A COMMON ARCHITECTURE PROTOTYPE FOR ARMY TACTICAL AND FCS UAVS

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Abstract

The U.S. Army is fielding several unmanned air vehicles (UAV) within the Tactical, Light Attack, and Future Combat Systems (FCS) Command, Control, Communication, Computers, Intelligence Surveillance and Reconnaissance (C4ISR) classes over the next several years. Each UAV program will develop its own mission processing architecture unless the Army implements a common approach that is responsive to a broad set of mission and functional requirements. To address this need, the U.S. Army Aviation Applied Technology Directorate (AATD) conducted the Manned / Unmanned Common Architecture Program (MCAP) Phase III project for the development of a common UAV embedded mission processor architecture that will enhance interoperability through design commonality, reduced ownership costs and improved processing capabilities. The MCAP Phase III architecture is based on commercial off-the-shelf (COTS) electronics and software and open systems interface standards. The architecture provides commonality between platforms, interoperability between systems, variability isolation and supportability for the integration of modular elements into a scaleable, networked architecture. A key part of the MCAP III program is a lab demonstration that will consist of autonomous applications that permit single operator control of the Shadow 200 tactical UAV acting in support of the Army's concept of operations employing manned and unmanned platforms. This paper will present highlights of the development of the MCAP III common embedded computing architecture system.

Project Overview

The goal of MCAP Phase III was to develop an architecture capable of supporting several Army UAV platforms, instantiate it for a lead instantiation vehicle, and demonstrate the resultant system performance in a laboratory environment. The platforms of interest range from Tactical and Light Attack, to Future Combat Systems (FCS) C4ISR.

Throughout the MCAP III project there were several related programs that were taken into consideration for sources of requirements, design, components, regulations and architectural standards. Some of these are depicted in Figure 1. Notably, system requirements were derived from representative FCS missions and vehicles, although the MCAP III architecture development was conducted independent of the FCS system program. Also notably, the MCAP I and II programs provided the system-of-systems conceptual operating environment concepts, and manned vehicle system architecture prototype respectively.

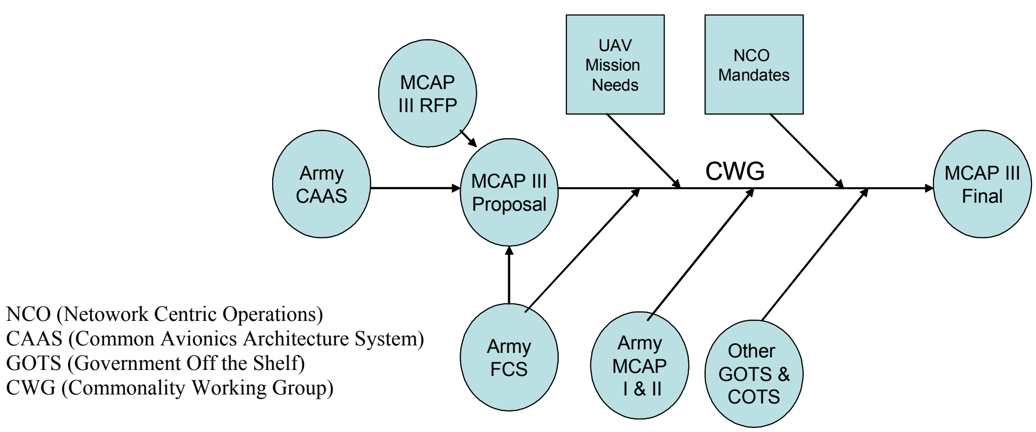


Figure 1. MCAP III Influences

MCAP Phase III had four major tasks;

1) Requirements Analysis and System Engineering - The goal was to gather information about user and stakeholder needs, regulatory requirements, and market trends. This was performed by systematic application of the Department of Defense Architecture Framework (DoDAF) to generate various operational, systems and technical standard views of the Unmanned Air Vehicle Common Architecture Prototype (UCAP) system in operation.

2) Common Architecture Definition – Using the results of Requirements Analysis and System Engineering, this activity developed the common architecture preliminary design, the UAV Mission Avionics Technical Architecture, and platform instantiations of the UCAP.

3) Detailed Design and Development – The purpose of this activity was to conduct software and hardware detailed design and development of the UCAP, particularly as it applies to the Lead Instantiation Vehicle (LIV).

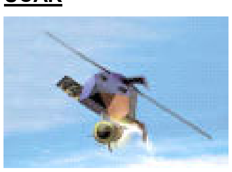
4) Lab Demonstration – The purpose of this activity was to test the performance of the UCAP system under "systems-in-the-loop" environment for the LIV. This activity had a second purpose which was to provide preliminary validation of the vehicle installation for the system.

The remainder of the document highlights the results of the MCAP III program.

Requirements Analysis and System Engineering

The MCAP III project addresses three classes of UAVs, specifically Unmanned Combat Armed Rotorcraft (UCAR), Class IV Medium Altitude Long Endurance (MALE), Extended Range/Multi-Purpose (ERMP), and FCS Class III, Shadow 200. There are two aircraft identified as potential options for the Class IV system, specifically a Fire Scout variant and a production configuration of the A-160 Hummingbird. A brief description of each UAV system, its capabilities, and how it will be employed in the FCS environment is shown in Figure 2, where UE is the Unit of Employment, UA is Unit of Action, MUM is Manned/Unmanned, BDA is Battle Damage Assessment, A2C2S is Army Airborne Command and Control System, C3 is Command, Control and Communications, EO/IR is Electro-Optical/Infrared; SAR/MTI is Synthetic Aperture Radar / Moving Target Indicator.

UCAR



- Organic to UE
- Provided to UA for specific missions
- Capable of cooperative teaming with manned aircraft (MUM Ops)
- Mobile Strike, Close Combat, BDA, Armed Recce, and Security are all expected missions
- Controlled from ground, helos, A2C2S, and Mobile C3 via TCDL

Fire Scout (Class IV)

- Assigned to the UA
- EO/IR/laser
- SAR/MTI
- Comm relay when JTRS is fitted
- Current UA O&O shows unarmed, but demos with multiple weapons are in process
- Controlled from ground, helos, A2C2S, and Mobile C^3 via TCDL
- Selected by FCS as initial Class IV vehicle

Shadow 200 (Class III)

- In full rate production
- EO/IR sensors
- Comm Relay
- ConOps being refined in real ops with Stryker Brigades today, in Iraq
- Expected to be assigned to FCS UA
- Most space, weight, and power constrained
- Unarmed missions only today
- Can do limited Met survey
- Could drop small emergency logistics payloads

A-160 (ER/MP)

- Self-deployable within the theater of operations (> 2000nmi range)
- Long endurance (> 24 hours) making it ideal for missions requiring persistence (i.e. Comms Relay, Surveillance)
- Normally assigned to UE
- Has capacity to insert other uninhabited vehicles (air or ground)
- Can also be used to deploy unattended sensors

Figure 2. MCAP III UAVs of Interest

Operational Concepts

The Concept of Operations (ConOps) analysis began by identifying the range of operational scenarios that will be performed by the subject air vehicle systems. For this study, three broad scenarios were chosen:

Caspian Sea Small Scale Contingency

This scenario has been approved by U.S. Army Training and Doctrine (TRADOC) Command. It characterizes operations in regional conflicts which have dominated U.S. military combat operations since World War II. Operational needs in this scenario tend to focus on reconnaissance, surveillance, communication relay and target designation. They do contain target attack and cooperative operations elements, but of limited scope.

Major Theater of War

This scenario has been approved by the Defense Advanced Research Project Agency (DARPA). This scenario places more focus on direct application of combat power, while retaining the combat support capabilities of the earlier scenario. Here the focus is on Suppression of Enemy Air Defenses (SEAD), target attack, Signals Intelligence (SIGINT), and increased levels of cooperative operations and vehicle autonomy.

Stability and Support Operations

This scenario addresses operations after combat operations have generally ceased. Here the focus is on wide area surveillance and communication relay.

System Requirements Definition

For purposes of the MCAP III study, each of the airframes was allocated specific FCS oriented missions. The ConOps scenarios, with associated UAV mission allocations are shown in Table 1.

Table 1. MCAP III ConOps Scenarios with Assigned UAV Missions

Scenario	Supported Force	Platform	Mission	Remarks
TRADOC-Approved Caspian Sea Small Scale Contingency	Current Stryker BCT, Modular UA	Shadow 200	Communications Relay Reconnaissance Target Acquisition	No Laser Range Finder / Designator
	Current Stryker BCT, Modular UA	A-160	Target Acquisition & Designation, BLOS Engagement, Wide-Area Surveillance, Mine Detection	A-160 performing UE_x ER/MP functions
	FCS Battalion	Shadow PIP/1B	Reconnaissance Target Acquisition & Designation, Met Survey, Mine Detection	Performing Class III functions. Recce with EO/IR and SAR.
	FCS UA	Fire Scout	MuM Operations, BLOS/NLOS Engagements, Target Attack	Performing Class IVa functions.
DARPA Approved Major Theater of War	FCS UE	A-160	Win-T Relay Package Relay, Target Attack, Logistics Delivery, SIGINT, MuM Operations	Performing ER/MP functions, critical supply delivery.
	FCS UE	UCAR	Security Mobile Strike, Suppression of Enemy Air Defenses, MuM Operations	High value targets, force protection, cooperation with attack helos.
Stability and Support Operations	FCS UA	A-160	WRP Relay, Wide Area Surveillance, Persistent Stare	Performing Class IVb functions

Each of these scenarios was decomposed further into operational vignettes per platform and mission. By analysis of the various vignettes we identified those operational situations which require the greatest level of resources from the UCAP. This analysis was performed by systematic application of the DoDAF to generate various operational, systems and technical standard views of the UCAP system in operation. The Popkin System Architect tool with the DoDAF (C4ISR) Option was used to facilitate this analysis.

In the Framework, there are three major perspectives, i.e., views that logically combine to describe an architecture description. These are the Operational View (OV), Systems View (SV), and Technical Standards View (TV).

The Operational View (OV) is a description of the tasks and activities, operational elements, and information exchanges required to accomplish DoD missions. The OV contains graphical and textual products that comprise an identification of the operational nodes and elements, assigned tasks and activities, and information flows required between nodes. It defines the types of information exchanged, the frequency of exchange, which tasks and activities are supported by the information exchanges, and the nature of information exchanges.

The Systems View (SV) is a set of graphical and textual products that describes systems and interconnections providing for, or supporting, DoD functions. The SV associates systems resources to the OV. These systems resources support the operational activities and facilitate the exchange of information among operational nodes.

The Technical View (TV) is the set of rules governing the arrangement, interaction, and interdependence of system parts or elements. It includes a collection of the technical standards, implementation conventions, standards options, rules, and criteria organized into profile(s) that govern systems and system elements for a given architecture.

UAV System Requirements Definition was accomplished through the analysis of the operational needs identified as part of the operational views (OV's). Utilizing the system external interfaces and the functions identified as part of the DoDAF Operational Activity Model (OV-5) effort, allocations were made to the computing system for each platform. The system external interfaces provided insight into the capabilities required for each function. The resultant allocation is consistent with the work associated with producing the DoDAF system view SV-5, Operational Activity to Systems Function Traceability Matrix.

Some decomposition of operational functions was necessary to support allocation to UAV system functions. This effort was performed in parallel, and iterated with, SV-4 views (Systems Functionality Description). The result of this analysis enabled the sizing of the processing requirements for each platform. Figure 3 illustrates this approach. To this point, the above analyses encompass the entire system of systems. However, the MCAP III objective is focused on properly sizing the UCAP Mission Processor. Therefore, we narrowed the focus to those functions allocated from the System of Systems analysis to the Mission Processor.

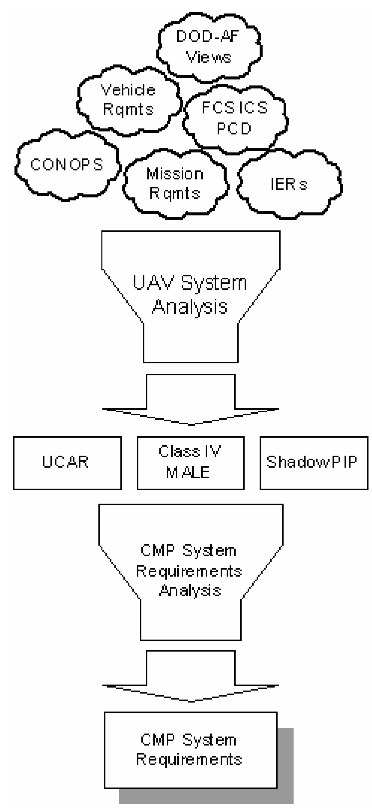


Figure 3. Platform Requirements Analysis

From the UAV system analysis of aircraft system functions, a context diagram was created. A context diagram is an object oriented design technique, similar in content to the SV-1 System Interface Diagram. The purpose of a context diagram is separate the broader system view into two types of components. The system being designed is shown as a circle in the middle, representing those components over which we have freedom to design and change. Surrounding this are rectangles representing the context, or systems which we did not have the ability to fully define or change.

Common Architecture Definition

For the MCAP III Mission Processor we identified four classes of external context subsystems: 1) External Communication Links, 2) Air Vehicle System Interfaces, 3) Payloads, and 4) Weapons.

Figure 4 shows an example context diagram for the MCAP III Mission Processor system. The systems referenced within the subsystems are representative of the superset configuration. Content within each rectangle is a representative example of possible subsystems.

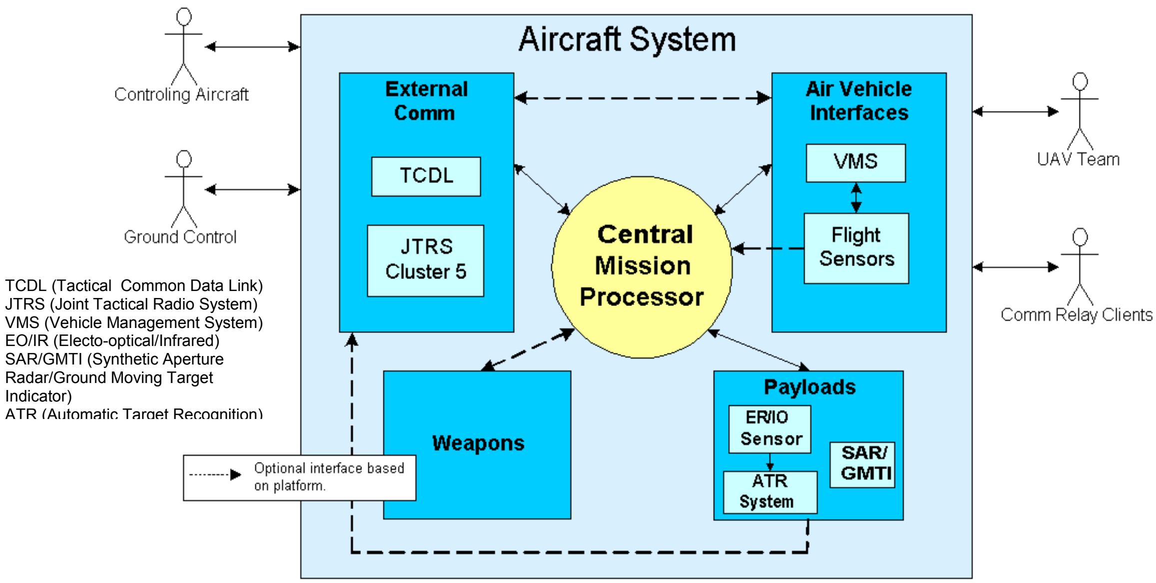


Figure 4. UCAP Context Diagram

The processing functionality in the UCAP is provided by multiple generic processing resources networked together through a switch fabric network which provides a high bandwidth path for inter-processor communications over PCI-Express serial bus. The switch fabric network supports IP-based traffic through encapsulation/extraction to allow applications running on the processors to communicate via Gigabit Ethernet (GbE).

Whereas the switch fabric network is provided to support inter-processor communications, the UCAP provides a GbE network to support platform interfaces to the UCAP and platform internetworking. This is a switched network supporting point to point gigabit connections to platform systems and processors. To connect the UCAP processing resources to the platform network, a bridge function is provided between the switch fabric network and GbE network.

Detailed Design and Development

The UCAP functional architecture is contained in a single processing domain. As shown in Figure 5, the system provides a basic set of functions; these include processing, networking, and data storage. The system also provides various interfaces for basic services like power, cooling, and battery bus (for real time clocks), as well as software interfaces to the processing functions like System of Systems Common Operating Environment (SoSCOE) and legacy applications.

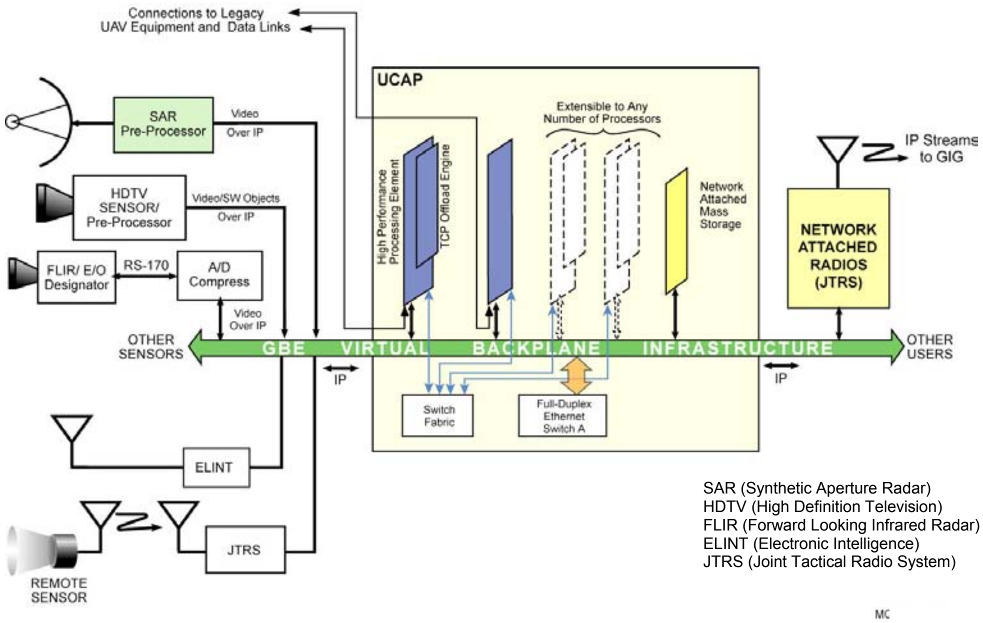


Figure 5. The MCAP III UCAP Architecture

The physical size of the processor assemblies for general purpose processing and switching meet the CompactPCI 3U form factor requirements. Additionally the UCAP provides a removable non-volatile storage device, which meets the Personal Computer Memory Card International Association (PCMCIA), PC Card Standard.

Analysis of vehicle platform requirements resulted in two physical form factors being necessary for the UCAP to scale between the range of processing and size, weight and power (SWAP) requirements. These were referred to as LRU-1 and LRU-2. LRU-2 was the smaller of the two, and accommodated 1/2 the processing capacity with 1/3rd volume compared to LRU-1. As shown in Figure 6, these LRU's are able to be configured as a single unit, or as networked cluster as in the case of the UCAR.

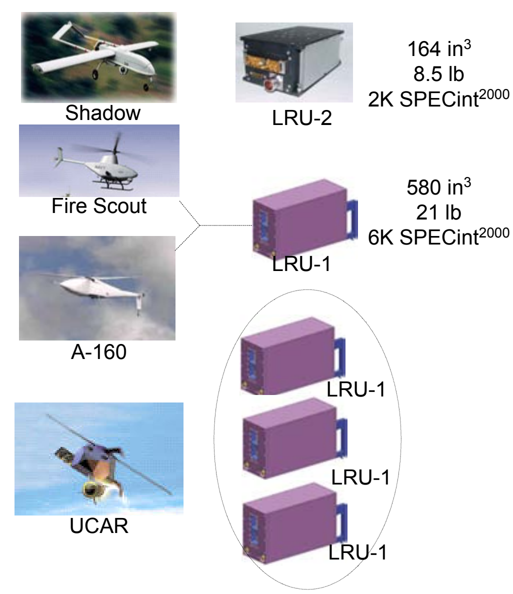


Figure 6. Platform System Configurations

Embedded Processing Architecture

To achieve the goals of interoperability and commonality, a single architecture was applied across multiple unmanned vehicles. As shown in Figure 7, the software infrastructure maximizes the use of common building blocks and open standards as interfaces between layers so that goals of openness, growth, technology insertion and interoperability could be achieved.

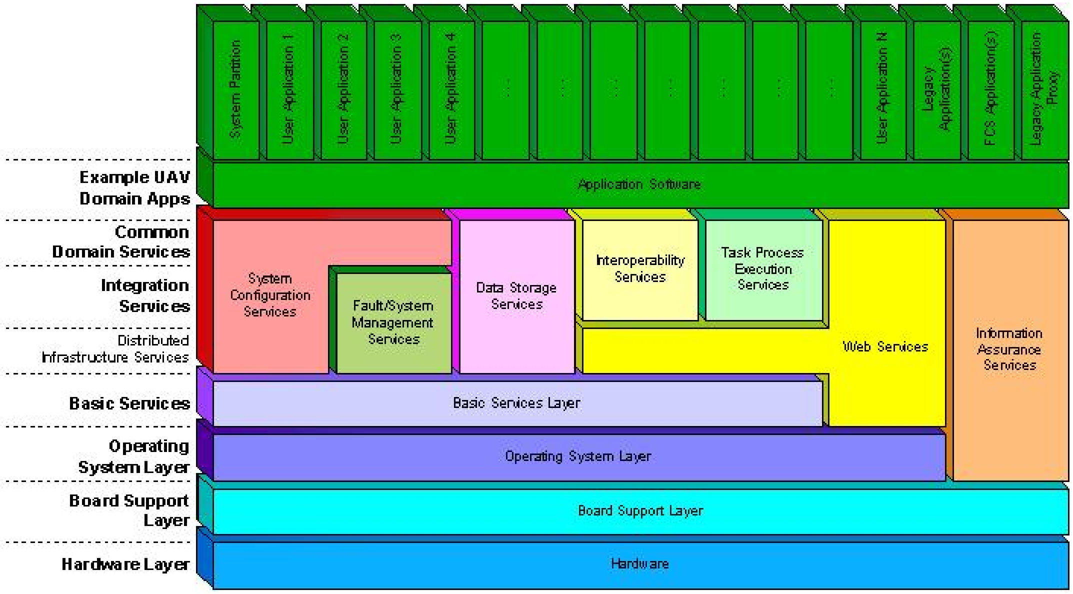


Figure 7. Our Approach Uses a Layered Architecture Based on Open Standards

The layers of this architecture include the Board Support, Operating System, Middleware, and Application layers. The Board Support layer is the hardware interface layer that consists of the hardware specific software required for operation with the MCAP III hardware architecture. Included in this layer are the standard Board Support Package (BSP), chip support package, boot code, and device drivers. The Operating System layer consists of the POSIX compliant LynxOS-178 operating system. LynxOS-178 is a COTS, real-time deterministic operating system that provides spatial, temporal, file service, LAN and kernel partitioning. The Federal Aviation Authority (FAA) has certified LynxOS-178 to DO-178B Level A in flight-critical applications.

The Middleware layers, consisting of Flight2 Operating Environment, and SoSCOE, provide functionality to the application layer for framework services, common infrastructure services, and information management services. Applications access these services through Application Program Interfaces that utilize open standards. The UCAP Design concept will adopt, through technology insertion, the FCS SoSCOE software layers/components as they reach maturity. This will ensure commonality with FCS SoSCOE and complete interoperability with future FCS C4ISR applications.

The Application layer consists of software applications specific to the mission of the UAV. This architecture supports both flight-critical and non-flight critical applications, and is envisioned to host SoSCOE applications developed by FCS.

Lab Demonstration

The prime objective of the demonstration was to validate the ability of the Mission Processor's architecture and infrastructure to service future ConOps-derived mission capabilities for all four UAV types. In order to accomplish this objective, a vehicle-in-the-loop lab demonstration was selected as our system test mechanism. The Shadow 200 platform was deemed the most highly volume-constrained platform and therefore this platform was chosen for the test.

The following key functions from the Shadow 200 Reconnaissance Mission were selected to be demonstrated:

- Automated Route Surveillance – Convoy Following: Including Automated Mission Planning, Mission Plan Execution, Autonomous Mission Re-planning and Execution, and Patrol
- Region of Interest – Includes Automated Surveillance, Enhanced Situational Awareness (Overlay of UAV Compass Heading on Map Image, Split Screen Display, Directional Payload Control for Photographic Reconnaissance, Auto-Route and Terrain Avoidance, Defined Corridors for UAV Flight), Automated Alternate Flight Plan/Reconnaissance, Automated Tail
- Autonomous Intruder Avoidance - Redirect "Evasive Maneuver" System

To accomplish these objectives, the demonstration system integrated Tactical Common Data Link (TCDL) (simulated), Payload Sensors (Electro-Optical/Infra-Red (EO/IR) and High Definition (HD) imagery) (simulated), Vehicle Management Computer (VMC), and UCAP Mission Processor (LRU-2).

A block diagram for the lab demonstration layout is shown in Figure 8. This environment included the forward body section of an AAI Corp. Shadow 200, with the prototype mission processor and Plug-in Optronic Payload-200 (POP-200) mounted in the fuselage, and High Definition Television (HDTV) cameras mounted to each wing. It also included a UAV Controller Station with a 4-tile display. Simulated TCDL provided the interface between the ground vehicle convoy-based UAV Controller and mission processor in the operational scenario. The following sections describe the demonstration systems in further detail.

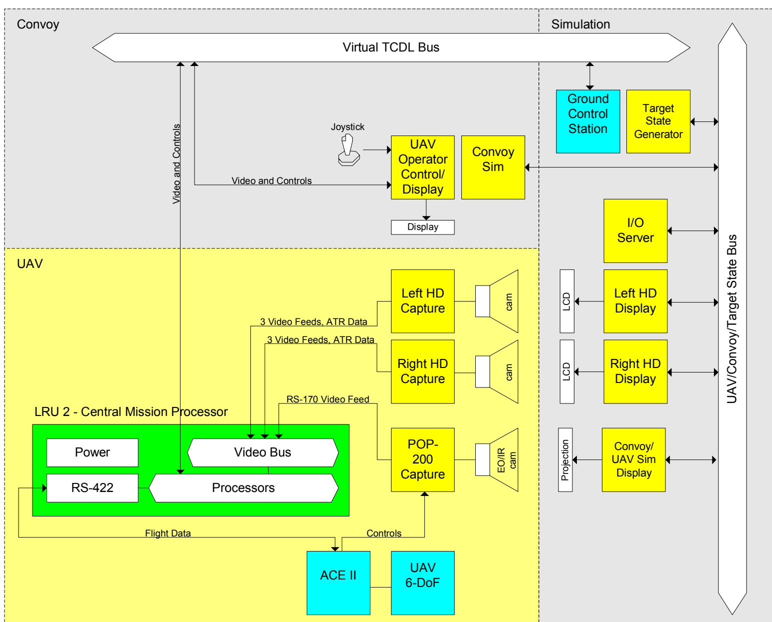


Figure 8. MCAP III Laboratory Demonstration Interfaces and Topology

High Definition (HD) Image Capture

Each of the two Capture Device Simulation Computers captures an image at 1920x1080 pixels through a pair of High Definition cameras. The image is cropped into three sections: a) the captured image down-sampled to a resolution of 640x512, b) the Region of Interest (ROI) at a resolution of Mx512, where M is a positive width from 0-640, and c) the Intersecting Region at a resolution of 640x1080, depending on HD camera field-of-view overlap. The second section is the UAV controller selection of the sub image from the combined left and right image displays being sent separately from the left and right capture devices. The third section is the intersecting sections of the left and right images, composing the overlaying parts for use in stereoscopic analysis. All video streams are compressed via JPEG2000 encoding and sent to the UCAP via Ethernet.

EO/IR (POP-200) Image Capture

The POP-200 EO/IR sensor captures a 640x512 RS-170 video. This video is compressed via JPEG2000 encoding and transmitted to the UCAP over Ethernet.

UAV Controller Display

The image in the Convoy UAV Control Station 4-tile display is presented as shown in Figure 9, with the top two sections representing the left and right High Definition video feeds down-sampled to half of the original resolution (640x512 each), the bottom left section representing either the High Definition section of the ROI selected in the top section of the display or the birds-eye view of the current UAV flight plan, and the bottom right section being the video feed from the POP-200 EO/IR sensor.

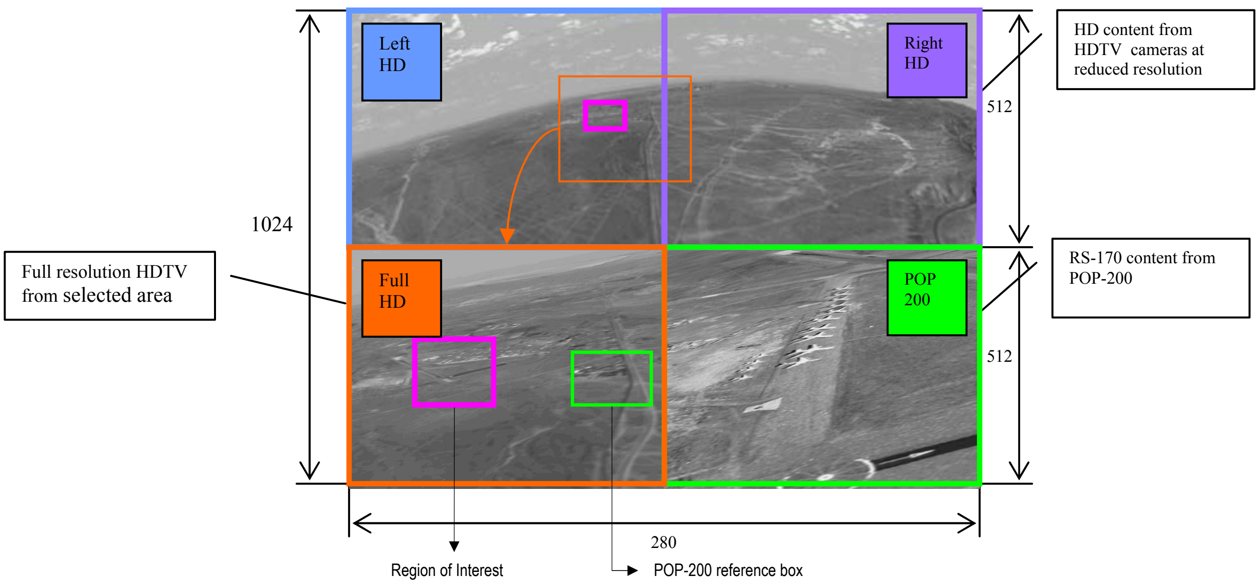


Figure 9. Convoy Controller 4-Tile Display Format

Mission Manager/Planner

The Mission Manager/Planner module, shown in Figure 10, processes mission information received from the Simulation Operator through the Communications Manager and the TCDL data link. The Mission Manager/Planner is further divided into Path Planning and Monitoring. The Path Planning module is generates a detailed UAV flight plan from launch location to the destination location. The Path Planning module is used to avoid terrain obstacles, re-planning to a target or threat location, and incorporates the surveillance behavior/pattern, as necessary, as a part of the UAV flight plan. The Monitoring module monitors the status of the RSTA, Sensor, Mobility, and Communications Managers and notifies the Mission Manager/Planner if a re-plan is necessary.

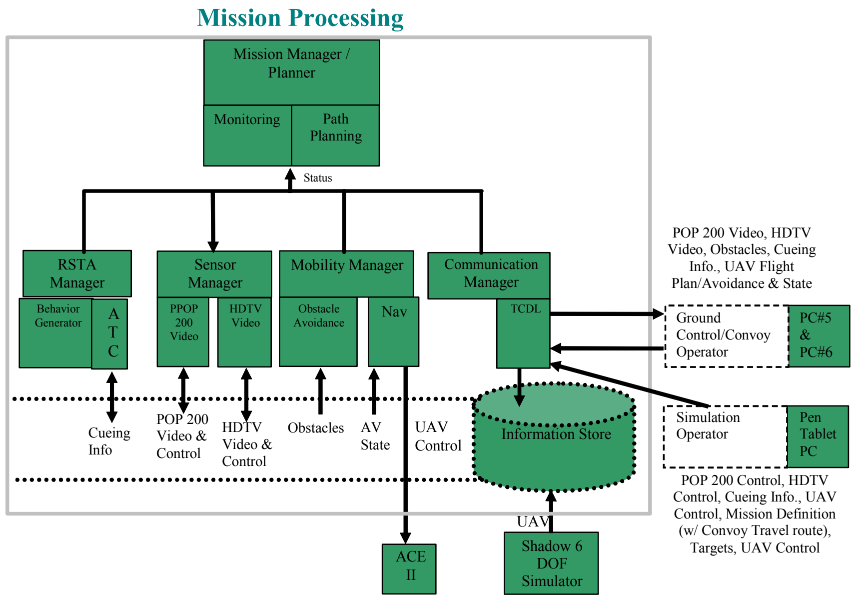


Figure 10. UCAP Mission Processing

Communications Manager

The Communications Manager provides basic management of the external communication sources (UAV to Ground Control/Convoy Operator & UAV to Simulation Operator) via the simulated TCDL datalink.

RSTA Manager

The RSTA Manager module uses the Behavior Generator module to generate a surveillance pattern(s) that fulfills the mission constraints for route surveillance, surveillance at a particular location, vehicle following, etc. That behavior information is provided to the Path Planner. The Automatic Target Cueing (ATC) module transmits target cueing information to the Ground Control/Convoy Operator and receives target cueing ("engage target") input from the Ground Control/Convoy Operator.

Sensor Manager

The Sensor Manager module receives information on the current UAV state, UAV flight plan and surveillance requirements. Sensor Manager arbitrates and automates the control of the available sensors (POP-200 video) for route surveillance, surveillance at a particular location, and vehicle following surveillance.

Mobility Manager

The Mobility Manager module processes the flight plan information and provides status of the UAV relative to the flight plan. The Obstacle Avoidance module is used to vector the UAV around dynamic air-vehicle obstacles, such as another UAV. The Navigation (Nav) module is used to send navigation control information to the ACE II flight computer and executes the flight plan.

Information Store

The Information Store is a database representation of the UAV's current world model. It facilitates data sharing by disseminating data between software modules within the UCAP. It implements a "publish and subscribe" mechanisms for data dissemination between software modules and for communication to external resources such as the Ground Control/Convoy Operator.

During each phase of the various scenarios, measures of performance will be captured and the data analyzed to determine requirements fulfillment. Those measures of performance are listed below.

Performance Measurements

For each of the scenario phases, the processor utilization, memory utilization and network loading will be measured while the system is tasked with various load scenarios. This testing is scheduled to be performed in October 2005.

Conclusions

The MCAP Phase III project developed a common embedded processing architecture that will reduce total ownership costs and enhance interoperability. In support of that objective, four representative platform types were surveyed and Operational Concepts were gathered, system requirements were defined and a common architecture using open standards and COTS components was designed for each. The performance of a smaller form-factor prototype mission processor will be measured in a system-in-the loop laboratory demonstration where representative applications were hosted that enabled increased autonomy.

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