of-the-window Direct View Mode. These sources include the following:

- Vehicle's performance and status data (e.g., speed, position, and engine data)
- Communications status information, such as the number of messages queued at different priority levels
- Unit status information, including readiness and supply levels
- Georeferenced tactical data from command and control systems, such as FBCB2.

This concept is illustrated in Figure 9. The R&D team is studying the benefits of possible combinations of these sources of information into either an augmented reality (synthetic data over real) view or an augmented virtuality (sensed real data over synthetic) view. These combinations of expanded SVB capabilities will help earn the SVB's way into the fighting vehicle fleet. Additional systems engineering work on the vehicle's electronics is required to provide this full range of capabilities.

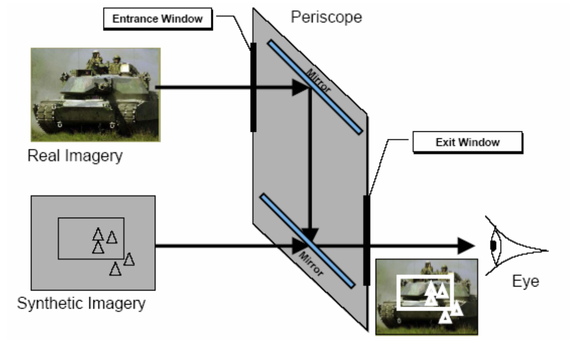

Figure 9. Implementation Concept for Blended Mode Operation

CONCLUSIONS

The SVB described in this paper is a key technology for enabling ET in armored combat vehicles. In its Training Mode configuration, the SVB also serves as a multipurpose display for any conformal source of video from within the vehicle. Furthermore, and perhaps more significantly, the SVB blended View Mode provides a display environment for information that can significantly enhance situational awareness and operational effectiveness. In particular, the SVB support for the presentation of the night-vision systems video makes it an attractive alternative to using night-vision goggles, especially in environments with disruptive changes in lighting.

It is possible to extend the basic SVB concept to provide operational capabilities that will earn a role on the operational vehicle. This paper describes SVB's capabilities as a multipurpose, adaptable, video display device to enhance the situational awareness of the driver, as well as support ET. In particular, the ability of the SVB to rapidly switch between the optical view and multiple sensors, including those for night vision, can reduce the risk of night blindness.

After a limited study of the driver compartment of the Abrams, Bradley, and Stryker was conducted, the Stryker ICV driver compartment was selected as the target environment into which to implement the SVB and demonstrate its applications. This SVB design can be adapted to provide similar capabilities to other crew members of the Stryker ICV. As part of the acceptance of the prototype, government human factors and Stryker driver SMEs will conduct an evaluation of the SVB with respect to usability and training effectiveness. Evaluation methodology and criteria will be developed during the later stages of Phase II of this SBIR project.

The R&D team followed a modular approach to develop the SVB concepts. This methodology should be easily applied to other VBs and other application environments (e.g., commander's stations) in current and planned fighting vehicles of the U.S. Armed Forces.

This SVB achieves its performance specifications (collimation and multiple viewing modes) with a minimum number of additional optical elements. In addition, this SVB switches between view modes without moving parts and it images a large image source while requiring the smallest incremental volume to accommodate the additional components due to the compactness of the concept. Thus, this SVB supports the driver's direct view out of the Stryker, driver ET, night-vision images, and a blended View Mode for overlay of information on the real-world image. This same SVB provides the basis for implementing an advanced SVB that has the capability of presenting video products from a variety of operational and tactical sources.

ACKNOWLEDGMENTS

The R&D team wants to thank Dr. Michael Lamvik of RTI International for his many contributions to the development of the SVB concepts and in particular for his work in developing computer-aided design (CAD) models of the various optical subsystem configurations. The R&D team also wants to thank Mr. Henry Marshall, an RDECOM–STTC Science and Technology Manager, at the inception of the program, and Ms. Bonnie Eifert, the RDECOM–STTC Contracting Officer Representative for the program, for their technical guidance and help in obtaining information about the various fighting vehicles that were considered during the study.

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