Augmented Reality:
A New Tool to Increase Safety in Maritime Navigation

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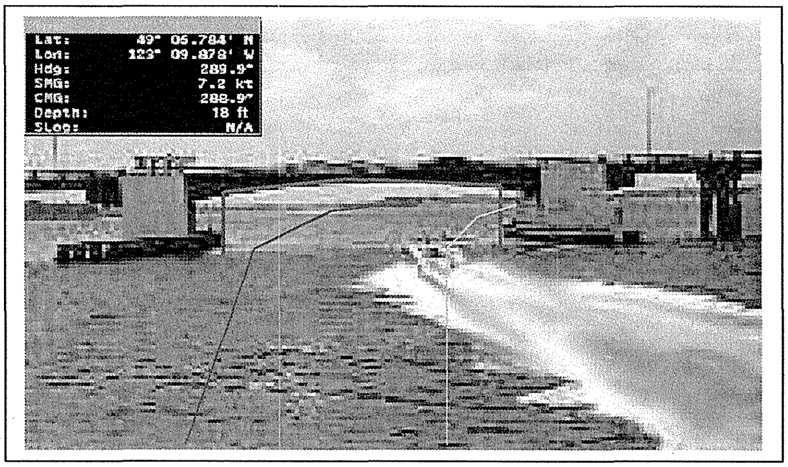
ABSTRACT

Augmented Reality (AR) is a visualization technique in which computer generated graphics are superimposed over one's view of the real world. This paper reports results of recent studies in which navigation data was superimposed into a ship pilot's field of view, including a system recently installed on the US military s High Speed Catamaran Joint Venture (HSV-X1). The system displays both navigational and tactical data on a bridge mounted display. The AR capability is achieved by merging a camera input with computer generated data. The system has demonstrated an unprecedented ability to enhance operator situational awareness, increase safety, and aid in ship navigation. The system's intuitively understood presentation of navigational data provides a clear benefit in low visibility and nighttime conditions. Ongoing efforts include transition of AR capability to the amphibious environment. This system will be installed on an LCAC (Air Cushioned Landing Craft) and an AAV (Amphibious Assault Vehicle).

1. Introduction

Augmented Reality (AR) is an emerging technology in which computer generated imagery is superimposed over a real-world image. The adjoining figure (which is notional and was developed by the USCG using Powerpoint) shows the initial goal of this effort, which was to provide channel markings electronically. During 2001 a system was developed that provided this capability. The system was implemented using a wearable computer, head mount display, plus DGPS and orientation sensors.



Subsequent efforts focused on examining the impact that Augmented Reality (AR) has on an operator's cognitive capabilities under high workload conditions. A system was created that augmented a boat operator s view with navigational information, and also introduced secondary tasks to enable measurement of the operator's residual attention capacity when performing the primary task of navigation under various conditions. We hypothesized that AR may be of minor consequence under low stress situations, but might significantly augment operator cognitive abilities during a high stress, high workload situation.

Finally, the system was upgraded for installation upon the Joint Venture (HSV-X1), a 96 meter high speed catamaran being evaluated by the Navy and Army under a two year lease. This generation system is commonly known as the ARVCOP system (Augmented Reality Visualization of the Common Operational Picture). The system was installed upon the Joint Venture during November, and tested at the Naval Warfare Development Center s Limited Operational Experiment (LOE) #2, held off Panama City, Florida during late November and early December 2001. The system was modified to enable importation of data from the Mine Environment Data Acquisition Library (MEDAL), which is part of the Navy s GCCS-M system (Global Command and Control System — Maritime).

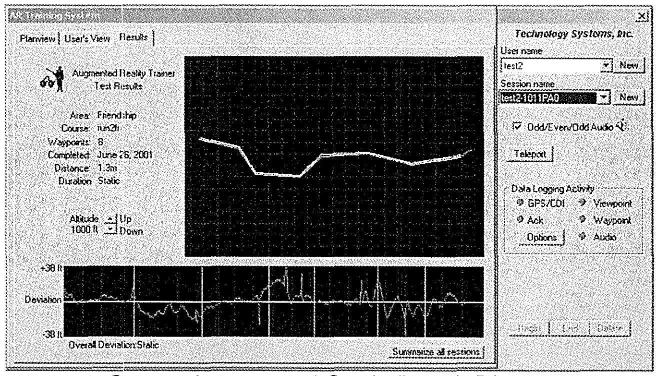
2. Cognitive Studies

2.1 Cognitive Study Overview

Initial test results indicated a 342% increase in operator performance using AR. Further test results demonstrated that operator residual cognitive capacity significantly benefited from the introduction of AR for what we term Display Adept subjects, but not the Display Na ve subjects. This implies that AR has strong potential, but that display format and user training may be a major variable in AR effectiveness. Significant human factors oriented data relating to the fielding of AR systems were also collected and are being incorporated into future designs. The implications of the initial effort were that: AR potential to enhance cognitive performance is demonstrated, the side-load task used to measure residual cognitive capacity and NASA TLX workload assessment methodologies were robust and valid, and that display form factor and content are a major variables in AR cognitive impact.

2.2 Cognitive Study Details

The AR prototype was evaluated using a control condition (CON) of no AR display, plus three different display modes: course deviation indicator (CDI) display, plan-view display (PVD), and forward pathway display (FPD). Research trials consisted of navigating a pre-set course, which had seven legs totaling 1.2 miles. Course changes varied from 30 to 60 degrees and overall course was symmetrical (providing the same course regardless of the run s direction).



Course Layout and Study Result Display

The research design was a two factor repeated measures design (4 treatments by 2 workload conditions by subjects) with the following dependent variables: perpendicular error from desired track centerline taken at 1 Hz, maximum excursion from centerline per leg of the course, time to complete the course, and subjective workload evaluation using the NASA TLX (task load index) instrument. Additionally, under the high workload condition the number of correct odd-even-odd sequences detected and the number of false alarms was recorded.

Our intent was to capture repeatable measures of human performance while navigating using varying display methodologies. We implemented this by introducing a secondary side load task that provides an indication of the operator s residual cognitive capacity. Since the AR capability is fundamentally a visual task, we did not want the secondary task to directly interfere with the information processing channel of the primary task (i.e. the secondary task should not be visual). Koonce, Gold and Moroze (1986) utilized an aural secondary task of digit monitoring to assess pilots abilities with three different types of visual flight displays (one traditional head-down display and two different head-up displays) with great success. Although the pilots performed adequately with the display types under normal workload conditions, using the aural secondary task they demonstrated a significant difference in performance between the two different types of head-up displays. We developed a similar capability to support future assessment of different Augmented Reality (AR) displays, along with traditional navigational displays (e.g. heads down equipment) in navigating a boat over a standardized path.

The NASA TLX (Task Load Index) ascertains the operator s subjective estimate of workload on six scales. The scales are:

The mental demand of the activity,
The physical activity required,
The degree of time pressure or temporal demand,
How hard he had to work (mentally and physically) to accomplish the task,
How satisfied the operator was with his performance, and
The frustration level experienced.

Thus, beyond the primary objective measures of performance, we obtain a measure of the subjective workload experienced while using the system.

Subjects —the minimum research design needed a minimum of four experienced boat operators and four novices to evaluate the display systems. Additional participants were desirable, however weather and scheduling issues resulted in only five persons completing a full set of trials using all four navigational systems. The five subjects were all male and ranged in age from early the 20s to mid 60s. Each operator was introduced to the course to be navigated, briefed on the AR system and the types of displays to be used, and introduced to the workload task.

Equipment - The AR system used was based upon the VIA II wearable computer system, enhanced with D-GPS, an orientation sensor, and an HMD, plus supporting electronics. The eyewear used was the Sony RA-100, coupled to an orientation sensor manufactured by Precision Navigation. This subsystem is accurate to 0.5 degrees, with a resolution of 0.1 degrees. It provides tilt information (0.2 degree accuracy) from an electrolytic fluid based tilt sensor. The Differential GPS selected is that used by the majority of the commercial pilots, manufactured by Starlink Corporation. The unit includes an integrated GPS and differential antenna system, and provides an industry standard NMEA 183 output.

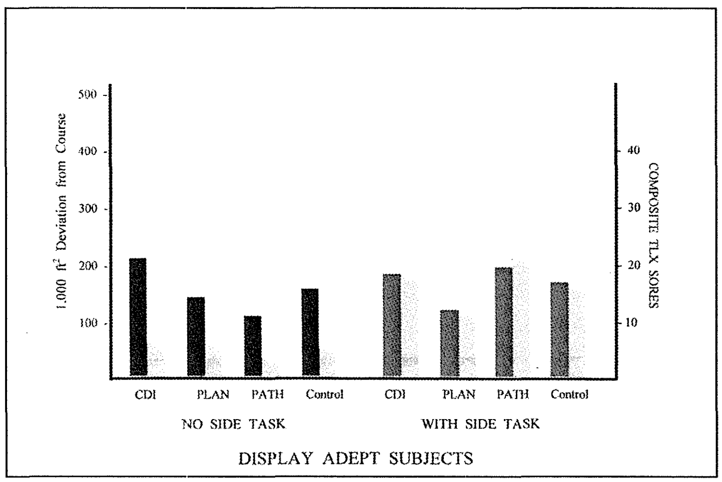
A variety of test platforms provided by the Maine Maritime Academy were used in the cognitive studies evaluation of the AR system, along with 40-foot cabin-class diesel powered boat.

2.3 Cognitive Study Results

Due to the small sample size (N=5), plus very large individual differences in performance with the different display types, parametric statistical tests could not detect any significant differences in the display types in terms of RMS error scores. However, there was an increase in error scores between the performance with no secondary task and that when the secondary task was present, and as expected, there was a significant difference between subjects.

Looking at the subjects ability to handle the secondary task while performing the primary task of navigating with the four different display types, we noted that some subjects seemed to handle the secondary task well while others could detect only a small proportion of the target digit sequences. Those who detected a large number of the target sequences in the secondary task had had prior experience with aircraft flight displays and some even had experience in using head mounted displays. We subsequently called those subjects display adept subjects. Those who had difficulty in detecting the digit sequences while performing the primary task had no prior experience in the use of wearable visual displays or with airplane navigational course displays. We called those subjects display na ve subjects. The same pattern of performance of the two groups noted under the workload condition was also clearly present under the no workload condition. That is, there were no significant differences in performance with the four displays for the display adept subjects, and the display na ve subjects performed much worse using the CDI or the Pathway displays than with the more traditional Plan-view or Control displays.

The display na ve subjects were nearly fully task-loaded with the primary task and did not have much residual capacity to attend to the secondary task, detecting only 25% of the target digit sequences. The display adept subjects were able to detect about 65% of the target digit sequences.

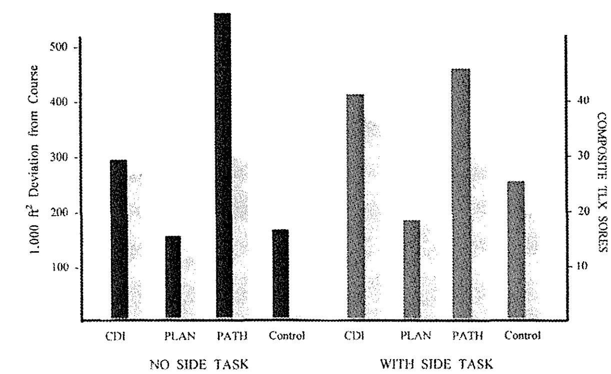


DISPLAY ADEPT SUBJECTS

Separating the subjects into display adept and display na ve , there was no significant difference between the performance of the display adept subjects under no workload and workload conditions, and no significant difference between the display types under either workload condition.

The display adept subjects performance under the no workload condition exhibited the trend noted earlier from the preliminary study; that is, the CDI was the most difficult and the pathway easiest for the subjects.

The display na ve subjects, on the other hand, performed worst using the CDI and the Pathway displays than when using the Plan-view or the Control displays. On the trials where the secondary workload task was present, these subjects performed best with the Plan-view display, and the CDI and Pathway performance had the most error.



DISPLAY NAIVE SUBJECTS

The subjects reported workload seemed to track rather closely with the actual vehicle performance. Over all of the subjects, the composite NASA Task Load Index (TLX) scores showed an increase in perceived workload when the secondary task was present. In terms of TLX scores, the display adept subjects reported much less overall workload than the display na ve subjects under no workload and workload conditions.

Combining all of the subjects, there was no significant difference in composite TLX scores between the Plan-view and the Control displays and no difference between the composite TLX scores on the CDI and Pathway displays.

2.4 Discussion

2.4.1 Environmental factors

Due to costs and the variability of environmental conditions, real-world data collection was very constrained. Besides heavy pitching seas and rain and fog, the availability of an appropriate vessel to conduct the trials, the availability of subjects for the length of time required, and numerous equipment adjustments that had to be made all adversely affected the costs and length of time to conduct the study. For example, one subject s trials were conducted with winds of 25-30 knots and a 3 knot current, and in the middle of one of the runs the wind blew the GPS antenna off of the top of the cabin into the water! The environmental conditions tended to contribute such great.variability to the performance that statistical differences in the display types would be most difficult to obtain. With the variability experienced in this study, a power analysis suggests that a sample size of near one hundred subjects would be necessary to detect any statistically significant differences between the displays.

An alternative is to perform studies in a controlled environment, such as a simulator. However, this would eliminate the benefit of operating in a real world setting, which would produce practical solutions viable in the real world environment.

2.4.2 HMD Issues

The limited display brightness of the HMD was unable to generate luminance visible in the ambient light of a sunny day. This resulted in difficulty seeing the AR image, which was even further exacerbated when turning toward or away from the light source (e.g. into or away from the sun).

The HMD used in this study had a 22 degree field of view. In practice, this was not sufficient to support maritime operations without the addition of various display cueing mechanisms that negatively impacted the objective of the effort, which was to provide an intuitively understood visual aid.

The optical focal length of the image presented in an AR display must be the same as the focal distance of the real world being viewed, or the images will not merge. The commercially affordable displays available provide a focal length of 15-20 feet, which presented another limitation.

2.4.3 Training and Display Format

The principal researcher noted that some people have trouble getting used to the path display while others have no trouble at all. It was felt that some would need an entire day of practice with the displays before being able to perform reasonably well with them, but the project did not have the time or the resources to provide such familiarization training. The difficulty in transitioning to new types of displays experienced by some of the subjects, but not others, is not unique. Such has been experienced in aviation, however, extensive training is generally provided to the pilots to ensure their smooth transition to the new displays.

Some subjects were enthusiastic about the new, different displays, and saw all sorts of possibilities for them. They were eager to try out the AR system, regardless of the display type. But, other subjects were quite confused and seemed to not feel comfortable trying to navigate the boat with the head-mounted displays, especially the CDI and Pathway displays. After a trial using the pathway display, one subject asked So Where am I in this display? Even after his trials, he seemed to not understanding the CDI or Pathway displays at all. The Control and Plan-view displays were more similar to what these subjects were accustomed to using and thus were more acceptable and provided considerably better performance.

A key question that has not been explored in any detail is the degree to which display content should range along a continuum of concrete to abstract. Concrete information is representational of how the information is perceived in the real world, while abstract information uses symbols to represent objects or characteristics of objects or variables in the real world. The symbols used in abstract presentations do not have any inherent meaning relevant to that which it represents. Thus, the user must learn just what the abstract symbol means or represents. In processing abstract information, the user must utilize higher level resources to lend information (meaning) to the symbols before he can understand them. After training and extensive practice, many operators learn to respond to the abstract presentation of information rather automatically (automatic processing). But, when under high workload or the influence of other stressors, the automaticity of responding to the abstract symbols often breaks down and the user is faced with the task of engaging higher-level processors to interpret the meaning of the symbols used in the display.

2.4.4 Use of Secondary Task

The side task used the aural channel to minimize conflict with the visual-perceptual-motor activities of the primary task. Because of the potential hazards of channel buoys and markers, lobster pot buoys, random debris in the water, and other boats moving or stationary in the real world , the boat s helmsman cannot simply ignore the primary task in order to accomplish the side task. This secondary task (side task) was most helpful in classifying subjects as display adept or display na ve based upon their residual attention capacity to devote to the secondary task while performing the primary task of navigating the course.

2.5 Cognitive Study Summary

Overall, the study demonstrated the effectiveness of the research methodology, specifically the use of side load tasking and TLX measurements. The major shortfall of the study design was the low number of subjects for which data was collected.

The use of HMDs for AR is not warranted at this time, the technical shortcomings of current designs preclude real world use. We are currently exploring different form factors for merged image presentation.

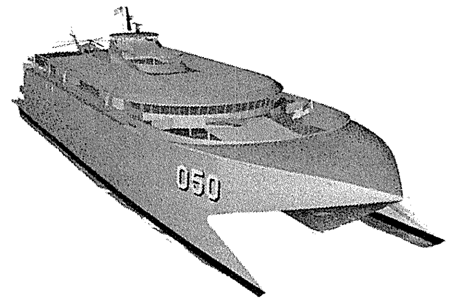
The test results indicate that a key element in AR effectiveness is the user s familiarity with computer driven display systems. Users that are adept at using these types of displays clearly benefit from AR, which is demonstrated by their higher residual cognitive capabilities while under stress. Users not adept at using this type of display were clearly cognitively saturated regardless of display format.

Future AR designs should pay attention to form factor and display content. User training is an area that needs to be explored, and which parallels other AR implementations such as those used in aircraft HUDs. Finally, environmental factors play a major role in the ability to collect study data, and need to be factored into future study designs.

2.6 Augmented Reality Visualization of the Common Operational Picture (ARVCOP)

2.6.1 ARVCOP Overview

Following this effort effort, The Naval Warfare Development Center funded creation of a next generation system to support Mine Countermeasure (MCM) operations. This system and work has been titled Augmented Reality Visualization of the Common Operational Picture (ARVCOP).



Joint Venture (HSV-X1)

The ARVCOP system was developed for installation upon the Joint Venture (HSV-X1), a 96 meter high speed catamaran being evaluated by the Navy and Army under a two year lease. The ARVCOP system uses a fixed camera and display monitor to present the augmented reality image. This has resolved many of the problems associated with the original prototype.

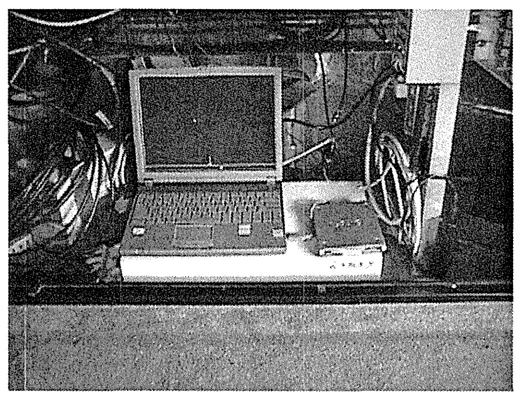
The system was installed upon the Joint Venture during November, and tested at NWDC s Limited Operational Experiment (LOE) #2, held off Panama City, Florida during late November and early December 2001. The system was modified to enable importation of data from the Mine Environment Data Acquisition Library (MEDAL), which is part of the Navy s GCCS-M system (Global Command and Control System — Maritime).


Bridge Mounted ARVCOP Display

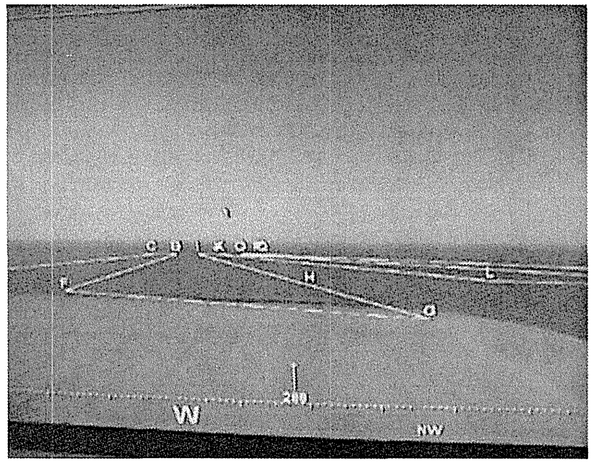
2.6.1 ARVCOP Results

The following summarizes experiment results and is copied directly from the Navy s Quicklook Report summarizing LOE#2 results.

ARVCOP provided a visual overlay of navigation aids during the transit from port to sea. Correlation of real world navaids to ARVCOP generated counterparts was observed to be less than 50 yards. The ARVCOP display was viable during daytime, with various sun angles. Display clarity was adequate, but could be improved if a fully digital augmentation process were used. D-GPS capabliity performed as expected, however the digital gyro interface was occasionally down due to an electro-mechanical failure (>95% uptime). The current design has eliminated all image jitter issues observed in earlier trials. Icons and text provided in the ARVCOP image became cluttered at far distances. Some method for determining depth perception of the images is recommended. Higher camera position (such as on top of the bridge), camera tilt angles and/or filters to manage visual clutter are possible alternatives. Transfer of data from medal (via floppy disk) was achieved, but needs to be improved to support timely operations. The system provides a 90 degree forward looking field of view, and it is desireable that this be expanded to 360 degrees to enable ARVCOP visualization of AUV, EOD, and similar operations supported from the ship bridge. It is recommended that the camera be mounted centerline on top of the bridge. The bow of the vessel must be in the forward field of view, and the stern in the after field of view. Use of a high resolution digital camera will allow the use of a wide angle lens without their typical warped image. The display should be mounted center line into the forward overhead panel for the forward view and on the aft table top for the aft view. ARVCOP provided visualization of the BPAUV route, including the end waypoint used for BPAUV retrieval. A night palette is required to support operations in low light. Night runs were conducted at 40 knots along a q-route to support drop of 4 BXP sensors. ARVCOP provided a clear visualization of the q-route (both centerlane and boundaries), along with a circular indication of each BXP drop point. All data was imported from MEDAL. ARVCOP accuracy was at least equivalent to the other bridge systems and provided a very intuitive

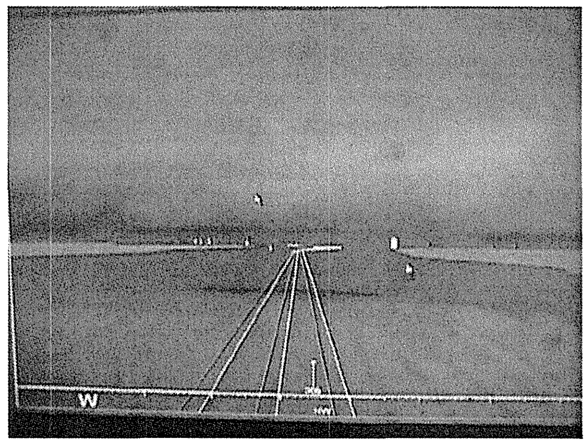

ARVCOP Electronics

indication of relative lane position during operations. The next morning ARVCOP supported VEMS tests onboard Joint Venture, and provided visualization of the transit route along with the actual location of the individual VEMS as reported via medal. Position accuracy correlated with both the bridge systems and the additional D-GPS navigation system brought on board by VEMS test personnel. MEDAL data was transferred via disc to the ARVCOP computer. It is recommended that a network interface be developed to receive MEDAL data real-time.



ARVCOP Image of BPAUV route

During late January ARVCOP was used in an exercise held of Morehead City, NC. The system was evaluated as an Aid to Navigation and displayed the channel boundares for the harbor entrance with high accuracy. Included in the display were electronic buoys, channel markings, and land masses.



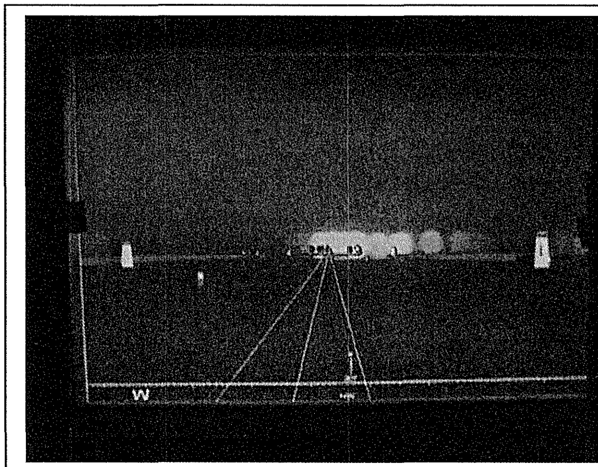
Entrance to Morehead City, NC

The system was also used in night approach to both Morehead City,NC and Little Creek, VA. Its ability to clearly define the channel location against the backdrop of shore lights was highly effective in increasing operational safety.

Finally, the system was used in low visibility and provided an effective navigational image while channel markers and the shoreline were obscured.

2.6.3 ARVCOP Summary

This generation of AR device has resolved the shortcomings of previous prototypes by incorporating a fixed mount camera, electronic image integration, stabilized orientation sensing, and a traditional display monitor to achieve functionality that has been demonstrated to be effective and easily used in the ship bridge environment. The ARVCOP capability has been demonstrated to be effective in a range of applications including mine countermeasures and ship navigation at night and during periods of low visibility. Numerous concepts for additional system enhancements have been identified.



ARVCOP use at night

2.7 Next Steps

The ARVCOP system has been identified by the ONR EDSS (Expeditionary Decision Support System) as a system worthy of additional R&D. Funding is anticipated that will support the EDSS effort by providing prototype Augmented Reality (AR) capabilities upon LCACs and AAVs. Included is development of a fully digital AR system (including EDSS compatibility), creation of LCAC and AAV specific variants, support for testing and demonstrations, and delivery of additional systems for multi-vehicle experimentation. The objectives of this effort are:

To create a fully digital ARVCOP capability

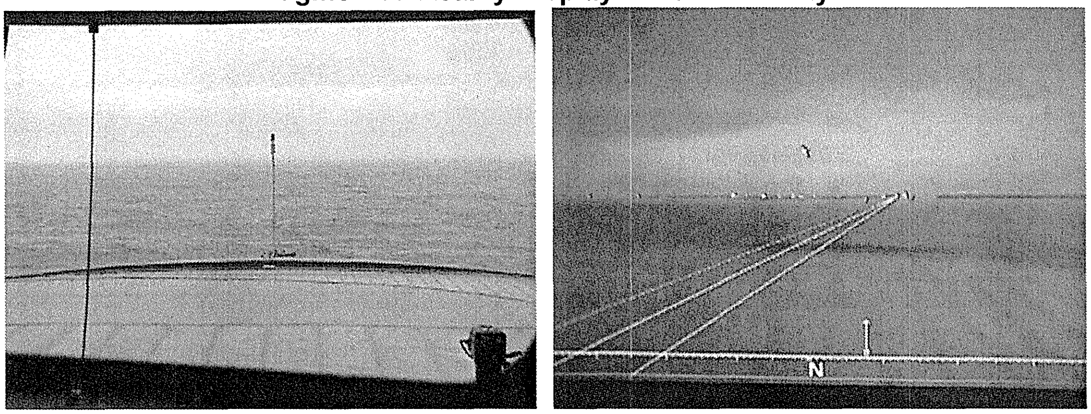
To install ARVCOP on an LCAC

To install ARVCOP on an AAV

To experiment with ARVCOP as a visualization device for EDSS data

To gain real-world experience with ARVCOP through testing during amphibious warfare at-sea training operations.

Augmented Reality Display in Low Visibility



(Real World) **(AR Enhanced)**

3.0 Summary

The digital ARVCOP capability represents a significant next step in the maturation of this technology. By creating a fully digital system, a system with sufficient image resolution and flexibility will be developed that will be capable of meeting the challenges of the amphibious environment.