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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Improved Crew Efficiency and Situational Awareness through Multi-Function Video Display

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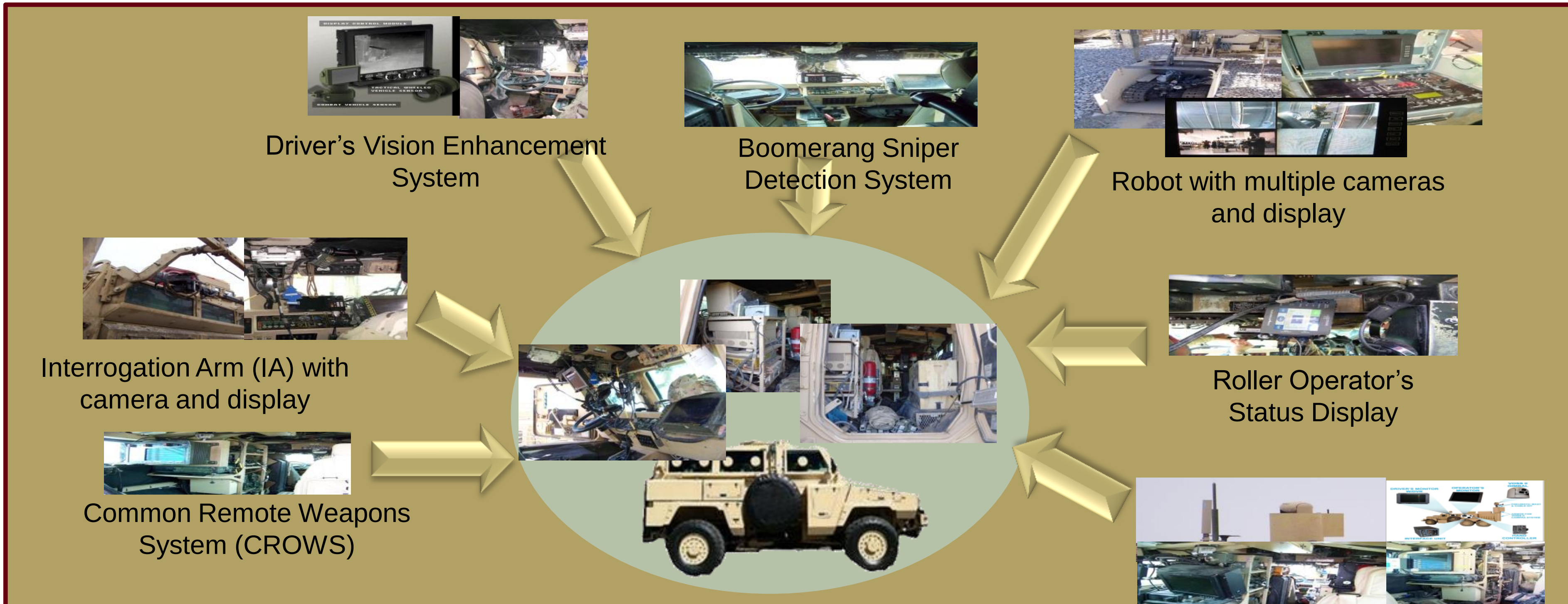
Sensor - Vehicle Integration Becoming an Impossible Task

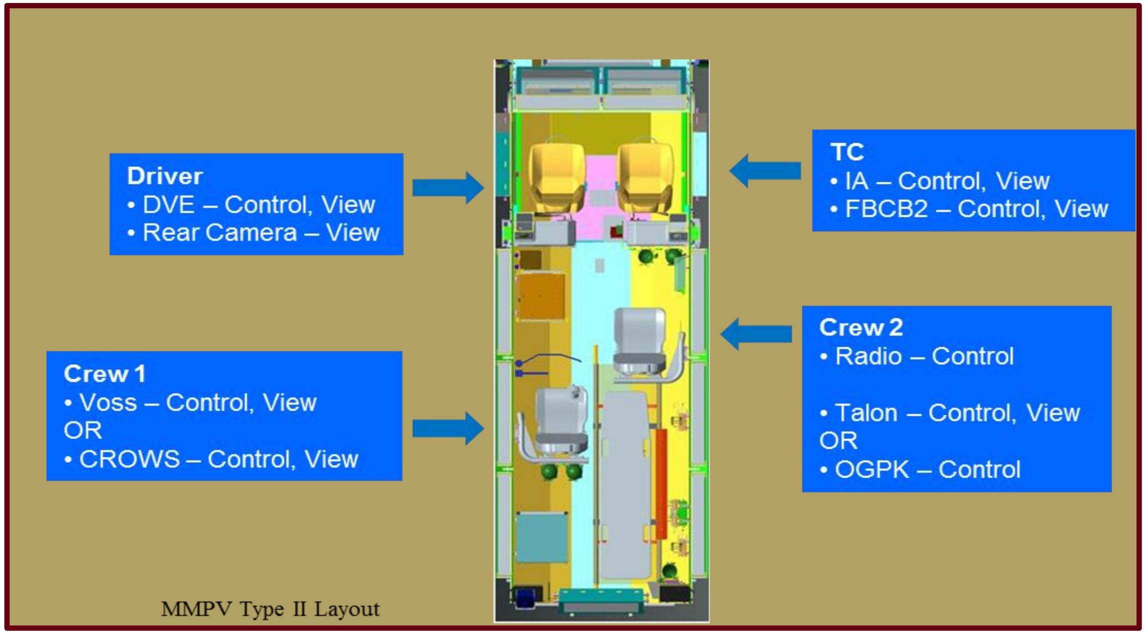
- **Evolving nature of Improvised Explosive Device (IED) threats has led to the need for multiple systems to perform detection and neutralization**
  - Each with its own Operator's Station for control and display
  - Control and view by single Soldier
  - Integration challenge with limited room for future capability



Even If They Could Fit - Too Many Displays to be Effective!

Route Clearance Platoon and MMPV Type II

- **Typical Mission:**
  - Clear hundreds of km of one-way vehicle traffic of IEDs and explosive hazards
  - Average detection rate under 10 kph
  - Continuous multi-day mission length
  - Operate day and night and under all weather conditions
  - Operate over varied complex terrain
    - Highways
    - Confined urban roads
    - Dirt trails
  - Tasks include:
    - Explosive hazard detection, classification, neutralization
    - Force protection
    - Casualty evacuation
  - MMPV Type II is most common vehicle in Platoon as it is highly configurable
  - Used primarily for force protection and command and control



MMPV Type II Layout

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MVD Solution to Sensor Stovepipes

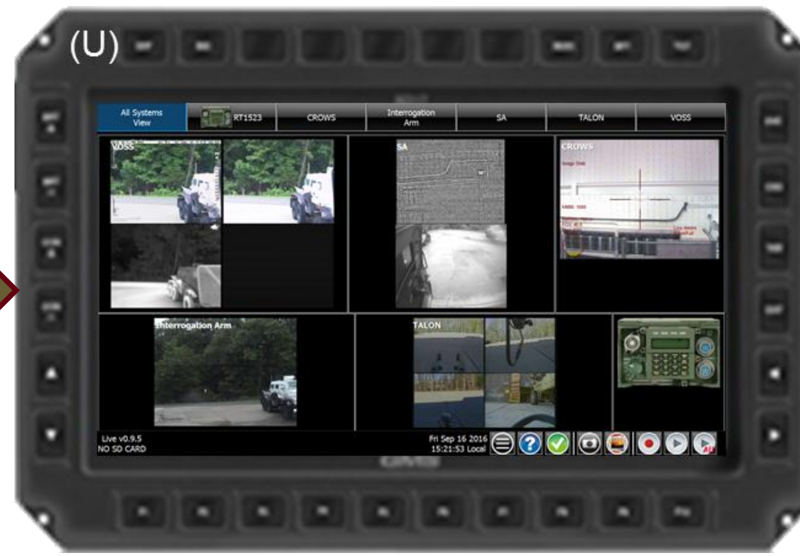
- **NVESD has developed a software middleware, called Multi-Function Video Display (MVD), that efficiently distributes imagery and sensor control to all crew stations within a vehicle eliminating current display(s) per sensor "stovepipes"**
  - Single touch screen display for viewing all sensor data and control on vehicle
  - Creates a seamless common interface across all sensors
  - Enables capability growth without increasing display size, weight, and power requirements
    - Configuration doesn't require 8x displays with 8x SWaP to provide capability
  - Plug-n-Play VICTORY-like architecture based upon open standards
  - Government developed and owned
- **Software middleware is hardware independent**
  - Identical code running on touch screen hardware also running on wireless devices: laptop, tablet, smartphone
- **Collaboration with PL-Assured Mobility Systems**
  - Addresses Forward Reconnaissance & Explosive Hazard Detection (FREHD) and Capability Production Document (CPD) requirements for Medium Mine Protected Vehicle (MMPV)
  - Successfully demonstrated MVD system to PL-AMS leadership and MSCOE, and secured position as display in Program of Record MMPV Type II vehicle

MVD Solution to Sensor Stovepipes Continued

- To accommodate all of the varying enablers required to successfully detect and neutralize IEDs, route clearance vehicle crew stations have become overburdened with displays
  - Trying to keep track of what is happening on multiple different displays, each with a different user interface and control scheme, over the course of an eight-hour mission is exhausting
- MVD eliminates this difficulty by bringing all sensor feeds and controls into a single display
- MVD is customizable enabling the operator to focus in on only the information that is relevant at the moment.
  - View all feeds simultaneously
  - View a single enabler of interest
  - View any subset of enablers

Current crew station includes separate displays for each of the enablers in use, limiting room for future capability growth and creating integration challenges

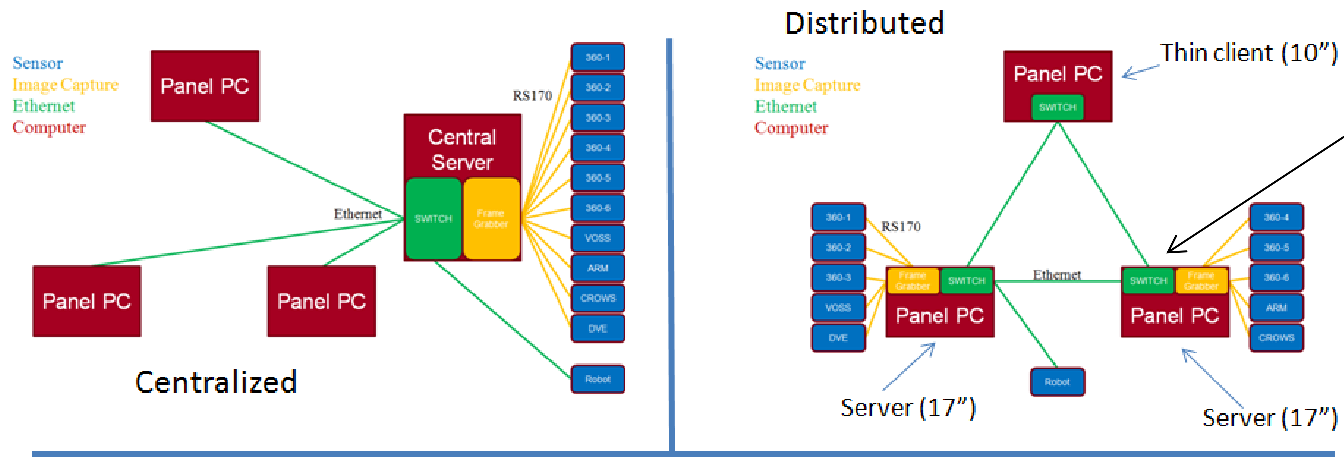
This Becomes This



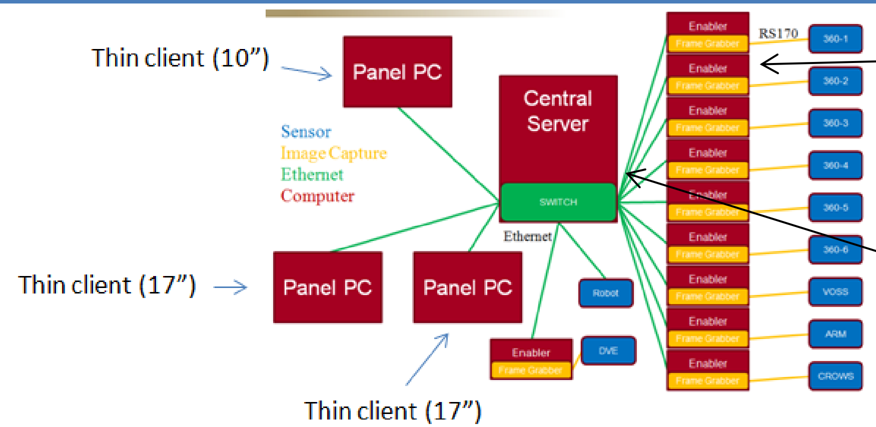
MVD combines enablers onto single display for simultaneous view and control of all enablers at every crew station

Architecture Study of Hardware Alternatives For MVD Functionality

- **Multiple hardware architectures are possible solutions for MVD**
  - Functionality necessary is identical in each architecture, it's a matter of where it's performed
  - Identical software on each architecture demonstrates HW independence
  - Multiple sources of hardware components available



Server display capable of acquiring, compressing, and distributing imagery



VICTORY-Like
(PM-AMS Preferred)

Enabler allows legacy analog sensor to be displayed and controlled in digital system

Server switch provides compression processing and Ethernet

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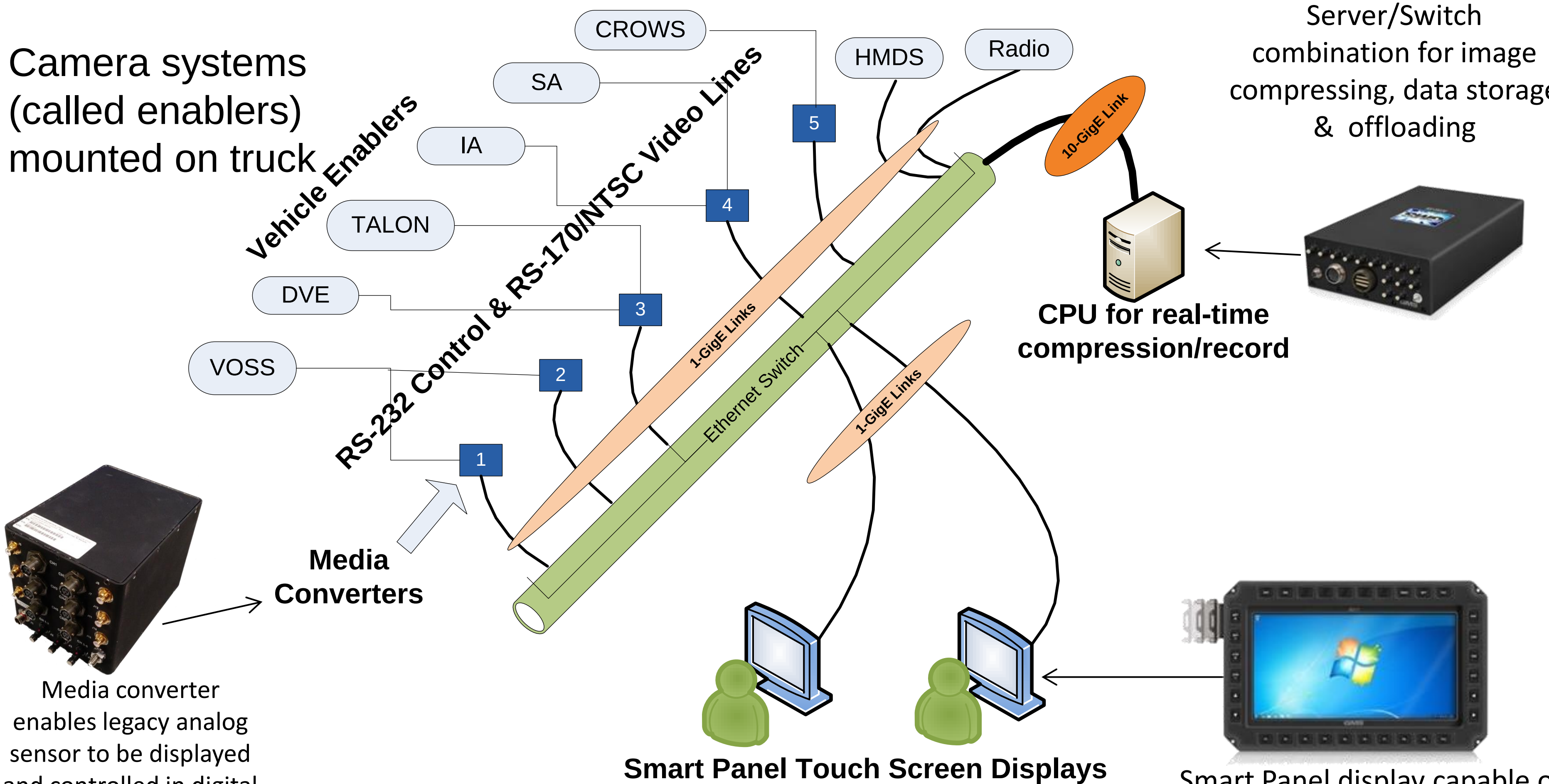
Final Architecture For MVD Functionality



Media converter enables legacy analog sensor to be displayed and controlled in digital system

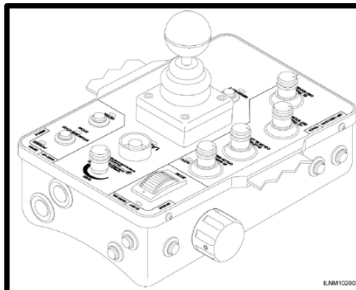
Smart Panel display capable of decompressing imagery and control

MVD Software

- **MVD uses a modular Qt plugin-based architecture that allows new systems to be added without modifying or recompiling any of the pre-existing code**
  - Many thousands of lines of C/C++ code spread between core libraries, graphical user interface frontend, and server backend
  - 3K lines of Java code for Android devices
  - Code has gone through multiple rounds of static analysis to ensure reliability and best programming practices, and code coverage testing to ensure every line operates as intended without errors
  - Use of standards for interfaces and data formats
  - FFMPEG and libx264 used for video compression
  - SDL used for gamepad integration
  - Pleora eBUS SDK used for controlling iPort devices and generic gigE Vision devices
  - Oracle VirtualBox used for running virtual machines (current approach for apps with only executable available, i.e., HMDS)
- **Real-time video with less than 100ms (measured) of latency between time of event and display of event**
- **Video recording and snapshot capture along with playback of recorded video allows for DVR functionality**
- **Full control of Interrogation Arm, VOSS, and Robot through touch screen and game controller**
- **Seven different arbitration schemes for sensor control**

MVD Common UI and Controls

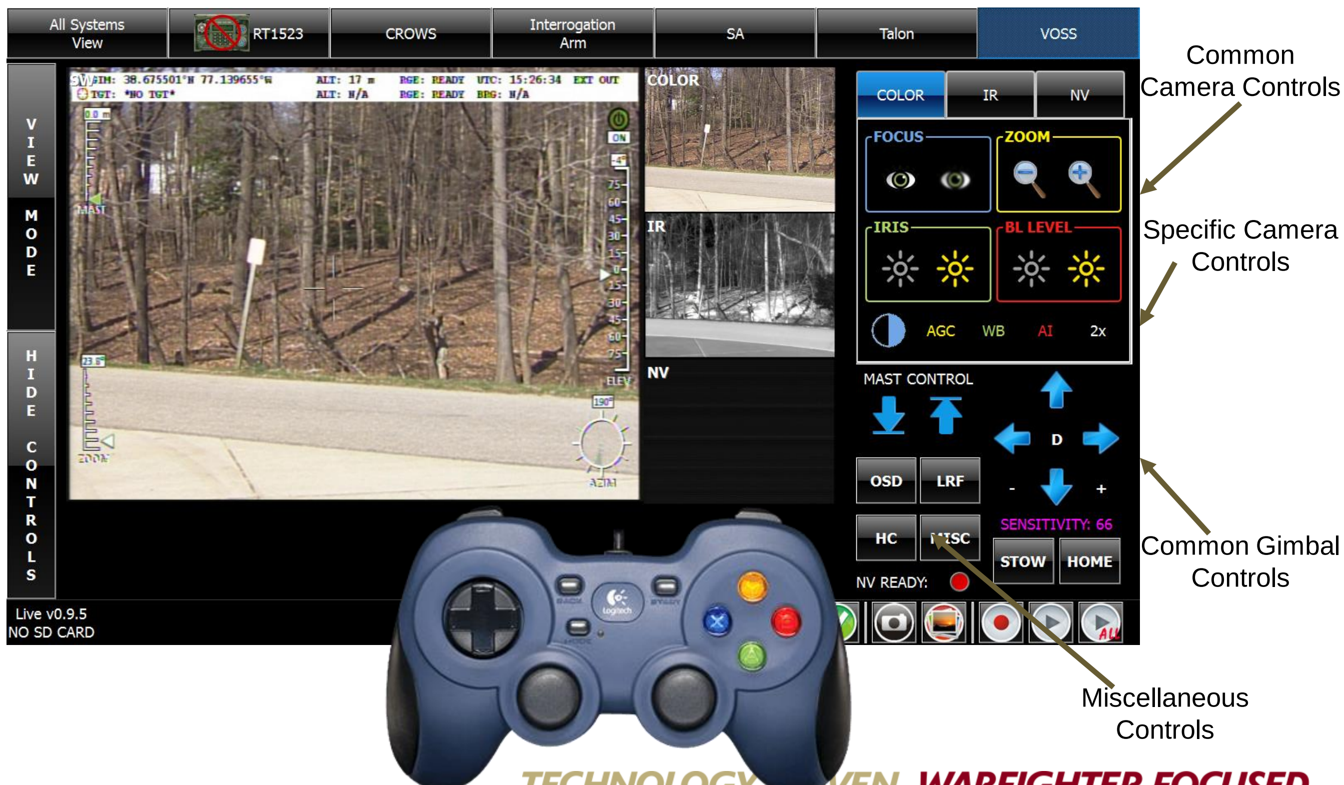
- MVD makes user interface and control scheme for each enabler as similar as possible to limit amount of confusion an operator experiences when switching between enablers
- VOSS and IA camera have completely different proprietary controllers
- MVD uses combination of touchscreen and common game controller



VOSS Kneeboard

Interrogation Arm Camera Display and Controlls

- Controls duplicated between them enabling operator to use whichever is most familiar
- Systems with similar functions will have user interfaces that are nearly identical
- Greatly decreases training burden



MVD Hardware

- Core of MVD is software which can run on many different hardware platforms
- For success needed hardware that:
  - Could meet baseline system requirements
    - View all systems
    - Control VOSS, IA, and Robot
    - Record and playback data
  - Did not diminish performance of included systems
    - Example: VOSS must still meet its PD and FAR requirements
  - Did not add excessive latency
  - Minimized SWaP
  - Milspec
  - Had enough headroom for system growth and expansion
  - Met system budget per vehicle
- Performed technology trade study looking at displays, switches, servers, media converters

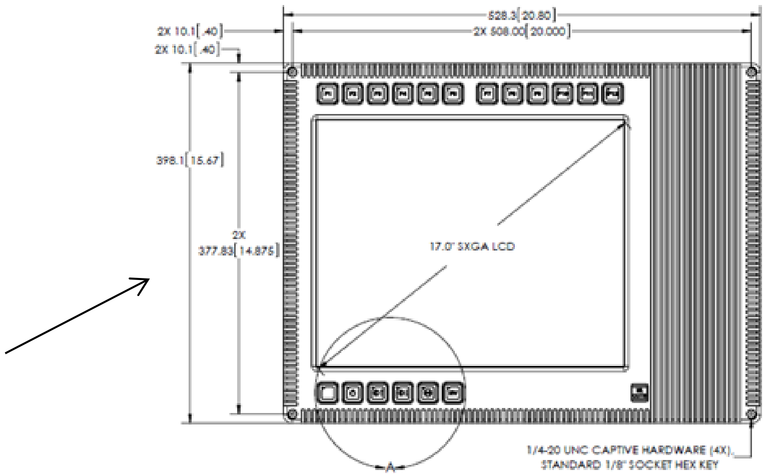
Smart Touchscreen Displays

- Needed both client and server versions of display under 5” thick
- Received proposals from numerous companies and chose several to make prototype displays for early demos
  - 2 10” clients
  - 2 17” clients
  - 2 17” servers
  - Clients all 3.5” thick
  - Server 5” thick with internal switch and frame grabbers

Server

Client

- Prototypes performed successfully during initial system demos but even 3.5” displays proved to be too thick for quick egress
- Worked with other vendors looking at several designs under 2” thick
  - Processor to the side of display, increasing size in x and y dimensions
  - Processor in bump out behind monitor, 2” thick everywhere but at bump out



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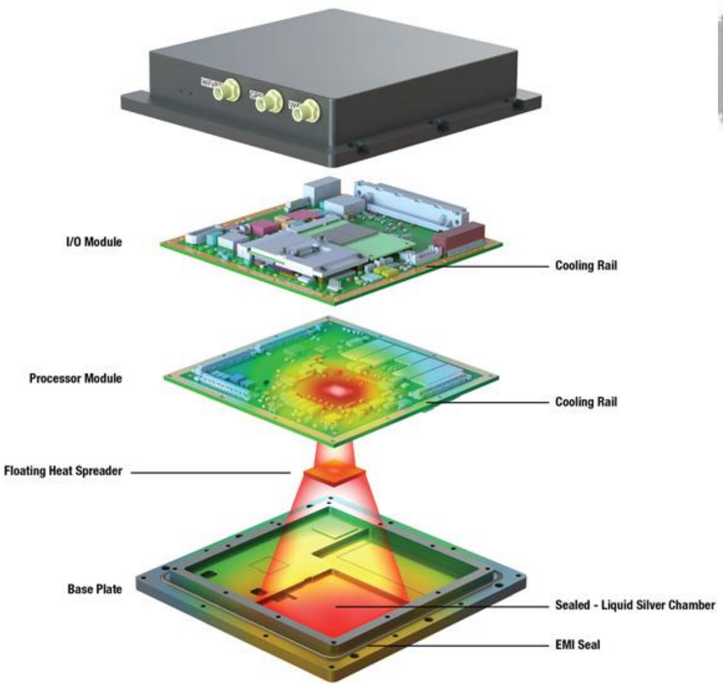
Smart Touchscreen Displays

- 1st design proved too large for the customer and 2nd design proved too difficult to cool
- Found GMS, had 2" thick, conduction cooled, milspec, touch screen displays with quad core i7s
- Processor module can be upgraded and sits in a pool of liquid silver, providing the necessary cooling.



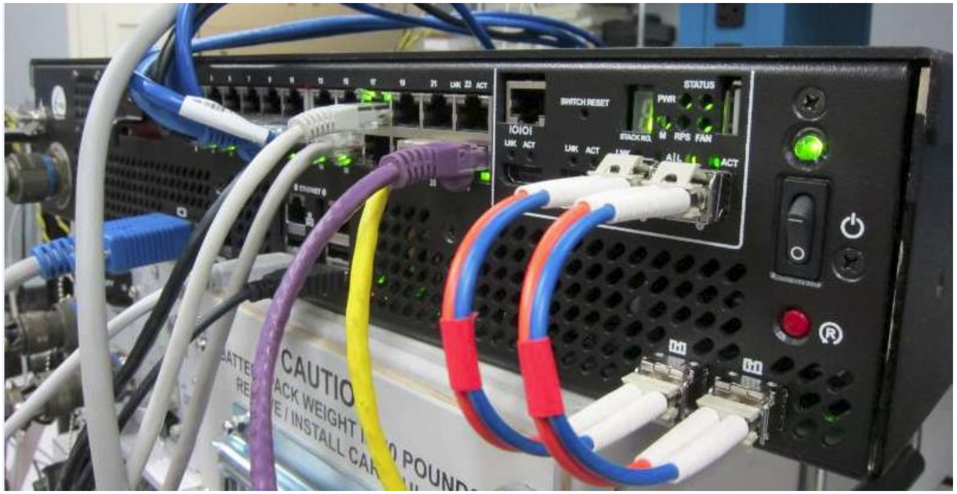
RuggedCool Technology

GMS HD17W

- Vendor: General Micro Systems Inc.
- RuggedView™ 12" & 17"Smart Display
- Intel Core i7 CPU with 4 cores up to 2.4Ghz
- Supports up to 128GB of DDR3 memory with ECC
- 1GigE connectivity
- Quad removable 2.5" SATA SSDs
- Windows Embedded Standard 7

Servers and Switches

- Server needed enough Ethernet bandwidth to take in numerous raw video feeds (initially 14) and enough horsepower to compress them for delivery to clients
- Built prototype server combining a dual processor Xeon with a Dell PowerConnect 5524 24 port switch with two 10 gigE optical ports
  - Server and switch are connected by the two 10 gigE ports
- After demos found ruggedized server and switch
- PM WIN-T purchasing fully ruggedized servers nearly identical to needs of MVD
- WIN-T server mated with Milspec switch supporting 10 1-gigabit connections and 2 10-Gig connections



Server Prototype

Milspec Switch

WIN-T Server from GMS

Servers and Switches

- **Ruggedized switches cost $8-12k and added an extra component to system**
- **Investigated use of software switch**
  - Worked with software switches made by multiple vendors
  - Switches worked well for small throughputs, but throughputs in the 2Gb/s sustained range were either too latent or completely unstable
  - Software switches become more expensive the more features added and can quickly get into the 10s of thousands of dollars
- **Convinced GMS to add switch into their next generation server**
  - Switch costs roughly $2k per unit
  - Replaces VMs in the original box
  - 10gigE port connects server and switch internally
  - Final version will expose 12 gigE ports and an additional 10gigE port

GMS SO302-NV

- Vendor: General Micro Systems Inc.
- SO302-NV Rugged, Fully Sealed Server with 12-Port Intelligent Switch
- 1GigE and 10GigE connectivity
- Intel Xeon E5-2658 Ivy Bridge-EP CPU with 10 cores up to 2.4GHz ea.
- Supports up to 128GB of DDR3 memory with ECC
- Quad removable 2.5” SATA SSDs
- Windows Embedded Standard 7

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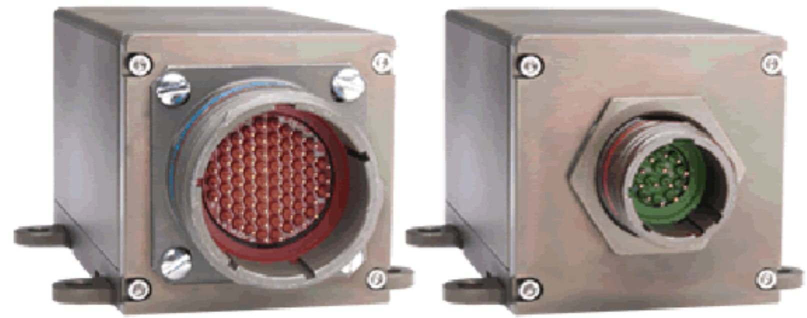
Media Converters

- **All systems on MMPV are legacy analog sensors**
- **Need device to convert from analog to digital and packetize data for use on GigE network**
- **Pleora iPort Analog Pro**
  - 2 RS-170 input streams digitized and packetized, then streamed using GigE Vision Stream Protocol
  - 2 RS-232 feeds for controlling connected devices
- **Identical ruggedized version of iPort**
  - The 3+ two stream media converters needed per vehicle did not meet vehicle budget

Pleora iPort Analog Pro



Ruggedized iPort Equivalent

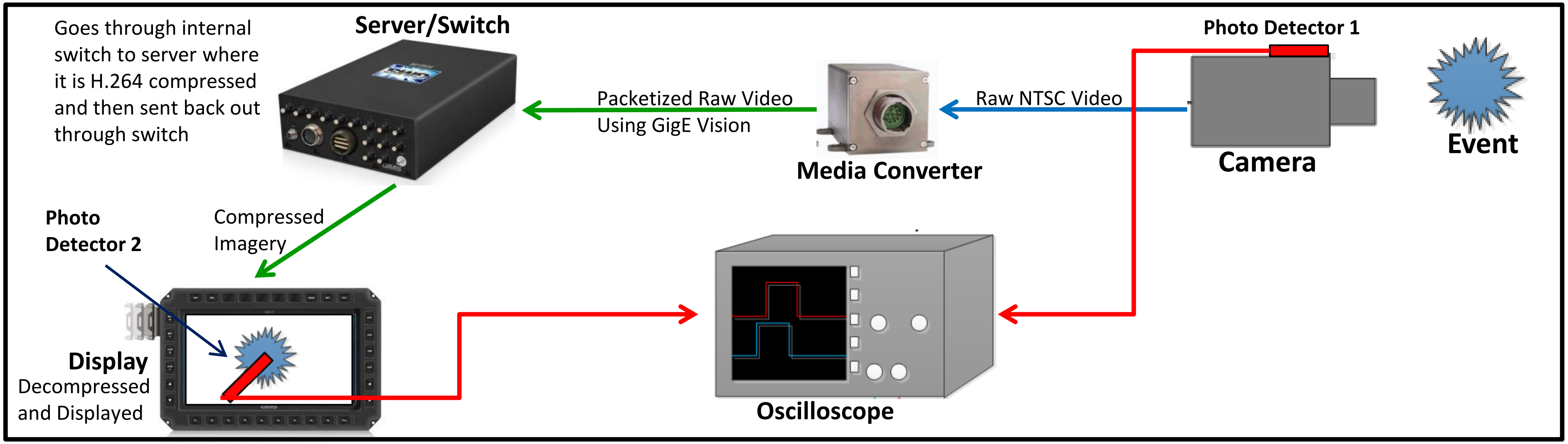
- **Worked with Vendor to create media converter with minimal required feature set**
  - Only need one media converter per vehicle
  - Cost rolled in with other system components

GMS SVE-6CV

- Vendor: General Micro Systems Inc.
- SVE-6CV Rugged, Fully Sealed Video Encoder
- 3 x 1GigE Connectivity
- 6 Analog Video Feeds In – 6 GigE Vision Feeds Out
- 6 RS-232 Control Lines

MVD Latency Testing

- **The MVD architecture involves a network between the displays and some amount of compression and decompression to meet bandwidth constraints**
- **A latency of even a few frame times is perceptible and has a negative impact on user effectiveness, experience, and usability**
- **Performed experiment to analyze latency along imaging chain**



- **Two photo detectors connected to oscilloscope.**
- **Photo detector 1 co-located with camera and measures time event occurs**
- **Imagery digitized at media converter and sent to server**
- **Server compresses video and multicasts it out to displays**
- **Display receives compressed video, decompresses it, and displays it**
- **Photo detector 2 held against display to measure time event is displayed**
- **Latency is time between when photo detector 1 and photo detector 2 see event**

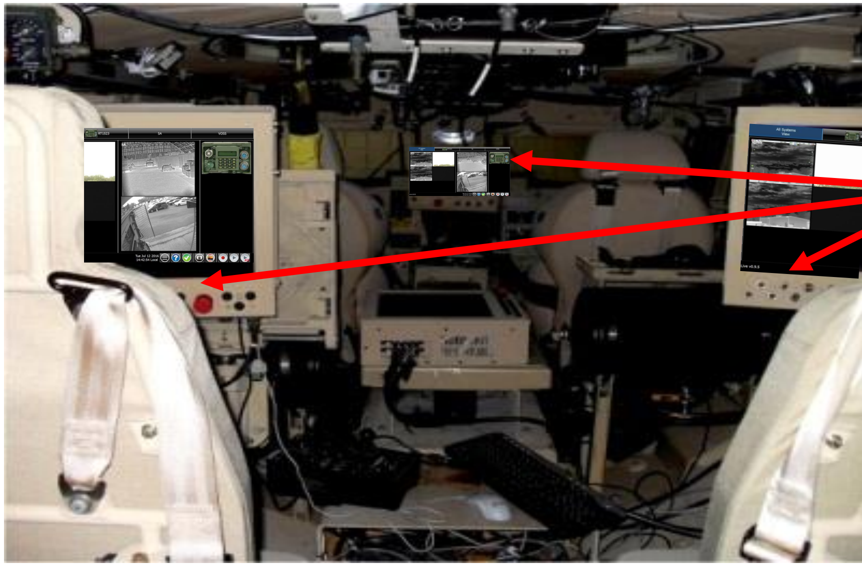
Measured latencies under fully loaded system in sub 100 millisecond range

Soldier Testing

- **MVD tested by soldiers at end of MMPV Type II Operational Testing**
  - Soldiers just finished multi-month test using truck enablers for carrying out real world route clearance operations
  - MVD installed on two trucks and Soldiers given 4 hours of training
  - Soldiers used MVD equipped trucks to carry out day and night operations
  - Feedback was very positive
    - One Soldier said “I wish we had it all test”
    - Another said “MVD would have made my life easier”
    - OT Lead Training Specialist described MVD as fantastic and would change the way we fight
  - Obtained many Soldier anecdotes about how they currently use the truck and its enablers, and the situations where MVD greatly improves their operational efficiency

“MVD would have made my life easier.”

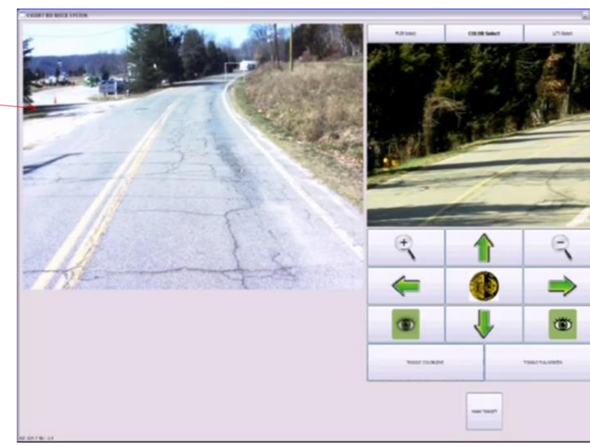
MVD - Improvements to Situational Awareness



All enabler feeds, at all crew stations simultaneously, greatly improve **Situational Awareness (SA)**.

- **Truck wide improvements:**
  - Multiple sets of eyes on the same sensor
  - Operator of a sensor of no immediate value (e.g., robot while moving) can now assist with looking for threats through other feeds.
- **Operator improvements:**
  - Leverage both NFOV sensors and WFOV sensors to perform threat detection tasks while maintaining SA.
  - Slew-to-cue: easily slew NFOV sensors to areas of interest within WFOV sensors can increase detection standoff by 2-10 times that of eyes only, also effectively eliminating the “soda-straw” effect.

Wide FOV Sensor for SA



High Mag Sensor

Slew-to-cue Using MS-GUI

SWAP Reductions

As more enablers are added to the MMPV Type II and MVD takes control of more of the current enablers, SWAP will decrease.

- Near Term:
  - PL-AMS has asked NVESD to more closely integrate additional enablers to MVD.
    - Fully control the Interrogation Arm (not just the camera.)
    - Fully control the Talon Robot
    - Investigating replacement of dedicated CROWS display.
    - Investigating replacement of dedicated FBCB2 display.
    - Replacement of Mine Roller display and control

Interrogation Arm DMA/RCU, CROWS DCP, FBCB2 MFoCS, MTRS OCU/LCU

- Future:
  - Requirements for remote visualization capabilities between trucks.

Threat Detection Algorithm Analysis

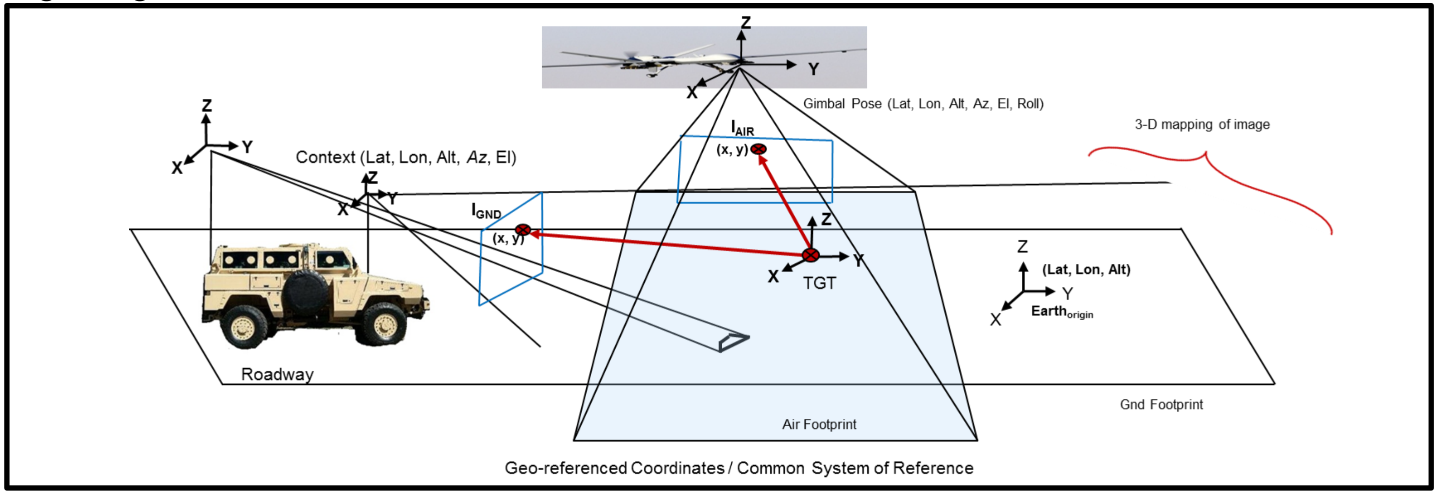
- **With all vehicle enablers networked together, MVD can have impact on algorithm performance**
  - All data from all enablers now in same location simultaneously
  - More than enough processing power to run sophisticated detection and tracking algorithms
  - Detection algorithms can now leverage additional information to improve Probability of Detection (PD) and reduce False Alarm Rate (FAR)
  - When considering future remote visualization requirements, additional detection improvements are possible given sensors on other vehicles
- **To test out concept, NVESD used roadway threat detection algorithm results of multiple sensors run over same test lane**
  - Sensors included Ground Penetrating Radar (GPR), metal detector, VOSS (visible and MWIR), Multi-Sensor Suite (MSS) Gimbal (visible, MWIR, SWIR)
  - Fuse algorithm outputs to improve performance over that of single algorithm
  - GPR far outperforms other sensor algorithms, detecting nearly all targets (buried metallic devices)
  - GPR has fewer false alarms as well
    - But even 14 FAs per kilometer is too many when each alarm must be interrogated
  - Goal is to have aggregate PD outperform GPR at low false alarm rates

System	PD	FAR (/km)
VOSS	<<1	27
MSS	<<1	50
GPR	~1	14
Metal Detector	<<<1	18

Detection Algorithm Performance

Threat Detection Algorithm Output Correlation

- **Sensors not collocated with same fields of view, orientations, focal plane sizes**
  - Sensors on different vehicles and data taken at different times
  - Need to transform results into common system of reference to fuse them together
  - Exactly the situation of the MMPV Type II enablers, particularly when considering the future capabilities of integrating remote visualization into MVD



- **Sensor outputs combined using simple correlation function**

$$\textit{Correlated Confidence} = f(C_i \ldots C_N, TOD, P(Target|S_1,S_2,\ldots S_N))$$

C_i: the confidence value of sensor i where i =1,2,…,N

N: the number of participating sensors

TOD: individual sensor's time-of-day performance (Pd/PFA)

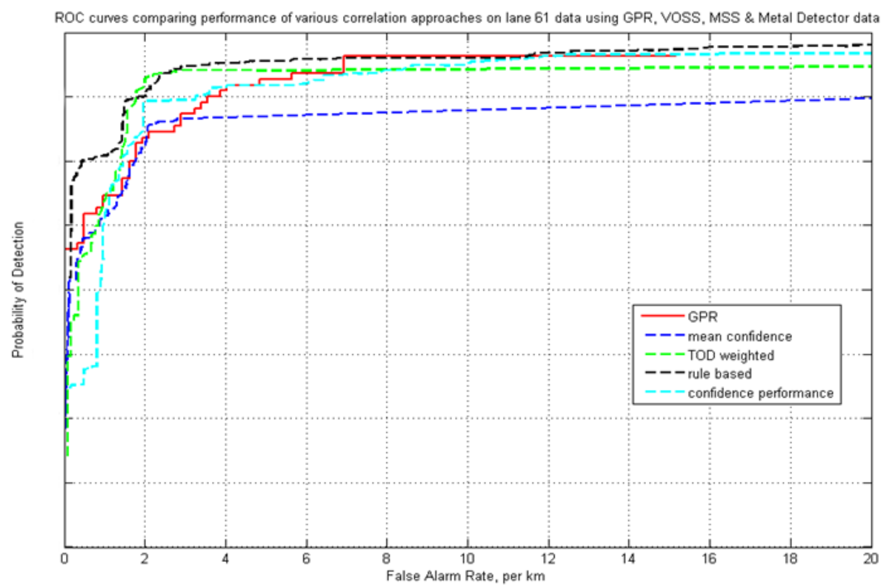
$P(Target|S_1,S_2,\ldots S_N)$: the probability that a target exists given the declaration event (**Threat** or **No Threat**) of each participating sensor system

  - Formed correlation function based on analysis of sensor performance on training lane

Threat Detection Algorithm Results

- **Tested 4 different correlation methods**
  - Mean Confidence – Arithmetic mean of each sensor's confidence
  - Time-Of-Day (TOD weighted) – Weighted mean of each sensor's confidence based on historical TOD performance
  - Confidence Performance-Based:
    - Bins confidence of each sensor and calculates each sensor's historical *P(Target|Confidence Bin)* results
    - Arithmetic mean of participating sensors' *P(Target|Confidence Bin)* results
  - Rule-Based: a modified version of TOD algorithm
    - TOD output is multiplied by the $P(Target \mid S_1, S_2 \ldots S_N)$ which is probability that a target exists given declaration event (Threat or No Threat) of each participating sensor system
    - Correlated confidence is changed to reflect historical results that show P(Target | GPR normalized confidence is high) ≈ 1
- **Rule-based confidence performs best**
  - Consistently outperforms GPR by about 5% - 10% over key region below three false alarms per kilometer
- **Results are over a very limited data set and used primarily to illustrate potential benefits of real-time sensor / information fusion that MVD is capable of**
- **More sophisticated algorithms can be developed that better combine the complementary information that each sensor provides**

GPR, VOSS, MSS, and Metal Detector



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Conclusions

- **Stove-piped method of adding new capabilities and sensors is replaced by the "tablet-like" capability of the MVD.**
  – Multiple improvements in capability to current configurations
  – Built-in processing headroom to allow for future growth
- **Improves communication between the MMPV Type II crew which leads to improvements in crew efficiency**
  – Decreases time spent searching for suspected explosive hazards allowing greater safety during missions.
- **Potential to tap into many of the combat developers' future capability production document programs, changing the way route clearance is performed**
- **Potential to affect all DOD ground vehicles with sensors by acting as the operator's display, thereby achieving substantial SWAP reductions and saving money.**