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Technology Challenges for Military and Avionics Displays

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The defense display science and technology (S&T) program must address problems facing warfighters that the commercial world will not. These problems require the creation of revolutionary display materials, devices, and visual system technologies. Breakthroughs needed in display technology for defense and security personnel may be organized into technical challenge areas including: ultraresolution, flexible, wearable, true 3-D, near-eye and intelligent. These challenges and the results of a Department of Defense (DoD) Special Technology Area Review on Displays are reviewed.

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3-1: Invited Paper: Technology Challenges for Military and Avionics Displays*

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Abstract: *The defense display science and technology (S&T) program must address problems facing warfighters that the commercial world will not. These problems require the creation of revolutionary display materials, devices, and visual system technologies. Breakthroughs needed in display technology for defense and security personnel may be organized into technical challenge areas including: ultraresolution, flexible, wearable, true 3-D, near-eye, and intelligent. These challenges and the results of a Department of Defense (DoD) Special Technology Area Review on Displays are reviewed.*

Keywords: technology challenges; ultraresolution; true 3-D; wearable; intelligent; defense; avionics; displays

Introduction

Prior to 1989 defense display research was led by the services. During the 13-year period from 1989 through 2001 the DoD strategy for displays was driven by the $1B DARPA High Definition Systems program. DARPA has since pointedly avoided displays. In 2002 displays became once again a service-led investment area. External and internal reviews were conducted to identify areas of interest to services for the new service-led era.

Special Technology Area Review on Displays

A special review for defense display science and technology (S&T) was undertaken from 2002-2004 by the DoD Advisory Group on Electron Devices (AGED), a formal industry-government panel chartered by the Under Secretary of Defense for Acquisition, Technology and Logistics, that reports to the Director for Defense Research & Engineering. The outcome of the DoD AGED STAR on Displays was a detailed report approved for public release by the Office of the Secretary of Defense in June 2004.[1] Attendees and summaries of the 28 S&T topics considered are included in this 120-page report. The STAR report contains AGED's 18 findings and four recommendations to the services regarding access, planning, investment, and transition. These AGED recommendations are presented in full in Figure 1.

Reliance Analysis of DoD Displays S&T Posture

Reliance is a permanent S&T coordination process amongst the services and defense agencies. An internal review of the funded defense displays programs was examined by a team of experts from the Air Force, Army, and Naval Research Labs (AFRL, ARL, NRL) under the DoD Reliance Technology Panel on Electron Devices (TPED). Displays comprise a Sub-Sub-Area under the Electro-Optics Area of TPED, with the chair rotating amongst the services. The Displays reliance panel, chaired by AFRL, established a structure with which to analyze all DoD displays programs based on 7 categories: direct-view; virtual-image; true-3D; novel; materials; basic research; and human factors. These categories are defined and illustrated with application examples in Table 1. The team determined that, in 2002, the service planned investments in display S&T for the period FY2002-FY2006 averaged about $21M per year, comprising about $5M for direct-view, $8M for virtual-view, $1M for true-3D, $1M for novel, $1M for materials & basic research; and $5M for human factors. In addition, Congressional marks added an average of $25M per year for FY2002-FY2004, of which $8M per year was for flexible.

Strategy and Vision

The defense displays S&T strategy continues to have three components: (a) leverage the commercial display market to the maximum extent possible; (b) continually assess the display needs of currently deployed defense capabilities; and (c) envision and invest in display requirements of future systems. The DoD vision is illustrated in Figure 2.

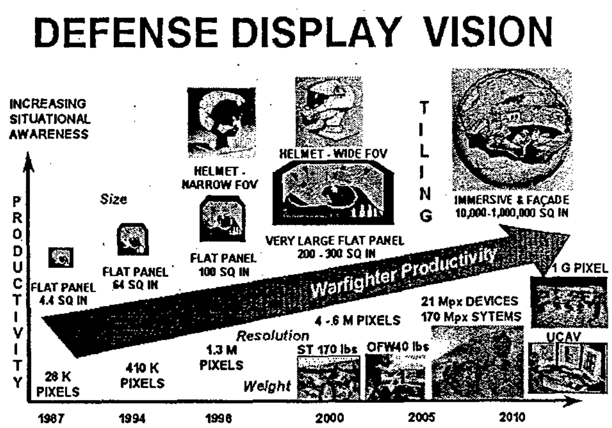

Figure 2. Display S&T fuels warfighter productivity.

* To be published in Proceedings of Society for Information Display (SID) Americas Display Engineering and Applications Conference (SID, San Jose CA, 2005), paper 3-1; and to be presented at ADEAC2005 in Portland OR, 25-27 October 2005.

ADVISORY GROUP RECOMMENDATIONS

Access

DoD should take steps to mitigate the risk of its current, near-absolute reliance on off-shore sources of commercial displays and thin-film-transistor (TFT) active matrix backplane fabrication facilities. The U.S. should encourage off-shore manufacturers to establish domestic TFT LCD fabs. Supplier relationships, especially for avionics-grade and combat systems displays, should be carefully monitored to provide early awareness of potential disruptions. International projects and links between the DoD S&T community and off-shore display research institutions should be strengthened.

Planning

DoD should establish a more rigorous mechanism to manage and coordinate available investments in displays—both planned and added—to optimize payoff to the warfighter. Such mechanism as is chosen would cause the maintenance and communication of defense-wide displays databases and roadmaps, the analysis and assessment of on-going programs, and the formulation and advocacy of recommendations.

Investment and Payoff

DoD should invest in areas where military advantage is foreseen and government investment is timely. Display technology opportunities having defense-unique payoffs include thrusts in higher-resolution, true 3D, flexible, miniature, and intelligent (processor in display, efficient use of power, bandwidth). DoD should find innovative ways to close the information gap among warfighters that leverage the dynamic commercial market and academia to the maximum extent possible. DoD should have a coordinated Tri-Service display level of research funding comparable to that previously given to DARPA—a minimum of $100 M/year is recommended.

Specific investment opportunities include $150M to create 25 megapixel display technology, $50M to create 300 Mpx visualization systems, $50M to create sparse true-3D devices, $60M to create miniature displays for helmet systems; $75M for wearable displays for global warriors, and $100M to create standard definition roll-up flexible displays (spread over 4-5 years each).

Transition

The services should fund engineering development and manufacturing technology to rapidly leverage commercial displays and to transition DoD display technology into warfighter configurations and platforms. The warfighter must not be technologically behind the kid playing video games. A minimum funding level of $25M per year is suggested.

Figure 1. AGED Recommendations to DoD in the 2004 Displays STAR Report.

Table 1. Definitions of Categories and Applications for Defense Display Science and Technology Programs

Category	Definitions, Comments, Examples	
Direct 2-D	*Real Images:*	*Physical Image Location Coincident with Perceived Image Location* *User Can Usually Touch Screen on Which Eye Focuses* *Viewable Simultaneously by Multiple Persons* *Glance-able*
	Cockpits	Aircraft, Land and Sea Combat Vehicles Often Require Full Sunlight Readability & Night Vision Compatibility
	Wearable	Includes Wrist-Mounted, Hand-Held & Body-Worn Systems Excludes Virtual Image Systems Often Require Full Sunlight Readability & Night Vision Compatibility
	Consoles	Air, Land, Sea, Space Vehicles
	Workstations	Mobile Platforms, Transportable Centers, and Fixed Facilities
	Simulators	Real World and/or Synthetic Visual Environment for Training, Rehearsal
	C2 Centers	Jumbo Wall-Filling Displays Plus Consoles, Workstations, Wearables
Virtual 2-D	*Virtual Images:*	*Physical Image Location not Coincident with Perceived Location* *User Can Not Touch Screen; Nothing at Perceived Screen Position* *Viewable by Just One Person; High User Resistance, Training & Cost* *Optics Generate Magnified Virtual Image from Miniature Real Imager* *Near-eye Usage Paradigm; Includes NVGs, Binoculars, Telescopes*
	Helmet/Head	Special Training Required for Safe and Effective Use
	Sights	Viewable by Only One Person; Restricts Field-of-View at the Head/Eye.
	Head Up	Mounted in Aircraft as a See-Through Display in Front of Head Position
	Technology Components Limiting Acceptance: Microdisplays, Optics, Human Factors	
True 3-D	*Depth Perception via Ocular Disparity; Look-Around via Head Motion* *Approaches: Multiplexed 2-D (Direct or Virtual); Volumetric (Real); Holographic (Virtual)* C2 Centers, Training, Binocular HMDs, Binocular NVGs, Handheld	
Novel Ideas	*New Concepts: Out-of-the-box Approaches to Display Technology and Applications* Examples: Microcavities, Intelligent Pixels, Acoustic, Water, Interferometric, NEMS)	
Materials	*New Chemicals and Manufacturing Techniques* Examples: Phosphorescent OLEDs; Electroluminescent DNA; Roll-to-Roll Fabrication	
Basic Res.	*Fundamental Science Applicable, Amongst Other Things, To Displays* Examples: Multidisciplinary Initiatives for Liquid Crystals, Intelligent Luminescence	
Human Factors	*User Acceptance, Vision, Behavior, Attention, Training, Perception & Cognition Issues*	

Grand Challenges

Some technology barriers severely limit capabilities. Three of these so-called grand challenges, which may take decades or centuries to meet, are identified.

Visualization Gap: The DoD goal of maintaining informational superiority and situational dominance while reducing the forward combat footprint requires a continual closing of the 1,000X gap between presently fielded warfighter interfaces (no display at all for most, or less than 1 Mpx in platforms) and the capacity of the human visual system (estimated as 1 gigapixel at 48 bits per pixel at 72 Hz and 2xNTSC color space).[2]

Optical Magic: Classical optics trains need to be condensed into thin-film, conformal structures to reduce weight and volume while increasing resolution and field-of-view for projectors, HMDs, and night vision devices. Cost needs to go down by 10X.

Power Efficiency: Defense applications need a 10X increase from about 5-10 lm/W to 50-100 lm/W in converting electrical power into viewable images. Energy harvesting of pervasively available, renewable sources—including broadcast RF, solar, mechanical motion, and thermal differentials—is needed to help power displays and reduce batteries carried.

Technical Challenges

Technical challenges estimated to take 1-5 years to achieve consume most service S&T funding. Six examples of projects now funded are described below.

Ultraresolution (Direct-View): The direct-view thrust includes the in-budget AFRL ACTD program aimed at creating a technology base for 21 Mpx projectors and 160 Mpx systems for pilot training. Current technical goals include development of high-fidelity (20:20 acuity) projectors providing 5,120 x 4,096 pixels compared to the 1,600 x 1,200 pixels now available.[3] The Air Force has established a Future Long Term Challenge that requires visualization systems with aggregate resolution of 1 Gpx for air operations centers.

Flexible Display: The services' direct-view thrust now includes flexible displays. ARL initiated an in-budget FY2004-FY2009 $54M Flexible Display Initiative in support of its Future Force Warrior program with a goal of 6-in. qVGA by Dec. 2006 & 15-in. VGA, Dec. 2009.[4] An Air Force Flexible Display and Integrated Communications Device (FDICD) effort was initiated in 2004 with a 4-in. color qVGA p-Si-TFT phosphorescent OLED on stainless steel due by Dec. 2005 in support of its Battlespace Air Operations kit.

Wrist Systems (Direct-View): AFRL initiated an effort in 2002 to develop wrist displays as an on-the-move technology for pilots and dismounted airmen. A $100K in-house program delivered a successful 2-in. AMOLED UAV video field demo in Jan. 2004. AFRL also funded an extramural effort with a WiFi wireless sunlight-readable AMLCD wrist unit due by Oct. 2005.

Ultraresolution (Virtual-View): DoD needs a solid state digital replacement for IIT-based NVG systems, which currently provide about 5 Mpx image resolution over a 40° field-of-view in fielded systems. Funded programs for a digital replacement aim for 1 Mpx as higher resolution sensors, processors & displays are too hard. DARPA's MANTIS program aim is tri-IR-band HMD.

True-3D: True 3-D systems are required to enable intuitive understanding of spatial relationships in battle control, sensor & computer visualization, training, and medical applications.[5] Service investments are primarily via $100K in-house evaluations of prototypes and $850K SBIRs to create new hardware options.

Resonant Microcavity CRT: Novel efforts include resonant microcavity phosphors (RMPs). A current AFRL $1.6M 2005-2007 SBIR III effort focuses on developing an ultra-efficient RMP-CRT to replace the 4-in. powdered-phosphor CRT in the F15 HUD.

Congressional Earmarks

Congress has added some $25M or more to defense S&T budgets for displays since 1989. Recent examples of display research efforts funded by Congressional adds to service budgets include $40M to Micron/Pixtech for field emission display technology, over $10M to Microvision for virtual retinal scanning displays, $22M to eMagin for miniature active matrix organic light emitting diode displays, $3M to CTC for a 3D table viewer using LC-shutter glasses, $5M to MCNC for display performance and environmental evaluation, over $25M to USDC for flexible display infrastructure, $3M to L3DS & UDC for flexible displays, and $10M to Trident for ultrawideband-wireless wearable displays.

Discussion

A number of opportunities exist for DoD to advance display technology and provide the warfighter with improved knowledge and survivability. Areas where defense advantage is foreseen, but will not be driven by commercial R&D, include 25 Mpx displays and 1 Gpx systems, virtual image head-up & head-mounted displays, flexible & roll-up displays, artifact-free true 3-D systems, low weight and bulk wearable displays, wireless video computer watches, and intelligent displays that eventually include all the functionality of the electronics now packaged separately in computers.

References

1. *Report of the Department of Defense Advisory Group on Electron Devices (AGED) Special Technology Area Review on Displays*, Office of the Under Secretary of Defense, Acquisition, Technology & Logistics, Washington DC 20301, Cleared for Open Publication 15 Jun 2004, 120 pp. Available from NTIS, Springfield VA 22161.
2. Darrel G. Hopper, "1000 X difference between current displays and capability of human visual system: payoff potential for affordable defense systems," in Proceedings of SPIE Vol. 4022 *Cockpit Displays VII: Displays for Defense Apps.*, (SPIE, Bellingham, WA, 2000), pp. 378-389.
3. AFRL/HEA High-Res. Advanced Technology Development, Philipp Peppler, philipp.peppler@mesa.afmc.af.mil .
4. J. M. Pellegrino, G. L. Wood, D. C. Morton, and E. W. Forsythe, "Flexible display technology for the objective force," in Proc. SPIE Vol. 5080 *Cockpit Displays X* (SPIE, Bellingham WA, 2003), pp. 1-8.
5. Darrel G. Hopper, "Reality and Surreality of 3-D Displays: Holodeck and Beyond," in *Electronic Information Display Conference Digest,* London UK Nov. 21-23 (SID, 2000), 10 pp.