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THESIS

CAPABILITIES ASSESSMENT AND EMPLOYMENT RECOMMENDATIONS FOR FULL MOTION VIDEO OPTICAL NAVIGATION EXPLOITATION (FMV-ONE)

by

Patrick N. Coffman

June 2015

Thesis Advisor: Raymond R. Buettner
Second Reader: Carl L. Oros

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After examining the capabilities of FMV-ONE, I believe that the Marine Corps' planned implementation within the geospatial intelligence community leaves the true potential of the software untapped. The underlying mathematical engine has capability expansion potential that can provide benefits across the functional areas of the Marine Corps, most importantly, to operations, fires, and aviation support. FMV-ONE's toolsets need to be expanded, and the software needs to be fielded to additional communities beyond the intelligence enterprise.

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Patrick N. Coffman
Captain, United States Marine Corps
B.S., United States Naval Academy, 2007

Submitted in partial fulfillment of the
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NAVAL POSTGRADUATE SCHOOL
June 2015

Author: Patrick N. Coffman

Approved by: Raymond R. Buettner
Thesis Advisor

Carl L. Oros
Second Reader

Dan C. Boger
Chair, Department of Information Sciences

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ABSTRACT

The Marine Corps has a capability gap in its inability to exploit full motion video in real time. Currently, Marines are unable to rectify, orthorectify, and georectify live video streams, which would allow for real-time geolocation coordinate extraction. MITRE Corporation's Full Motion Video Optical Navigation Exploitation (FMV-ONE) is a platform agnostic software solution capable of processing Motion Imagery Standards Board-compliant video streams. Using structure from motion theory, video is processed through computer vision-informed algorithms, and users are able to generate precision coordinates without the need for Controlled Image Base (CIB) or Digital Point Positioning Database (DPPDB) references. Additional capabilities include a multi-aspect video viewer, reference imagery generation and Cursor on Target export, and live video rewind.

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TABLE OF CONTENTS

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LIST OF FIGURES

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LIST OF ACRONYMS AND ABBREVIATIONS

3-D	three dimensional
ACE	air combat element
AFSOC	Air Force Special Operations Command
BDA	battle damage assessment
Bn	battalion
CAS	close air support
CASEVAC	casualty evacuation
CCD	coherent change detection
CDD	capability development document
CE	command element
CENTCOM	United States Central Command
CIB	controlled image base
COA	Course of Action
COC	command operations center
CONUS	contiguous United States
COT	cursor on target
DCGS-MC	distributed common ground system-Marine Corps
DOD	Department of Defense
DPPDB	digital point positioning data base
DST	direct support team
DTED	digital terrain elevation data
DVR	digital video recorder
FAC	forward air controller
FMV	full motion video
FMV-ONE	Full Motion Video Optical Navigation Exploitation
FO	forward observer
G2	intelligence section of a General officer-commanded unit
GCE	ground combat element
GCS	ground control station
GEOINT	geospatial intelligence
GFC	ground force commander
GPS	global positioning system
GUI	graphical user interface
HA/DR	humanitarian assistance/disaster relief
HLZ	helicopter landing zone

HQ	headquarters
Hz	hertz
IC	intelligence community
IDF	indirect fire
ISR	intelligence, surveillance, and reconnaissance
ITC	ISR tactical controller
JIPOE	joint intelligence preparation of the environment
JPEG	joint photographic experts group
JTAC	joint terminal aircraft controller
KLV	key length value
LCE	logistics combat element
LIDAR	light detection and ranging
LP/OP	listening post/observation post
MAGTF	Marine air ground task force
MARSOC	U.S. Marine Corps Forces Special Operations Command
MCPP	Marine Corps planning process
MCSC	Marine Corps Systems Command
MEB	Marine Expeditionary Brigade
MEF	Marine Expeditionary Force
MEU	Marine Expeditionary Unit
MGRS	military grid reference system
MISB	Motion Imagery Standards Board
MPEG	motion picture experts group
MOS	military occupational specialty
MSE	major subordinate element
MSOB	Marine Special Operations Battalion
MSOC	Marine Special Operations Company
MSOT	Marine Special Operations Team
MTT	mobile training team
NGA	National Geospatial-Intelligence Agency
NSG	national system for geospatial intelligence
O&M	operations and maintenance
OEF	Operation ENDURING FREEDOM
ODA	Operational Detachment Alpha
OIF	Operation IRAQI FREEDOM
OJT	on the job training
OSD	Office of the Secretary of Defense
OSRVT	one system remote video terminal

PACOM	United States Pacific Command
PED	processing, exploitation, and dissemination
PID	positive identification
PMMI	Program Manager, Marine Intelligence
POL	pattern of life
RDT&E	research, development, testing, and evaluation
ROMO	range of military operations
ROVER	remotely operated video enhanced receiver
RTP	real-time transport protocol
RVT	remote viewing terminal
S2	intelligence section of a field grade officer-commanded unit
SA	situational awareness
SFM	structure from motion
SFODA	Special Forces Operational Detachment-Alpha
SIPRnet	secret Internet protocol routing network
SLAM	simultaneous localization and mapping
SOP	standard operating procedure(s)
SOTF	special operations task force
SPMAGTF	Special Purpose Marine Air Ground Task Force
STA	sensor tasking authority
TAD	temporarily assigned duty
TS	transport stream
UAS	unmanned aerial system. See UAV.
UAV	unmanned aerial vehicle. See UAS.
VM	virtual machine
VMU	Marine Unmanned Aerial Vehicle Squadron

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I. INTRODUCTION

The Marine Corps identified a capability gap in its inability to fully exploit live full motion video (FMV). In its search to identify solutions to rectify, georectify, and orthorectify full motion video, Marine Corps Systems Command (MCSC) recommended a material development solution, and accordingly, a contract was let out to MITRE Corporation's National Security Engineering Center to fill this gap. They produced what is now known as Full Motion Video-Optical Navigation Exploitation (FMV-ONE). The purpose of this thesis is to analyze FMV-ONE's capabilities and make employment recommendations for implementation across the Marine Corps.

A. PROBLEM STATEMENT

The United States deployed thousands of unmanned aerial vehicles (UAV) to Iraq and Afghanistan to support combat operations. Reports estimate that in 2009 alone, UAVs produced so much video that it would take an analyst 24 continuous years to watch it in its entirety.[1] Without the ability to process the footage collected, this information is useless to commanders. Maj. Gen. Bradley A. Heithold, former commander of the Air Force Intelligence, Surveillance, and Reconnaissance (ISR) agency and current commander of the Air Force Special Operations Command (AFSOC), conceded that additional manpower will not be the answer, but rather, a technical solution is required to sift through all this data.[2] He further identifies that the predominant user requests from FMV is simple geo-location, that is, the identification of an object's position on the Earth's surface.[3] Researchers at the Draper Laboratory in Cambridge, MA

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[1]Defense Industry Daily staff, "Too Much Information: Taming the UAV Data Explosion," *Defense Industry Daily*, May 16, 2010. Accessed June 1, 2015, http://www.defenseindustrydaily.com/uav-data-volume-solutions-06348/.

[2] Stew Magnuson, "Military 'Swimming in Sensors and Drowning in Data,'" *National Defense*, January 2010. Accessed June 1, 2015 via http://www.nationaldefensemagazine.org/archive/2010/January/Pages/Military%E2%80%98SwimmingInSensorsandDrowninginData%E2%80%99.aspx

[3] Ibid.

also identified similar concerns in their studies about tactical geospatial intelligence when they said

> Geospatial intelligence, which includes maps, coordinates, and other information derived from imagery, can address many of the intelligence needs of a tactical user. A potentially rich source of imagery to inform this geospatial intelligence is the Full Motion Video (FMV) from the U.S. military's thousands of fielded Unmanned Air Systems (UASs). Current programs promise to dramatically increase the number of FMV feeds in the near future. However, there are too few analysts to process that flood of FMV, thus much of it goes unused.[4]

There are two current methods to derive geo-location from FMV: (1) sensor operator object identification ("call outs"), and (2) still imagery extraction. Both of these methods will be covered in greater detail in following sections, but it is important to note that while they generally have proven adequate to operational needs, they also have limitations. The four main limitations considered in this thesis are that the methods are time consuming, require specially trained low-density personnel and equipment, are subject to inherent UAV global positioning system (GPS) error, and in the specific case of call outs, suffer from singularity (only one object may be identified at any given time).

B. RESEARCH MOTIVATION

As an intelligence officer with multiple deployments to Afghanistan, I am intimately familiar with each of these limitations. If there were a way to derive the geo-location of coordinates in real time, users could avoid the deficiencies in the current state and reduce the need for archival storage of collected FMV. The full integration of the capabilities provided by our fleet of UAVs is restricted by the limitations on the application of the information they provide.

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[4] Richard Madison and Yuetian Xu, " Tactical Geospatial Intelligence from Full Motion Video," *Applied Imagery Pattern Recognition Workshop (AIPR)*, 2010 IEEE 39: 1, doi: 10.1109/AIPR.2010.5759699

C. PURPOSE

The purpose of this thesis is to analyze the capabilities of FMV-ONE and make employment recommendations to the Program Manager, Marine Intelligence (PMMI) at MCSC. FMV-ONE was developed with a generic concept of operations in mind that suited the requirements and acquisitions process and is in line with current Marine Corps geospatial intelligence doctrine. Given the Marine Corps' mission sets and culture of expeditionary operations, we try to make the most efficient use of any tool at our disposal and leverage capabilities to enhance the impact of limited-sized forces. This research will explore other potential applications of FMV-ONE beyond the narrow vision that accompanied the development and acquisitions process.

D. THESIS STRUCTURE

This concludes Chapter I, the introduction for my research. Chapter II will provide background information on UAV and FMV operations from a National to Tactical framework. Chapter III will (1) introduce the recurring vignette used for analysis, (2) provide an "as is" description of the current state of Marine Corps FMV exploitation, (3) discuss the limitations in the current state, and (4) introduce FMV-ONE as a potential solution. In Chapter IV, I will (1) examine the capabilities and application of the current software (version 1.1); (2) make recommendations for enabled mission sets with the current version; (3) recommend expanded toolset capabilities in future software version releases; and (4) describe the attendant enabled mission sets that accompany those expansions. In Chapter V, I will make a recommendation on force-wide employment theory based on both the current capabilities and upon the recommended expansions. In Chapter VI, I will conclude the thesis and make recommendations for future areas of study.

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II. BACKGROUND: OVERVIEW OF INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE PROCESS AND FMV APPLICATIONS

Uncertainty is a given condition of warfare. Commanders burdened with the risks of combat decisions attempt to reduce this condition through careful and determined preparation incorporating the efforts of intelligence, surveillance, and reconnaissance operations. Visual information complements the cognitive construct of human thought, and as such, military forces have often sought image-based information to reduce their environmental uncertainty. In the Global War on Terror, the United States has fielded a robust and ever increasing fleet of imagery and video collection assets coupled with the personnel and equipment structures to facilitate its analysis and employment. As technical capabilities increase, so too must employment and integration procedures. One of the most heavily employed constructs in this regard is the collection of FMV from an UAV and subsequent processing of it through geospatial intelligence (GEOINT) systems for integration into planning and decision making.

1. Geospatial Intelligence

Joint Publication 1–02 defines Geospatial Intelligence (GEOINT) as "the exploitation and analysis of imagery and geospatial information to describe, assess, and visually depict physical features and geographically referenced activities on the Earth. Geospatial intelligence consists of imagery, imagery intelligence, and geospatial information."[5] The National Geospatial-Intelligence Agency (NGA) is a component of the Department of Defense (DOD) and the lead agency for GEOINT within the United States Government. GEOINT exploitation includes analysis of electro-optical, infrared, and radar imagery; full motion video; moving target indicators; geospatial information; and spectral, laser infrared, radiometric, polarimetric, spatial, and temporal data.[6]

[5] Department of Defense, *Department of Defense Dictionary of Military and Associated Terms* (JP 1-02), Washington, DC: Joint Chiefs of Staff, 2015, 108.

[6] Department of Defense, *Joint and National Intelligence Support to Military Operations* (JP 2-01), Washington, DC: Joint Chiefs of Staff, 2012, II-16.

2. Intelligence, Surveillance, and Reconnaissance

In order to gather the raw materials upon which GEOINT processes may be applied; forces must conduct collection operations commonly referred to as Intelligence, Surveillance, and Reconnaissance (ISR) operations. Joint Publication 1–02 defines ISR as "an activity that synchronizes and integrates the planning and operation of sensors, assets, and processing, exploitation, and dissemination systems in direct support of current and future operations. This is an integrated intelligence and operations function."[7] ISR operations provide the input into the GEOINT enterprise.

a. Collection Platforms

Within the ISR structure, there is a variety of collection mechanisms available to the user depending on location and what type of information is needed. Some common collection platforms include, but are not limited to, satellites, manned/unmanned aerial assets, static recorders (e.g., fixed cameras, Aerostat balloons), ground sensors, and undersea sensors. For visual information, a commonly used platform in recent operations is the unmanned aerial vehicle (UAV). The military has used the UAV extensively in recent conflicts for both passive intelligence collection and munitions delivery (close air support).

b. Record Types

Depending on the platform and mission, there are different types of records created by the ISR asset. Examples include still imagery, full motion video, electronic signals and measurements, and radar returns. The focus of this thesis will be on full motion video from UAVs.

3. Motion Imagery/ Full Motion Video

FMV has become a staple for U.S. military operations over the past decade. With each service and agency fielding its own platforms, standardization is required to ensure inter-service and interagency cooperation. An overview of the generic employment

[7] JP1-02, 131.

scenario is provided for reference with added discussion about the specific functions that FMV provides to the commander.

a. Motion Imagery Standards Board

With the ability to capture video from ISR assets, the GEOINT enterprise gained an immense capability. As with any military equipment, standardization is required to ensure interoperability across users and maximize efficiency and impact. To this end, the NGA established the Motion Imagery Standards Board (MISB) under Department of Defense (DOD)-Directive 5105.60 in order 'to formulate, review, and recommend standards for motion imagery, associated metadata, audio, and other related systems' for the DOD, Intelligence Community (IC), and National System for Geospatial-Intelligence (NSG)."[8] As the responsible entity in the United States government, they have defined motion imagery as

> imagery [a likeness or representation of any natural or man-made feature or related object or activity] utilizing sequential or continuous streams of images that enable observation of the dynamic temporal behavior of objects within the scene. Motion imagery temporal rates—nominally expressed in frames per second—must be sufficient to characterize the desired dynamic phenomena. Motion imagery is further defined as including metadata and nominally beginning at frame rates of 1 Hz (1 frame per second) within a common field of regard. Full motion video (FMV) falls within the context of these standards.[9]

A common question arising from this definition concerns the difference between motion imagery and full motion video The MISB makes no formal distinction between the two terms, though the board does specify that motion imagery must contain metadata associated with the collection. Connotatively, however, FMV traditionally has been known as a subset of motion imagery whose frame rate is between 24–60 Hertz (Hz)

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[8] "Frequently Asked Questions," Motion Imagery Standards Board, National Geospatial-Intelligence Agency, April 18, 2015, http://www.gwg.nga.mil/misb/faq.html#section1.1.

[9] Peter Buxbaum, "Standards for Motion," *Geospatial Intelligence Forum* 9, no. 5 (July/August 2011):2. http://www.gwg.nga.mil/documents/Standards_for_Motion.pdf, 6.

(similar to television frame rates).[10] For the purposes of this thesis, the terms are interchangeable.

The MISB is responsible for standardizing key components pertinent to the exploitation of full motion video. The minimum standard requirements for MISB-compliant imagery systems are: (1) be digital; (2) produce a compliant MPEG-2 Transport Stream (TS), although this does not apply to JPEG 2000 based systems or streaming (real-time transport protocol (RTP)) based systems; (3) use MPEG-2, MPEG-4 Part 10 (H.264/AVC), or JPEG 2000 image compression; (4) produce non-destructive (not "burned in") metadata; (5) comply with the minimum metadata set in 0902; (6) add metadata elements as needed for the task (e.g., from 0102, 0604, etc.).[11]

Standardization is crucial to interoperability across services and imagery systems. Individual services may not possess organic ISR assets to suit all of their collection needs, and thus must rely upon external units for assistance from time to time. This is often the case of the Marine Corps, whose primary UAV assets are small and of short duration and range. Because of MISB standardization, however, Marine Corps units may employ Air Force or Army ISR assets with relative ease as it pertains to the control and exploitation systems.

b. FMV Operational Overview

The collection of FMV from UAVs is a process with multiple components that must work together to produce usable results. The key components in this structure are the platform, the operator, the customer, and the processing, exploitation, and dissemination (PED) personnel. None of the actors necessarily need to be geographically co-located or even regionally proximate. This structure is mostly beneficial, though at times the separation can be detrimental for close coordination. The interoperability of the components is based upon the standards established for imagery systems by MISB and Internet protocol that enables global communications.

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[10] "Frequently Asked Questions," Motion Imagery Standards Board.

[11] Ibid.

The ISR operational components work together based upon remote control and access to information streams. As shown in Figure 1, the platform transmits video and telemetry data to any properly configured receiving device (within range). The Ground Control Station/Operating unit can relay/upload this transmission onto the Secret Internet Protocol Routing Network (SIPRnet) for global availability. The customer provides guidance and mission control to the operating unit, who actually inputs control signals to platform and sensor. Lastly, the PED units exploit sensor information and create intelligence products for customer.

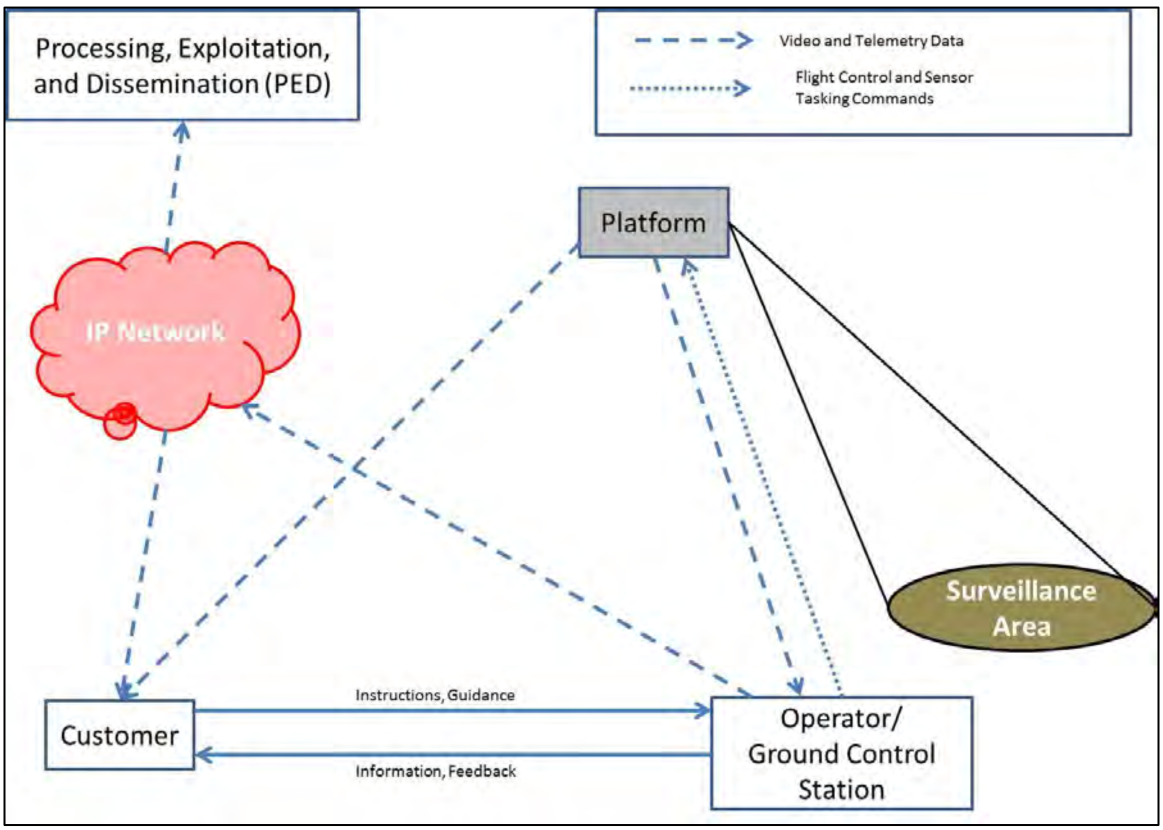

Figure 1. Intelligence, Surveillance, and Reconnaissance Operational Overview

(1) Platform

Numerous FMV-collecting platforms exist within the DOD ISR enterprise with global availability to Marine Corps units depending upon mission and region. These platforms range in decreasing size and capability from the globally-reaching RQ-4 Global Hawk down to hand-launched systems such as the RQ-12 Wasp. Some platforms, such as the small UAS family including the RQ-12 Wasp, RQ-11 Raven, and RQ-20 Puma, are organic to Marine Corps tactical level units. The Marine Corps also maintains three unmanned aerial vehicle squadrons that operate medium-sized Scan Eagle platforms. Other, larger UAVs such as the RQ-4 Global Hawk, MQ-1 Predator, and MQ-9 Reaper, belong to Army or Air Force units and must be requested via standard theater collection management protocol.

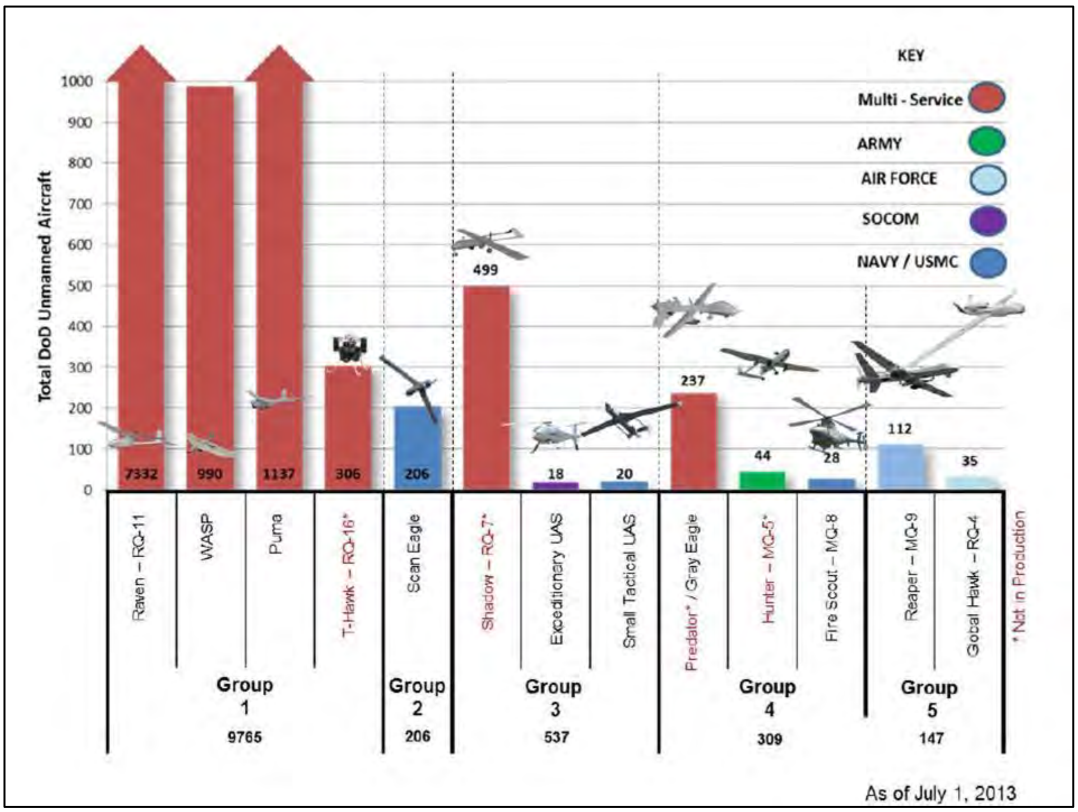

Figure 2. Current UAS inventory.[12]

[12] Vice Chairman of the Joint Chiefs of Staff and Under Secretary of Defense (AT&L), *Unmanned Systems Integrated Roadmap, FY2013-2038*, OSD Reference Number 14-S-0553, Washington, DC: Vice Chairman of the Joint Chiefs of Staff and Under Secretary of Defense (AT&L), 2011, 5.

Platform size and capability directly affect its operational employment. Small UAVs that are organic to the Marine Corps are generally for short range and short duration, and are used for immediate battlefield surveillance. The components of the ISR employment model typically are co-located, or at least geographically proximate. In these cases, the operator, customer, PED crews may be found in the same unit. With these platforms, the process complexity is greatly reduced, and responsiveness is dependent only upon the owning unit.

For the larger platforms that require external coordination, the process complexity increases, but the tradeoff for enhanced capability, range, duration, and analysis horsepower makes the additional coordination well worth it. It is under this model that the Group 3 and higher UAVs are operated.

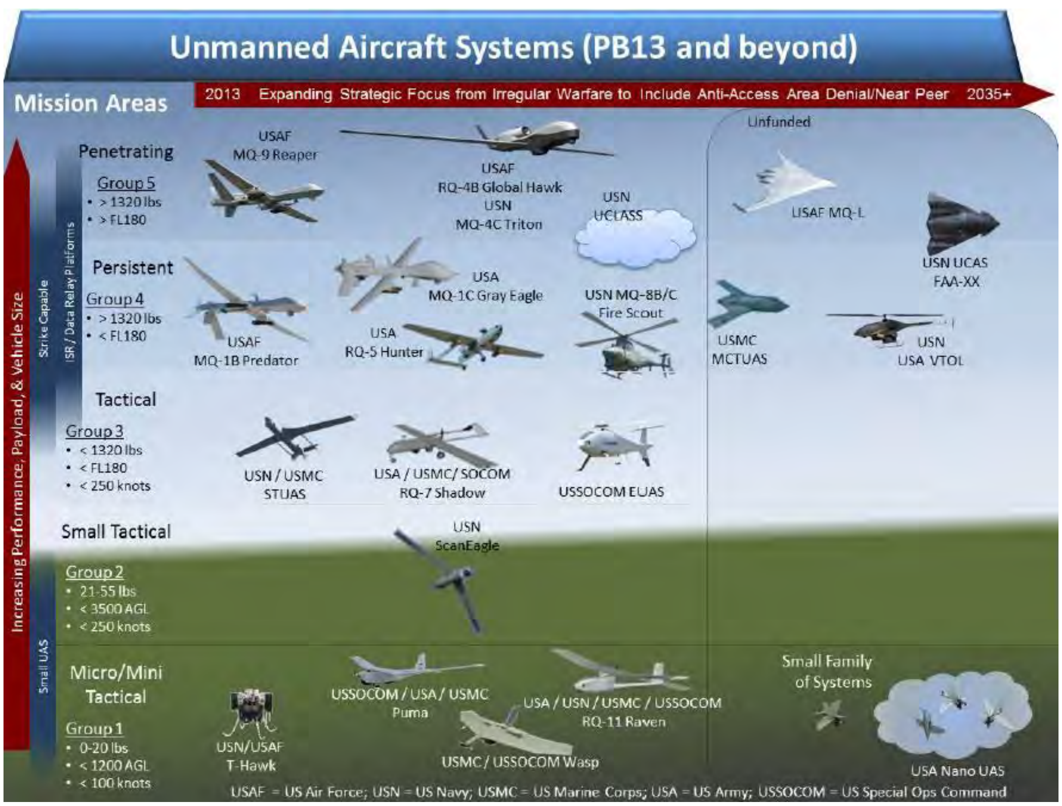

Figure 3. UAS Tiers and Comparison of Flight Levels.[13]

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[13] Ibid, 6.

(2) Operator

Entire units are dedicated to the operation of UAVs. Typically these company or squadron sized units are responsible for anywhere from 4–12 individual platforms. This includes not only the tactical employment (i.e., flying) but also the maintenance and other associated life cycle sustainment tasks. Depending on the size and capability of the platform, the operator may be regionally proximate to the target area (i.e., Predator, Reaper), globally separated (i.e., Global Hawk), or within direct line of sight (i.e., Wasp, Raven, Puma).

Each aircraft will have a dedicated crew to execute each mission. At a minimum, this includes a pilot and a sensor operator, but this standard varies among services. In deployed locations, these crews will operate out of a ground control station (GCS), with similar, albeit more permanent, structures established for the globally-distributed missions controlled from contiguous United States (CONUS) locales.

(3) Customer

The ISR customer is the unit for which the operator flies the platform. The need of the customer is varied, and the platform payloads are tailored to fill the specific mission requirements. Generally, the customer is geographically proximate to the target area, but this need not always be the case, particularly in the case of Group 5 UAV missions. The customer may need real-time visual information, or they may require more detailed post-mission analysis on the collected footage to translate the raw data to finished intelligence products. If properly resourced, the customer can view the FMV feed in real time, and in the case of a Group 2 and higher UAV, provide updated guidance to the operator throughout the mission via communications links.

The type of information extracted from the mission varies with payload, but geographic reference of the surveillance and reconnaissance target is a staple. In order to conduct operations, forces must know where people and places are. UAVs provide current information (and intelligence, when analyzed) for incorporation into mission planning and execution cycles. The customer may be an intelligence unit and possess the capability to perform some of their own analysis, but typically, customers will require external assistance in exploiting the collected information.

(4) Processing, Exploitation, Dissemination Units

Processing, Exploitation, and Dissemination units provide the external assistance customers require in analyzing the collected information from ISR missions. These are intelligence units with specialized equipment and training to exploit the FMV and other record types from the mission. Secure global Internet connectivity enables PED units to be located anywhere, similar to their flight crews. In fact, the establishment of permanent infrastructure in CONUS and other major bases for the PED process has been a necessity to keep up with the demand of UAV sorties. This arrangement allows a greater quantity of trained personnel to be available for mission support without the need to spend the money to deploy them to the forward location. Specialized equipment sets are easier to establish with reliable connectivity and operating environments, and associated technical support for the systems is more available.

PED units process the raw data received into a variety of finished intelligence products tailored to the needs of the customer. Examples include route studies for convoys, assessments of agriculture growth, identification of organic and manmade materials, and targeting or pattern of life support products. The rate of change of an environment outpaces the availability of traditional imagery collection assets, but the UAV in concert with dedicated PED crews is a tailored solution to this problem.

c. Availability and Access

The DOD fleet of UAVs has increased dramatically over the past decade due to increased demand and the subsequent attendant increase in funding for acquisition to fill the capability gap.[14] Deployed forces within the United States Central Command (CENTCOM) and Pacific Command (PACOM) are the predominant users of the fleet since that is where the majority of the Operation ENDURING FREEDOM (OEF) and Operation IRAQI FREEDOM (OIF) operations have transpired. The global need,

[14] Ibid, 14.

however, is detailed through the comparison of funding and inventory provided by the Office of the Secretary of Defense's (OSD) UAS Roadmap in Figure 4.

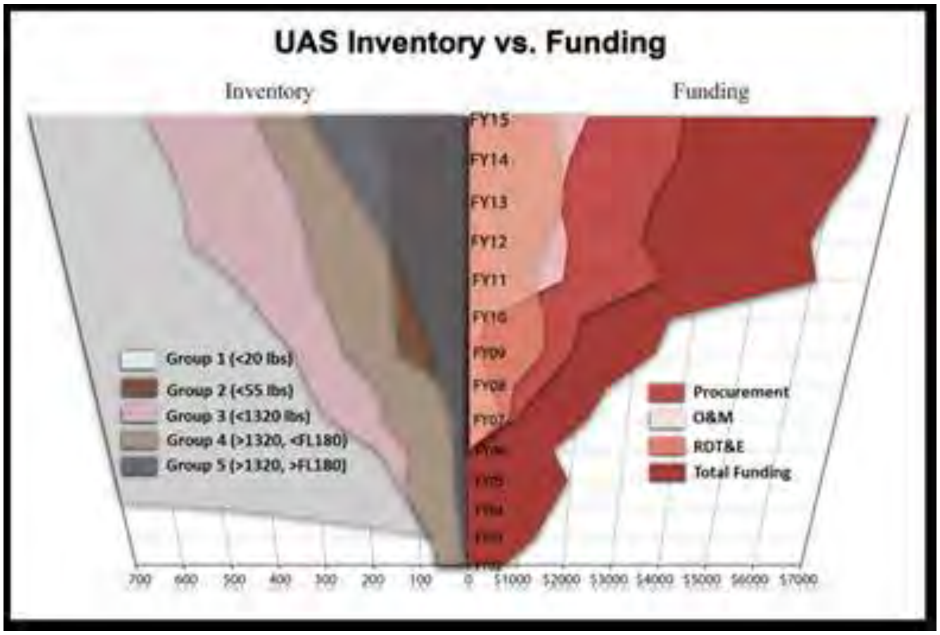

Figure 4. UAS Inventory versus Funding.[15]

The funding values highlight the developmental focus to incorporate rapidly advancing technology into our UAV fleets. Research, development, testing, and evaluation (RDT&E) funds for the past decade have nearly equaled the operations and maintenance (O&M) funds, with procurement outpacing both. Many systems were fielded in a rapid fashion to meet battlefield requirements and upgrades keep these older systems relevant, yet the advantages are undeniable in realizing the implementation of technological breakthroughs in the same time period. The trend of budget expenditures on unmanned systems in general, and specifically UAVs, will likely continue to grow as more capable systems are fielded to an ever-expanding scope of units and deployment theaters.

[15] Ibid, 4.

4. FMV Operational Applications

FMV can be used in a variety of scenarios in today's operating environments. Four key areas are situational awareness, command and control, intelligence collection and mission planning, and fires coordination and battle damage assessment. These functions are carried out by individuals and organizations with differing responsibilities, yet they often rely on the same mechanism to complete their mission: FMV.

a. Situational Awareness

The battlespace can be a chaotic environment. Holding the high ground in an engagement provides advantage in numerous ways, not the least of which is gaining a vantage point. This allows for visual observation of enemy forces and thus delivers precious time for commanders to align their forces advantageously. Today, the observational high ground can be achieved through UAVs. While the technology has changed dramatically over the centuries, the principle remains the same: see the enemy before he sees you and create for yourself a better understanding of your environment.

FMV feeds can be viewed in a variety of ways and are not restricted to static antennas linked to bulky computers and imagery systems. Expeditionary and tactical receivers enable maneuver elements as small as squads to see the sensor output from UAVs. Of course, headquarters elements in their combat operations centers (COC) can view the feed as well. Each element may gain different advantages from seeing the same feed, and communicating those impressions to one another will create a synthesized understanding of the environment. Greater access to UAV information enhances the situational awareness across the force.

b. Command and Control of Ground Forces

Long gone are the days of massing troop formations under direct visual and verbal control of their commanders. Distributed operations are the norm for deployed forces. This is not only a result of the counterinsurgency type of conflict we have been fighting in OEF and OIF, but also as a result of the demand signal for U.S. forces globally that requires small teams to deploy far from their home bases and higher headquarters. As an extension of situational awareness, UAVs allow for increased command and control capability of these distributed forces.

Managing multiple, dispersed maneuver elements simultaneously from a technology-enabled COC, in order to keep current on each mission, the commander relies upon radio communications and, often times, visual updates from UAVs. At the risk of micro managing tactical missions, UAVs give higher echelon commands the awareness and basis upon which they can make mid-course corrections if needed. A balance is struck between trusting the ground forces at the scene and providing aggregate, big picture information, that only a higher echelon COC has the advantage of knowing. To this extent, UAVs are invaluable to the conduct of regionally and globally dispersed operations.

c. Intelligence Collection & Mission Planning

Helmuth von Moltke is credited as being the first strategist to express the sentiment that no plan survives first contact with the enemy.[16] Accepting this truth, detailed preparation is a hallmark of successful military operations, if for no other reason than to identify mission contingencies should plans go awry. Intelligence collection is a cornerstone of this mission planning. The pace of daily operations in OEF and OIF requires a technologically aided intelligence cycle to keep up with the demand. UAV fleets have dramatically increased in size and capability to meet this demand, and even as we reduce forces in our primary engagements, the demand signal for UAVs in support of global intelligence collection continues to rise.

d. Fires Coordination & Battle Damage Assessment

Through the employment of combined arms, the ability to strike targets beyond one's physical line of sight is possible. Visual confirmation of targets, however, is still critical in our fires chain of approval, but with UAVs, we are released from the burden of needing human eyes within line of sight of a target. Now, the sensor on board the

[16] Antulio J. Echevarria, II, "Moltke and the German Military Tradition: His Theories and Legacies," *Parameters* 26:91-99 Spring 1996.

platform can relay the necessary information to all pertinent parties involved. This allows for reduced risk to personnel in manned assets, increases the element of surprise since sensor standoff distances greatly outrange that of the human eye, and with multiple people viewing the feed simultaneously in real time, the timeline for fires approval can be greatly reduced as well.

When combined arms are employed, there is no guarantee of effectiveness, and as such, battle damage assessments are required to determine munitions effectiveness, target impact, and determine potential future actions against the target. UAVs offer us the ability to examine these characteristics with the same standoff that the acquisition and targeting cycle enjoyed, in real time, and without the risk to force that a ground force examination would require. Physical examination by ground forces will always be the gold standard, but timely information and risk mitigation are well suited by UAV employment in their stead.

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III. CURRENT STATE, LIMITATIONS, AND ROAD AHEAD

A. VIGNETTE: OPERATION ENDURING FREEDOM

Deliberate targeting of insurgent leadership plays a crucial role in disrupting adversary operations but opportunities can be squandered because of the exploitation limitations manifested. To demonstrate the impact of the limitations in FMV exploitation, the following Afghanistan related ENDURING FREEDOM vignette is provided.

1. Scenario Description

Fox Company, a Marine Special Operations Company (MSOC), deployed to western Afghanistan with seven subordinate special operations teams and inherited a battlespace that covered nearly one third of the inhabitable country. The company's higher headquarters was located nearly three hundred miles away, and they provided additional support functions and retained the O-5 (Lieutenant Colonel) command level approval authority required for many combat functions in Afghanistan. The MSOC's teams were charged with varying missions that ranged from training Afghan Special Forces units, to establishing local police forces and conducting village stability operations.

One of the company's missions was to conduct raids, which are deliberate targeting operations seeking to kill or capture high value insurgent personnel. The intelligence support required for mission approval was substantial and the higher headquarters maintained veto authority at any time. Weeks of patient intelligence work and operations planning always seemed to balance precariously on the combined effects of the weather, regional narratives, and luck.

Midway through the deployment, the MSOC was planning a raid on a particular insurgent leader. The preparatory work for the mission was rigorous. The intelligence shop collected nearly 100 hours of surveillance video on the target, and had amassed significant numbers of human and signals intelligence reports as well. Once its headquarters approved the targeting justification materials, the MSOC shifted its focus to planning the immediate details of the mission. The intelligence process culminated in the production of a raid package.

The raid package was imagery intensive. The MSOC assessed the location of the target and completed a detailed analysis of the area. This included building and compound studies with specific items identified and measurements indicated from collected imagery. The MSOC requested additional imagery in order to ensure it provided the most accurate intelligence possible. The teams needed to know where all the doors and windows were, how tall and thick walls were, how wide the streets were, was there roof access, etc. Fortunately, the assessed location for this mission was a rural compound, which simplified the work, because without the congestion of urban life, compounds could be isolated for analysis with relative ease. All of the imagery requests were satisfied rapidly and analyzed in house by the MSOC's organic imagery analyst.

The Battalion commander felt comfortable with the rural location and all other details, and the mission was approved and scheduled. This was planned as a partnered mission with Afghan forces, so from the operations side, one of the training teams had to develop and rehearse the combined plan with their Afghan counterparts. From an intelligence perspective, the S2 ensured the updated assessments remained accurate from the initial justifications submitted weeks prior.

On the eve of the mission, however, the plans were disrupted. Within six hours of mission launch, the latest intelligence reports indicated that the target location had changed to an urban setting. The MSOC's higher headquarters wanted to cancel the mission unless the company could provide an updated raid package and scheme of maneuver for re-approval. The MSOC was now fighting the clock as well as the insurgents.

2. Process Deficiency Manifestation

Imagery analysis is time and resource intensive. Rectification, georectification, and orthorectification operations must be performed by a trained specialist on unique equipment with purposeful access to updated reference imagery databases. If any of these components is missing, the procedure cannot be completed. The more complex the area of interest, the more time intensive the process becomes. In this case, shifting to an urban location from a rural one significantly increased the complexity of the preparatory work.

In preparation for the mission, the MSOC had requested (and received) dedicated UAV support and the aircraft arrived on station over the rural site just as the S2 determined that the target location had changed. The updated raid package would require current imagery of the target site, complete with similar analysis of the details of the surrounding buildings. What was a relatively simple job for the MSOC's imagery analyst to conduct on the rural compound was exponentially more challenging and time consuming for an area covering two city blocks.

It was clear that the analyst would be unable to complete the task on his own. Sadly, though the S2 had over a dozen intelligence personnel in the shop, no one could assist either. The equipment for conducting measurements on full motion video imagery derived from UAVs requires specialized training, practice, and time. Notwithstanding the fact that the S2 only had one set of this gear at its location, only one other person was remotely familiar with its employment. The MSOC needed external assistance if this mission was to be salvaged.

It is common practice for UAV missions in Afghanistan to be supported by service members who are in the United States. Each aircraft has a crew associated with it for the Processing, Exploitation, and Dissemination (PED) of collected imagery. These airmen have similar training and equipment as the MSOC's imagery analyst, so they could assist with the raid package for the new target location. Fortunately for the MSOC, inclement weather in other parts of Afghanistan that night caused other UAV missions to be cancelled. This meant that those aircrafts' PED crews were on duty in the United States, but with nothing to do so the stateside shift officer told the S2 that he now had 30 analysts at his disposal. The MSOC imagery analyst directed these stateside PED teams and within an hour he had a finished product (Figure 6). The new location was approved by the MSOC chain of command and the mission was a success. Without the ability and luck to reach back to surplus manpower, this mission undoubtedly would have been cancelled.

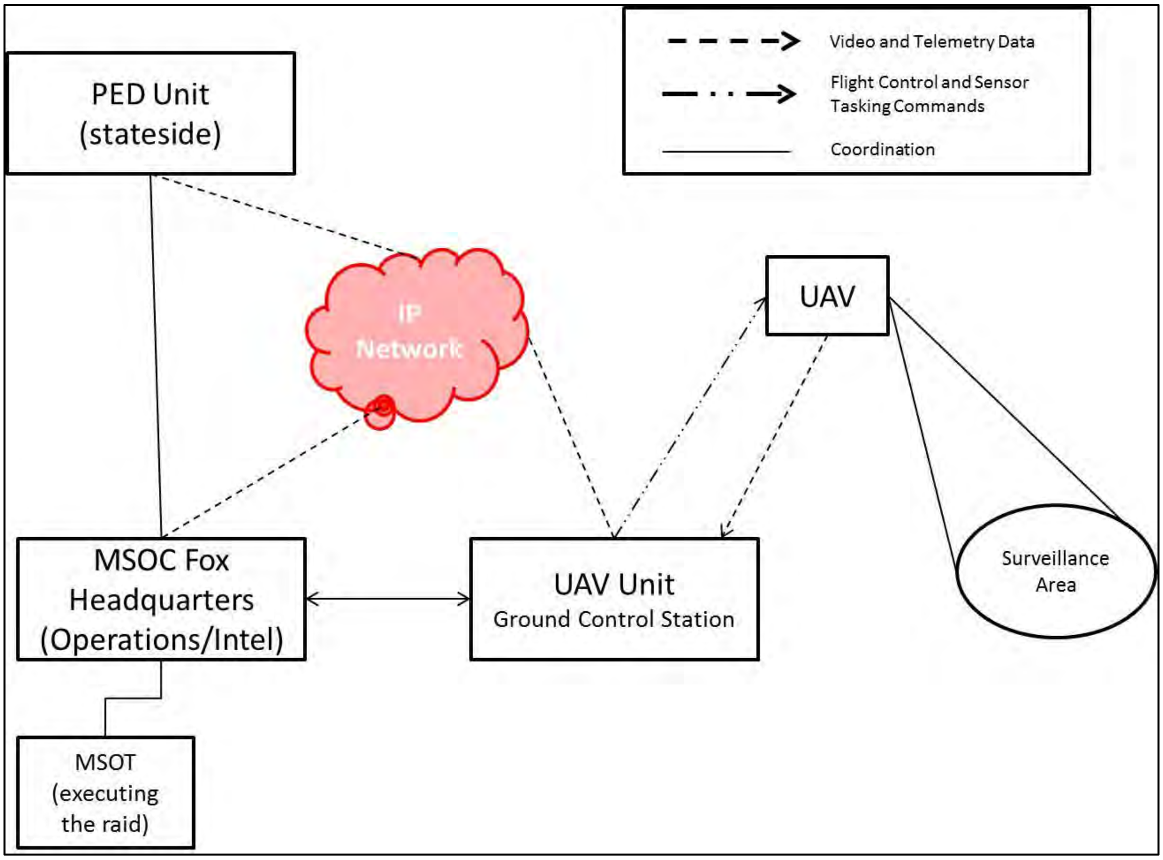

Figure 5. ISR Overview, MSOC specific.

Despite the successful outcome of the mission, the negative learning points must be internalized and addressed. Why is it so difficult to exploit motion imagery derived from UAVs? Why does it take special equipment and training to do what GoogleEarth can in my living room? In the most technologically advanced military this world has seen, this operational restriction is nearly laughable, if not utterly frustrating. It certainly has the ability to influence operations, and for that reason alone, it deserves everyone's attention.

B. CURRENT STATE OF USMC FMV EXPLOITATION

There are two primary ways to exploit full motion video in order to extract geolocation coordinates without the use of FMV-ONE. The first method (still imagery extraction) is for a trained specialist at the PED unit or customer level to manipulate the video footage and platform metadata through post-processing mechanisms on a geospatial workstation. The second method (sensor "call out") is for the sensor operator to physically move the crosshairs in real time, at which point the coordinates may be read off the FMV display or relayed over communications depending on the scenario. The former method is time consuming, but produces greater accuracy than the rapid, yet less precise real time method.

1. Method 1: Still Imagery Extraction

The Marine Corps trains enlisted Marines on the skills required to manipulate imagery for many intelligence and operations purposes. One of these purposes is to extract geo-location information for objects of interest. These trained personnel work on specialized equipment in dedicated intelligence shops or units in the pursuit of specific mission requirements as set forth by their commanders.

a. Personnel

The Marine Corps maintains GEOINT capability within the intelligence force structure with Imagery Analysis Specialists (Military Occupational Specialty (MOS) 0241) and Geographic Intelligence Specialists (0261). Imagery Analysis Specialists are the primary user/employer of FMV within the Marine Corps Intelligence Enterprise and operating forces. The imagery analysis field is for lateral transfers only, meaning that a Marine must first spend several years in another MOS before applying for transfer. Formal entry-level training occurs with the U.S. Army at Fort Belvoir, VA.

b. Unit

Imagery Analysis Specialists may be assigned to a variety of units within the Marine Corps. Example organizations include Marine Expeditionary Force (MEF) Intelligence Battalions, Marine Expeditionary Brigades (MEB), Marine Expeditionary Units (MEU), Marine Unmanned Aerial Vehicle Squadrons (VMU), and Division/Regimental-level intelligence sections (G-2/S-2). Equivalent sized units in the Marine Logistics Groups (MLG) and Marine Air Wings (MAW) may also rate Imagery Analysis Specialists. Commonly, the Imagery Analysis Specialist is located within a unit-level intelligence section that may or may not contain additional imagery-trained Marines.

c. Equipment

A typical employment scenario consists of a relatively stationary, office-like work environment with steady electrical power, Internet connectivity, and printing/display capabilities to support the given geospatial workstation. This work area may be a developed office setting or expeditionary in nature, but the basic components remain unchanged. The Marine will have a standard issue Marine Corps geospatial workstation computer to work on. This workstation will have a suite of approved software applications upon which the 0241 has received formal training and certification through their MOS formal schools process. This software and workstation are refreshed on a scheduled basis by service-level contractors to provide the specialist with the most current applications.

d. Mission

Imagery exploitation will be conducted in support of intelligence preparation of the environment (IPOE), operational planning, mission execution, and post-mission analysis, in both real world and training environments. One of the core capabilities of the Imagery Specialist is to derive precise geolocation coordinates. These coordinates can be used in a variety of products including, but not limited to, order of battle (OOB) studies, village and compound studies, route reconnaissance/lines of communication (LOC) studies, helicopter landing zone (HLZ) and expeditionary airfield studies, humanitarian aid/disaster relief (HADR) and crisis response activities, targeting, and any post mission analytical products such as battle damage assessments (BDA).

The process for extracting geolocation coordinates is depicted in Figure 5. Given the specialized workstation and formal schools training, the 0241 requires three separate applications and reference imagery along with Digital Point Positioning Database (DPPDB) coverage to derive precision coordinates (3-6 meter accuracy). One process flow includes as many as nine steps summarized as selecting the target in the video, extracting a still frame from the raw footage to align with reference imagery for first echelon grid refinement (using Controlled Image Base (CIB) reference imagery), then finding the corresponding target in DPPDB references for second echelon grid refinement and final coordinate estimation. As demonstrated in test environments, this process can take six minutes, though individual results will vary depending on conditions.[17]

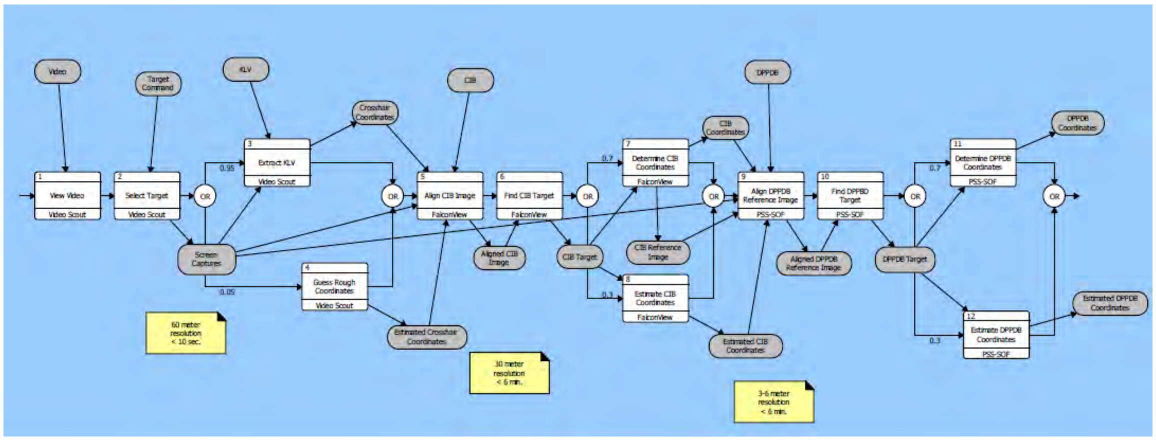

Figure 6. Geospatial Workstation Flow.[18]

With the derived coordinate in hand, the customer or PED unit will incorporate that into whatever mission planning product or command and control requirement they have. For long term projects, the repeated application of this lengthy process is not a critical factor, but for real time scenarios that require precision locations, this process may not meet the urgency of the situation.

2. Method 2: Sensor Operator "Call Out"

For units that are receiving UAV support but do not have trained Imagery Analysis Specialists, or do not have the time available to follow the first method, the sensor operator in the platform's mission crew can identify the coordinates required by "calling out" the location of requested objects. This method is faster than the deliberate still imagery manipulation, but it is also subject to inherent UAV GPS errors.

[17] Marine Corps Systems Command PMMI RTI Team, *Full Motion Video Exploitation Demonstration Plan, Version 1.3*, (Quantico, VA: 2014), 3.

[18] Ibid, 3.

a. Personnel

The sensor operator in a UAV mission crew controls the field of view for that platform. This can be an airman or soldier in a CONUS unit (Group 3+ UAVs) or a Marine organic to your unit (Group 1 UAVs). In the case of the Group 1 UAVs, the platform operator and sensor operator are the same individual; in the Group 2+ category, these roles are divided among the aircrew. Formal training of various lengths and rigor is required for each of these roles and responsibilities, and is conducted at varying locations according to service level requirements.

b. Unit

The operating unit of the UAV retains this capability. As discussed previously, these operators can be located as far away as CONUS military installations, and as close as the deployed area of operations. For Group 3 and 4 UAVs, this means U.S. Air Force squadrons and U.S. Army battalions, for Group 2 UAVs within the Marine Corps, this means the VMU. Smaller Group 1 UAVs are collocated with the customer. Communication with these operators is achieved through Internet chat software or radio transmissions.

c. Equipment

The sensor operator will require the standard control systems associated with their platform in order to manipulate the sensor in flight. This requires a reliable communications link to the platform, implying a logistics footprint including antennas. The standard employment for deployed locations is accomplished through a GCS laydown, while CONUS control is facilitated through similar architecture, albeit more permanent.

d. Mission

Within a UAV's FMV field of view, a fixed, centrally-positioned crosshairs can be placed over targets of interest and corresponding coordinates will be displayed on the viewing screen. This is accomplished as rapidly as the operator can slew the camera, within the mechanical limits of the device and under the restrictions of the platform's orbit. The resulting coordinate's accuracy is dependent upon the platform's internal GPS accuracy. Obviously, with one crosshair and one point of control, only one target may be identified at a time.

Guidance for the sensor operator depends upon the type of mission being flown. For ISR missions that support current ground operations, a member of the customer unit with sensor tasking authority (STA) will be in direct contact with the aircrew to direct their efforts. In the case of more routine collection missions, the sensor operator follows previously coordinated collection plans within his own judgment and sends the reports back to the PED unit and customer. Real time call outs are faster than the post-processing coordinate derivation, but they are limited in accuracy comparatively.

C. LIMITATIONS IN CURRENT STATE

As mentioned in the introduction, there are several limitations in the current state of FMV exploitation. The still imagery extraction method is time intensive and requires formally trained personnel on specialized equipment with access to reference imagery. The sensor operator call out method is limited by the inherent UAV GPS error and the singularity of the cross hair in the field of view.

a. Time Intensive

Time is money on Wall Street, but it can mean life or death in combat. While a few minutes spent manipulating software may not seem like a steep price to pay to derive accurate coordinates, it can spell victory or defeat for a unit whose mission hangs on that information. Understanding that the current process was created in concert with the tools available at the time, there is no reason why technological innovations should not allow us to simplify the coordinate derivation process and thereby speed up the whole cycle. Post-processing units are not truly exploiting "live" full motion video since they must extract still frames from the feed to perform their geospatial transformations, and even though sensor call outs meet the time requirement, they are limited in singularity and lack DPPDB-enabled accuracy.

b. Low Density Trained Personnel

Imagery Analysis Specialists are a low density MOS. Despite the capability they provide, employment is limited by their force-level quantity, which is in turn controlled by formal school throughput and doctrinal tables of organization. Formal training is valid for many tasks they perform, but to restrict the ability to generate DPPDB-enabled precision coordinates to a select group of individuals is a restriction the Marine Corps should not tolerate. Furthermore, intelligence is not the only functional field that requires or could benefit from coordinate information. If coordinate derivation is restricted to this field (Method 1) and to ISR customer's with STA (Method 2), the Marine Corps is overly constraining itself with respect to the exploitation potential of FMV.

c. Special Computers and Software

Requiring specific computers and controlled software packages to conduct coordinate derivation further restricts an already constrained work process and restricts widespread distribution to other functional areas, thus disenfranchising the rest of the MAGTF. A Marine unit may only have one 0241 assigned to them, and in all likelihood, that Marine will not have a spare geospatial workstation as part of his table of equipment. This places undue stress on this single functional point in the intelligence and operations cycles. The geospatial workstation is an immensely capable machine in terms of graphics and processing power, but like any high performance system, it rarely operates at full capacity. If the coordinate derivation process is simplified, thereby removing the complex and powerful computing requirements currently in place, a more widely available platform (i.e., a standard government provided laptop) should be able to perform the same functions.

d. Inherent Error in UAV GPS and Singularity of Call Outs

Sensor operator call outs occur in real time. Subject to the mechanical constraints and limitations of the sensor/platform combination and orbital characteristics, coordinates for targets of interest may be displayed as fast as the customer identifies the need. While this method of coordinate discovery meets the temporal classification of "live" exploitation, its inherent GPS error cannot be refined and the customer must accept the associated error with that sensor/platform combination. Under many circumstances, the accuracy of this type of call out suits the customer's needs, but in the even that they require more precision, there is no alternative to the time consuming post-processing derivation of the first method.

Sensor operators are further restricted by the physical crosshairs in the field of view. Only one target of interest may be identified at a time. Depending on the orbital considerations of the platform and the event being observed, the sensor operator may not be able to provide all of the coordinates that a customer requires for a given scenario. Suppose a person of interest is observed conducting some activity along the side of a building and the customer wants coordinates for several objects on that façade. Further suppose that just as the event was observed, that side of the building has gone out of the field of view of the sensor due to the platform's orbit. The only course of action is to wait for the platform to orbit back around and hope the objects of interest are still there. The singular nature of crosshair call outs, while likely not an epidemic issue, is an issue nonetheless that should be mitigated if possible.

D. ROAD AHEAD: FULL MOTION VIDEO OPTICAL NAVIGATION EXPLOITATION

The Program Manager for Marine Intelligence (PMMI) at MCSC submitted the requirement to address the capability gap manifested in the vignette and detailed in the previous sections. The specific requirements from the Capabilities Development Document (CDD) and a functional overview of FMV-ONE are provided below.

1. Marine Corps Systems Command & MITRE Corporation

As demonstrated by the vignette, Marines are currently unable to rectify, georectify or orthorectify full motion video in real time. As such, in conjunction with the development of the Distributed Common Ground System-Marine Corps (DCGS-MC), the Marines defined a requirement to address this problem.

DCGS-MC Intelligence Systems (IS) Capability Development Document (CDD) Requirement 6.1.3.36 Rectify, Georectify, and Orthorectify Still Imagery and Motion Video:

- DCGS-MC Increment 1 will have the capability to rectify, georectify, and orthorectify still imagery and motion video at 15 feet per second (fps) or less (threshold).
- DCGS-MC Increment 1 will have the capability, using standard discovery, to rectify, georectify, and orthorectify still imagery and motion/full motion video at 60 fps or less (objective).

Through the Analysis of Alternatives (AoA) associated with the Defense Acquisitions System, MCSC identified no existing solution to the capability gap, and thus recommended a new material solution be developed. As a result, MITRE Corporation produced FMV-ONE. FMV-ONE allows for true video exploitation, in real time, without the need for additional application interaction or use. Most importantly, FMV-ONE does not require reference imagery from the Digital Point Positioning Database (DPPDB) for comparison as the current methods do.

2. Functional Overview

When considering FMV-ONE, it is important to understand the theory behind why the software works, apply this theory to operational considerations, and ultimately, compare the current state to the road ahead.

a. Structure From Motion & Simultaneous Localization and Mapping

MITRE's solution is based upon the field of computer vision and the techniques of Structure from Motion (SFM) and Simultaneous Localization and Mapping (SLAM). Mathematical algorithms derived from SFM/SLAM theory allow for the estimation and reconstruction of a world state and sensor location in the presence of only visual sensor data and telemetry information from an unmanned aerial vehicle (UAV).[19][20] Continuous calculations are performed throughout a UAV's orbit in real time such that geospatial coordinates and elevation for any given point in the sensor field of view may be generated by a terminal user.

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[19] Patrick Coffman, (field notes, MITRE visit, 10-12 March, 2015).

[20] Stuart Heinrich, "FMV-ONE Math Review" (brief, MITRE Corporation, Bedford, MA, March 2015), iii.

b. Operational Considerations

FMV-ONE is based upon image processing, and as such, has certain computing constraints tied to its performance. Furthermore, specific considerations must be given to the source of the FMV that is to be ingested and processed. Lastly, and in contrast to current methods, it is important to understand that FMV-ONE can be run on multiple workstations simultaneously, providing cooperative work cases.

(1) Hardware Considerations

FMV-ONE is a platform agnostic software load; it may be run on nearly any computer. Current documentation aligns computer performance parameters with the specifications of the Marine Corps' geospatial workstation, though this is likely overly restrictive.[21] Optimization will occur with higher performance machines, but core level operation may be accomplished on much less robust or capable devices. Updated documentation outlining minimum requirements and recommended optimum specifications is forthcoming. Experimentally, the software may even run on a virtual machine (VM).

(2) Data Ingest

Data may be ingested into FMV-ONE via two primary means: (1) archival footage, or (2) live streaming. For archival operation, the system requires an MPEG.ts file with H.264-encoded video and MISB 601 KLV platform telemetry metadata. For streaming operation, an Internet protocol (IP) address and port number are required. The software accepts an MPEG.ts stream with all necessary data included, or it can be directed to two separate streams on separate ports, one with the H.264 video and one with the MISB 601 KLV metadata.[22] Transmission reception methods may be varied and are part of the recommended experimental research for proposed CONOPs. Colocation with

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[21] Dale Herdegen, Jenny Kancianic, Devin Lane, Nick Modly, Scott Robbins, and Allyson Smith, *Full Motion Video Optical Navigation Exploitation (FMV-ONE) System Administration Manual, Version 1.0,* (McLean, VA: MITRE Corporation, 2014), 1-2.

[22] George Moreno (MCSC Program Engineer, FMV-ONE), in discussion with the author, April 16, 2015.

a Ground Control Station (GCS) for the UAV is one method (i.e., VMU) to ensure data reception. Alternatively, client organizations only need access to an IP-addressed data stream via Ethernet cabling.

(3) Instance Operation

Multiple instances of FMV-ONE streaming the same transmission feed may be simultaneously running on geographically separated workstations. In its most basic functionality, FMV-ONE can serve as a multi-view FMV viewer. Application of geospatial tools is the intended use case, but to employ it in a more rudimentary fashion is possible as well. This multiplicative characteristic allows for any instance to exploit the video stream separately from every other instance, therefore creating opportunities to verify derived geo-coordinates at distributed locations or to divide work load within a given work section.

c. Work Flow Comparison

The current process of still image extraction and rectification is a complicated and time consuming endeavor. The work flow provided by FMV-ONE is more streamlined and requires fewer components. Simplicity is key.

(1) FMV-ONE Work Flow

FMV-ONE manifests the simplified process envisioned earlier. As shown in Figure 7, FMV-ONE reduces the process to three steps, all contained within the same software application. Furthermore, the process requires no specialized formal training or high performance graphics processing computers. Experimentally, the demonstrator derived the coordinate in less than one minute, with three-meter accuracy.[23] This surpasses the time required in the current process by nearly five minutes and eliminates the structural dependence upon reference imagery and DPPDB fusion.

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[23]Marine Corps Systems Command PMMI RTI Team, *Full Motion Video Exploitation Demonstration Plan, Version 1.3*, 4.

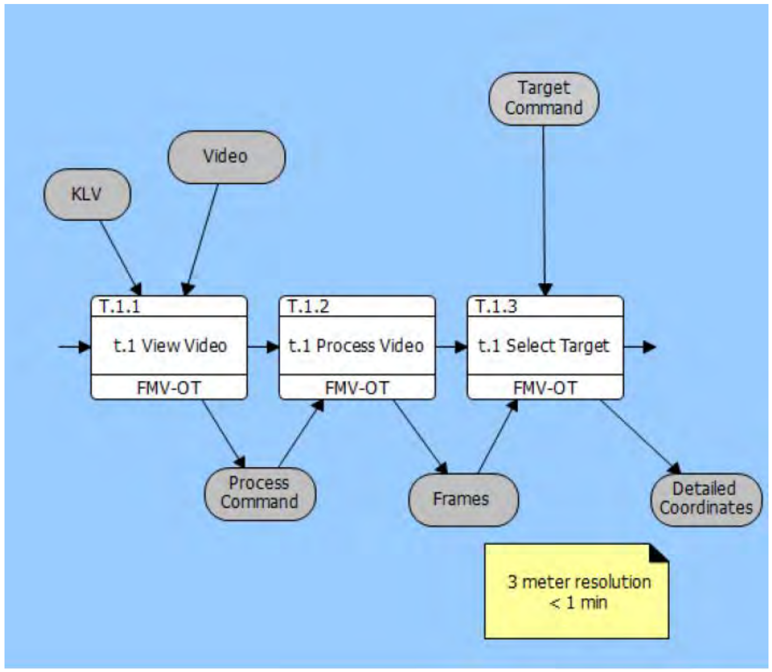

Figure 7. FMV-ONE Work Flow.[24]

(2) Process Comparison

In contrast to the nine-step, three-program process we currently employ, FMV-ONE derives coordinates in three steps and one program (Figure 8). The benefits from simplifying the process opens the coordinate derivation capability to reduced capacity workstations and collaterally trained Marines. No longer is precision-coordinate derivation the sole realm of the Imagery Analysis Specialist, but now it is available to any Marine or unit that has need of the capability.

[24] Ibid, 4.

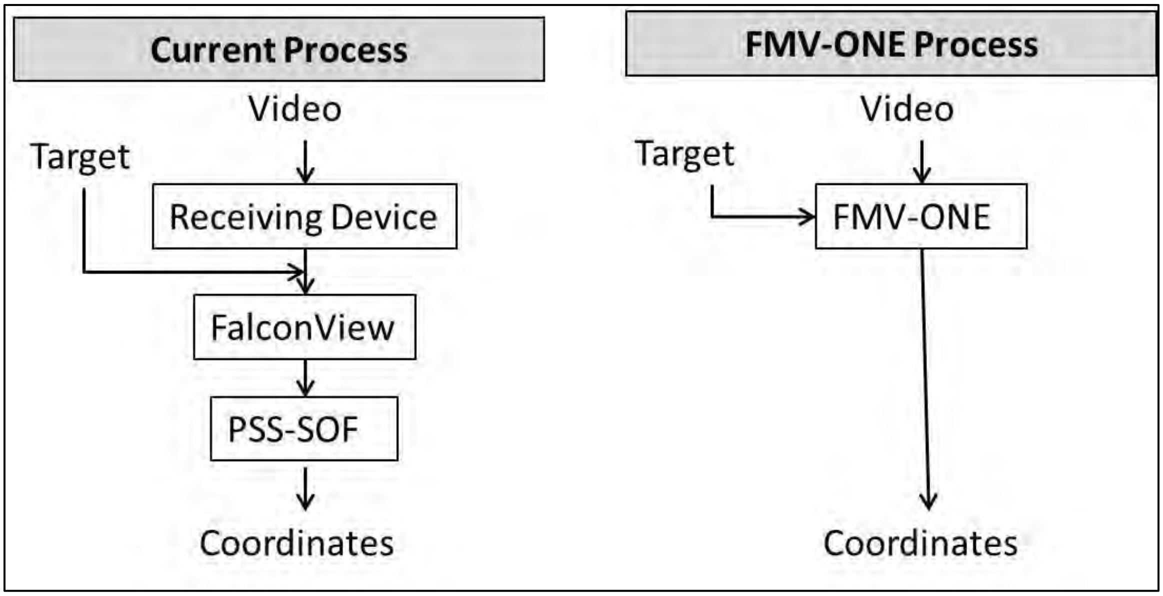

Figure 8. Work Flow Comparison.[25]

[25] Marine Corps Systems Command PMMI RTI Team, *Full Motion Video Exploitation Demonstration Plan, Version 1.3*, 3.

IV. CAPABILITIES ANALYSIS AND EXPANSION RECOMMENDATIONS

A. INTRODUCTION

FMV-ONE as a geospatial analysis tool for live video exploitation is the next evolutionary step in the way ISR video is incorporated into mission planning and command and control. MITRE and MCSC have demonstrated the functionality of the mathematical algorithms and developed an initial product release for operational fielding. The toolset included in this initial release is limited in comparison to current geospatial exploitation tools, but the real value lies in the mathematical processes and the expansion potential they yield.

In order to make employment recommendations, a survey of current capabilities and employment methods is covered below, followed by recommended expansion of capabilities and the attendant employment scenarios that necessarily follow. Ongoing software development can make these recommendations a reality in the not too distant future, and some toolset adjustments are already being worked on.

B. CURRENT CAPABILITIES

FMV-ONE has four primary functions. It may serve as an FMV viewer, it can generate MGRS points with user input, it can import and export GeoTIFF formatted files, and it can export Cursor On Target (COT) messages for ingest into external software programs requiring geocoordinate data. When compared against other fielded software packages in use within the DOD and U.S. government for geospatial exploitation, the application toolset functionality is limited. However, the potency in FMV-ONE rests with the demonstration of the viability of a new capability contained in the math engine and image processor. The expansion potential of the framework that Structure From Motion lays is exponential

1. FMV Viewer

As an FMV viewer, FMV-ONE has four main view options. The video feed may be seen in its raw format, as any other viewer would provide. It may also be viewed Sensor, Map, or Free view. Each option may be selected as the primary view in the main window of the software application, whilst the unselected view options remain available as smaller tiles along the border of the application window. The streams are continuously updated within all windows, and switching views is as simple as one mouse click. The main window also provides the generic geospatial information data associated with the UAV platform telemetry and GPS in an unrefined mode.[26] Sensor, Map, and Free view overlay the video feed onto base imagery and terrain data to give a 3D effect.

Sensor view provides a unique aspect for the user. The base imagery in essence is skewed to match the perspective of the sensor in flight as it moves around the target. The video stream is unskewed and viewed as it would appear directly from the platform, but with the imagery background constantly moving beneath it. This allows for a user to zoom in or out of the map to gain greater spatial situational awareness without having to change the zoom level of the camera. This is particularly useful in cases where pattern of life (POL) surveillance is required and continual positive identification (PID) of a target of interest is required.

Map view skews the perspective of the video to meet the form of an overhead satellite image and thus matches more accurately to a base imagery background file. This also is a unique view feature that FMV-ONE provides. Seeing the video in the context of base imagery or cartographic maps can allow for yet another aspect of situational awareness and for environmental comparison. These comparisons can allow the user to identify changes in the environment. These change detections are not technically aided such as the case with Coherent Change Detection (CCD) imagery, but rather, based upon the user's ability to discern changes with his own eye.

[26] This unrefined location data is a report of the internal platform GPS, and thus contains the organic error described. This is identical to the currently reported and displayed information from any UAV platform field of view or user display.

Free view is a view perspective that allows user manipulation in 3D with mouse input to alter the view point, similar to GoogleEarth. For users who are familiar with this functionality from other applications, or even from their personal use of this widespread software, the learning curve is shallow and the form factor acceptance will make usability more easily integrated into work flow.

Each of these views, excepting the Raw mode, can be overlayed upon digital terrain elevation data (DTED) to create a 3D perspective. With world-wide DTED easily available, this is a powerful enhancement for the end user. Given the current employment scenario aboard the Marine Corps' geospatial workstation, which comes with organic DTED, it is reasonable to estimate that any operational locale can be represented with elevation data. The user also may import his own base imagery, as created by FMV-ONE, to serve as the background in the event that there is no base imagery available. This also works well when the base imagery is outdated or inaccurate.

2. GeoTIFF Creator

The ability to create GeoTIFF files significantly enhances the organic intelligence capability of a Marine unit. CIB data is the gold standard for imagery analysis, but acquiring recent sets can be challenging in austere or rapidly changing environments. Marines historically operate in the far-reaches of the globe and in the aftermath of natural disasters, where current imagery is not available. FMV-ONE allows for the potential creation of CIB-like data with a single UAV orbit. Through the math described in chapter two, the software generates its own rectified, georectified, and orthorectified imagery that currently can be exported in GeoTIFF format. This exported file can be used in any software capable of processing it, including re-ingestion back into FMV-ONE.

The underlying process by which FMV-ONE can create and export GeoTIFF files is what allows for real time video exploitation. The world view estimation created by the image processor enables the precision location generation, and the formatting and exporting of a particular file is an added benefit of the work that the math engine already accomplished. The current export format is limited to GeoTIFF, although that may be expanded with new requirements.

3. Point-Dropper

In addition to the FMV viewer and the GeoTIFF creator, FMV-ONE enables the user to generate Military Grid Reference System (MGRS) coordinates or latitude and longitude coordinates directly in a live video stream. The user only needs to identify a geographic point of interest and click the mouse on a consistently identifiable (by his own eye) point between two and four times in the orbit. The associated error ellipse with each point decreases as the image processor works on the orbit, such that accuracy levels down to 3 meters have been demonstrated in tests.[27]

FMV-ONE generates coordinates based upon triangulation. As the platform orbits the target or point of interest, a minimum of two user inputs (mouse-clicks) are required, with increased accuracy gained up to four clicks. The recommended maximum accuracy is achieved with three clicks and diminishing returns are observed after four clicks. The error averaging process accounts for user-generated errors in mouse clicks, and the likelihood of clicking a slightly different spot on the target increases with each iteration. Therefore, the recommendation is between two and four mouse clicks.

Each MGRS generated includes an error ellipse for both lateral position and elevation. The error is a reduction of the uncertainty ellipsoid, which can be reduced further to a cylindrical approximation of error. This error is reported with a corresponding p-value of .90.[28]

4. Cursor on Target Export

FMV-ONE can export generated MGRS coordinates via standard Cursor On Target (COT) message format. The user can send the point information to any application that accepts COT message traffic given a host IP address and port number. The COT export includes latitude and longitude format, MGRS, and elevation. There is no error

[27] Scott Robbins and Kyle Fawcett, "FMV ON-Target, v 9.3a" (brief, MITRE Corporation, Bedford, MA, May 2012), 17-20.

[28] Stuart Heinrich, "FMV-ONE Math Review" (brief, MITRE Corporation, Bedford, MA, March 2015), 24.

ellipse transmitted in this message format, any recipient desiring the accuracy level of the generated point would have to acquire that information via separate channel.

5. Live Video Rewind

Similar to a Digital Video Recorder (DVR) that most people have in their homes now, FMV-ONE enables the user to rewind live video in five second increments, or to drag a cursor through the time bar to a specific frame. This new capability allows users to immediately re-investigate events or locations of interest as they occur. Current FMV viewers do not allow for this capability. The enhanced situational awareness to be gained from this ability is valuable because often times questionable actions observed on FMV, if confirmed, can contribute to justification for action against that individual, group, or location.

C. LIKELY USMC EMPLOYMENT OF CURRENT CAPABILITIES

In the development of the requirements for the CDD and the acquisitions process, PMMI MCSC had a vision of who would employ this tool and the manner in which they would do it. The personnel, units, equipment, and mission sets associated with geospatial FMV exploitation are outlined below.

1. Personnel and Units

The Marine Corps Imagery Analysis Specialist (MOS 0241) is the intended end user of FMV-ONE under the current employment strategy. This Marine is a formally trained still imagery analyst. Currently, the Marine Corps does not differentiate a video analyst by a separate designation or formal training. Historically, many Marines learn via on the job training (OJT) or short duration temporary assigned duty (TAD) schools to use full motion video in deployed environments. Even then, the exploitation is more accurately described as still imagery exploitation. That is to say, still frames are extracted from full motion video streams and manipulated in separate software for comparison against reference imagery in a traditional still imagery fashion.

Imagery specialists serve in a variety of units across the Marine Corps, as outlined in the previous chapter. They deploy with a standard geospatial workstation upon which to work that requires electrical power and Internet connectivity. Their ability to work in austere environments is limited only by the ability for their assigned or supported unit to establish a work environment with those characteristics. However, their workstation generally restricts them to an established work center such as an office or tent.

2. Missions

Imagery Specialists support their unit commander in numerous ways as a member of the intelligence section (G2 or S2). Their support to the intelligence effort includes anything imagery related. For generic characterization, imagery support is provided in the following phases of military operations: planning, execution, and post-mission.

a. Mission Planning

For the purposes of the planning phase, Imagery Specialists contribute to the Joint Intelligence Preparation of the Environment (JIPOE). JIPOE is a core mission of any G2/S2. This process contains four steps: Define the Battlespace Environment, Define the Battlespace Effects, Evaluate the Threat, and Determine Threat Courses of Action (COA).[29] Imagery analysis contributes substantially to each of these phases, either through initial characteristic identification or by sustained provision of updated imagery. Extracting precise location data for objects and features of interest is an important part of constructing the intelligence products used for the Marine Corps Planning Process (MCPP), facilitated through JIPOE.

FMV-ONE employment by an Imagery Specialist will allow for reliable precision location extraction in any environment. Responding to global crises and providing disaster relief often means that Marines will have inaccurate or outdated reference imagery when they arrive on scene, and in the worst case, CIB and DPPDB imagery may be non-existent. With FMV-ONE, this challenge is avoided altogether because the analyst may extract the MGRS grids directly from the live stream, or create organic reference imagery to exploit.

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[29] Department of the Navy, Headquarters United States Marine Corps, Warfighting Publication 2-3, *MAGTF Intelligence Production and Analysis* (MCWP 2-3), 2004, 5-2–5-25.

These coordinates can be used in a variety of products including, but not limited to, order of battle (OOB) studies, village and compound studies, route reconnaissance/lines of communication (LOC) studies, helicopter landing zone (HLZ) and expeditionary airfield studies, humanitarian aid/disaster relief (HADR) and crisis response activities, and targeting support packages like the one discussed in the vignette.

JIPOE is a continuous process, with sustained refinements created and injected into planning cycles as able and required. However, once an initial level of production is satisfied, a commander may proceed with missions. Once this step is taken, although the continuous JIPOE work will continue in the background, some intelligence efforts will shift to support current missions. In this vein, FMV-ONE can provide real time intelligence support to current operations.

b. Mission Execution

When available, ground force commanders (GFC) often choose to employ Intelligence, Surveillance, and Reconnaissance (ISR) support during their mission. ISR support can provide overwatch functions, target tracking and identification, or general situational awareness. Having "eyes in the sky" can be a great force multiplier if properly employed. An Imagery specialist working FMV-ONE in support of an ongoing mission can provide all of these things. In addition to the MGRS grid generation, the software also allows for local recording of the FMV stream to enable immediate rewind capability, distributed away from the Ground Control Station (GCS). The ability to rewind FMV streams in real time to re-inspect points or events of interest and analyze suspicious activity would be a significant addition to current operations mission support. From the higher headquarters command operations center (COC) or S2/G2, the imagery specialist could provide this input.

c. Post-Mission Analysis

Once the operation has concluded its execution phase, post-mission analysis is conducted. The results from this phase are used to evaluate mission effectiveness and contribute to future mission planning and execution decisions. One example of a standard post-mission analysis product is battle damage assessment (BDA). When close air support (CAS) or indirect fire (IDF) assets such as artillery or mortars are employed in the course of a mission, forces are required to assess their effects, both against the intended threat and against the non-combatant environment. Herein lies a potential challenge with a dependency upon DPPDB reference imagery for analysis. When a structure has been demolished or the landscape has otherwise been altered by high explosives, reference imagery databases do not update in real time. FMV-ONE would allow for the immediate generation of rectified image files to account for theses structural or landscape alterations. Current FMV study allows for generic BDA review, but cannot generate grids with the accuracy of FMV-ONE, nor can it generate new base imagery.

3. Vignette Revisited, Part I

If the MSOC intelligence team had FMV-ONE available to it on the deployment, the situation might have unfolded differently. At the point where the target location changed and a new raid package was required, Fox Company personnel could have contributed to the short-fused re-work required to regain mission approval. With the GeoTIFF exporter, the imagery specialist could have taken the processed data from a single UAV orbit and began manipulating it within his other software programs on the geospatial workstation. It is unknown if the MSOC still would have required some external assistance to complete the volume of analysis, but at the very least, a significant portion of the work could have been done organically on site.

D. EXPANDED EMPLOYMENT OF CURRENT CAPABILITIES

The Marine Corps' employment of FMV-ONE will be well suited to fulfill the missions discussed above. However, there is expanded potential for its use in its current version. Despite the limited graphical user interface (GUI) toolset in version 1.1, FMV-ONE can have a greater impact than what I believe the Marine Corps is currently envisioning in its geospatially-restricted fielding. Additional units and personnel beyond imagery specialists and their traditional work sections should have access to this software load to employ for an integrated effort across the Marine Air Ground Task Force (MAGTF).

1. Equipment

As a software solution, FMV-ONE should not be restricted to fielding only within the standard geospatial workstation. Optimal performance recommendations may dictate certain hardware standards that can only be achieved within that configuration; however the software will still function on less capably configured laptops and virtual machines, albeit with some reduction in performance speed.[30] This implies that other personnel may capably employ the software on their assigned general purpose computers. Any Marine who has need of the capability that FMV-ONE provides should be able to use it, not just the imagery specialist in an intelligence section.

Graphics processing is at the heart of the computational work performed within FMV-ONE. The geospatial workstation is optimally configured to perform this task with speed, but this does not preclude other workstations from also running the software. Standard intelligence workstations should be capable of executing the software, as should the computers found in a COC or Air/Fires shops. As a software load requiring no associated hardware adjustments, FMV-ONE is optimally suited for widespread distribution and employment across the family of Marine Corps computing systems.

2. Personnel

Employment of FMV-ONE does not require formal schools training or the assignment of an MOS code. The imagery specialist may be the most thoroughly trained Marine for this purpose, but the ease of use of FMV-ONE enables any collaterally-trained Marine to operate the software effectively. An on the job training (OJT) or mobile training team (MTT) session of one day will be sufficient to gain basic proficiency for anyone with cursory computer familiarity.

Intelligence, Communications, Command and Control, Fires, and Aviation are key communities of interest to receive this cross training. Every Intelligence Marine in an S2/G2 should be capable of using this software. Marines working in COCs or associated with command and control of current operations should also be proficient in its use. This

[30] Patrick Coffman, (field notes, Naval Postgraduate School, Monterey, CA, March 2015).

group often includes communications-coded MOS Marines. Fires personnel will find use in the SA-value of the software, even though it is not National Geospatial-Intelligence Agency-certified (NGA) for targeting grids yet. Forward Observers (FO) and Joint Terminal Aircraft Controllers (JTAC) could employ this software to great effect. Aviation Marines can use it as well, since mission planning depends largely on geospatial considerations. Though intelligence Marines are involved in the planning process at all echelons and types of units, why restrict a capability to one, low density field of operators?

Designating a primary MOS and employment method is necessary for the administrative processes that the Services follow in acquisition and fielding of equipment, but operational employment cannot afford to be restricted as such. Marines fight as a team and will do whatever is necessary to accomplish the mission. The employment potential of FMV-ONE dictates that additional personnel be trained to use it in order to maximize affects.

3. Units

Employment of FMV-ONE outside of the intelligence sections and units of the Marine Corps will increase its impact. The Intelligence Battalions and other units listed previously certainly will make ample use of the software to support planning and operations, but fielding this capability to additional units will enhance its effect. Given the ability of the software to be employed by nearly any collaterally-trained Marine on available computers, there is no reason why FMV-ONE should not be found in every Marine Corps unit. This is not to say that collateral employment will replace or subvert deliberate intelligence processes, but rather, we may gain enhanced, distributed situational awareness as individuals make use of the software in their own unique fashions.

Each component of the MAGTF should use FMV-ONE to meet their own needs. Although the software fits nicely into the intelligence niche, the GCE, ACE, and LCE can benefit from organic employment outside of dedicated intelligence purposes. The situational awareness created by the various view options is a C2 enhancement that any

MOS or mission can benefit from. Immediate extraction of accurate grids facilitates mission control and continuous geospatial awareness can decrease timelines for requested support such as CAS or resupply if the situation demands it.

4. Missions

In its current form, FMV-ONE is well suited to support command and control functionality and general situational awareness. Any MAGTF component can benefit from these enhancements. Dedicated intelligence personnel are not needed to provide a partial solution of a full JIPOE process. While collateral employment is no substitute for integrated planning contributions of the full intelligence enterprise, sometimes an organically-derived eighty percent solution that is available immediately will answer the mail.

Command and control during the past fourteen years of combat operations in Operation IRAQI FREEDOM (OIF) and Operation ENDURING FREEDOM (OEF) has cultivated a nearly insatiable appetite for information. COCs the world over have network and communications connectivity that enable nearly constant and instantaneous contact to operating forces. For better or worse, commanders have grown accustomed to (and in some cases reliant upon) immediate access to their subordinates at all times. This constant communication can be an obstacle to efficient operations at times. The verification of geospatial details of a mission or event updates can occupy unnecessary time and effort in a ground forces commander's (GFC) work load. FMV-ONE in a COC can relieve some of these information requests by allowing C2 personnel to exploit FMV mission data on their own, in real time, without interrupting the tactical mission. Furthermore, when intervention by a GFC's higher echelon is needed, the higher unit may enter the scenario with enhanced situational awareness.

UAVs provide more than just an extra set of eyes for GFCs and COCs. When armed, they can provide close air support. Even without NGA certification of derived grid coordinates, FMV-ONE can assist in call for fire situations by increasing baseline situational awareness for all approval entities involved. On past deployments, release authority for UAV-carried weapons often rested at the O-5 (Lieutenant

Colonel)/Battalion command echelon. Despite attentive monitoring of current operations, when a call for fire was initiated, there was inevitably a time lag before the releasing authority was brought up to speed on the current situation and felt comfortable with the scenario's risks in order to approve the weapons release. With FMV-ONE, a releasing authority may be quickly brought up to speed on events, grids, force locations, and collateral damage estimates by his own COC personnel. Deriving accurate grids at the commander's guidance and the ability to rewind the FMV to assist in building his SA and comfort level is an invaluable addition to the Marine Corps' current close air support procedures.

Beyond weapons, UAVs can carry payloads that support intelligence disciplines beyond imagery intelligence. As with any aircraft, UAVs are subject to the payload restrictions, and to date, this has often restricted platforms in their ability to carry out multi-discipline missions simultaneously. With technological advancements reducing payload sizes, this concern is decreasing. Combining disciplines on smaller aircraft, coupled with the use of FMV-ONE can allow for an integrated, real time intelligence picture. Cross-verifying multi-discipline information instantaneously increases its validity and value as analysts process it. Furthermore, cooperative discipline missions from a single platform will decrease the stress on an already overtasked fleet of UAVs, thereby reducing operational footprint and ultimately, operational costs.

UAVs fly in support of units that are separate from the personnel that operate the platform. The UAV mission team (i.e., pilot and sensor operator) typically is not geographically collocated with the supported unit. The supported unit usually supplies an ISR Tactical Controller (ITC) who provides guidance and direction to the platform's mission team via Internet communications channels or radio transmissions. This guidance and direction include sensor tasking authority (STA) to control not only the platform, but the sensor payload. The ITC is responsible for maintaining SA of the ground force and the UAV and coordinating their actions. FMV-ONE's viewer capacity is well suited to meet the needs of an ITC with STA. The ITC can be an imagery specialist in an intelligence shop, a JTAC on patrol, or any other suitably-trained Marine tasked with the job. The viewer functionality described earlier enables the ITC to perform whatever functions may be required of him in the conduct of a mission.

The current capabilities of FMV-ONE will be employed well under the current operational plans within the geospatial community but with a few expansions in fielding destinations and personnel, its impact could grow. The functional tools available in the GUI are limited compared to other current programs, but the situational awareness enhancements it can provide are value enough to warrant its widespread fielding across the MAGTF. FVM-ONE's impact will continue to expand as increased toolsets are added and algorithm updates are pushed to operating forces.

E. RECOMMENDED EXPANDED CAPABILITIES AND TOOLSETS

FMV-ONE acceptance in the Marine Corps will be based upon usefulness. Despite academic and programmatic personnel acceptance and support, operators will need to see the impact and benefit in order to believe in it; otherwise, it will remain an unused desktop icon. The current motion imagery exploitation process is familiar and provides a solution to planning and operational production requirements. Despite FMV-ONE's revolutionary processing algorithms, if the operator cannot create similar products to support his mission, the software will simply not take hold. To this end, the toolsets available in FMV-ONE must be expanded, which in turn will expand the mission set it can be applied against.

1. Measurement Tool

FMV-ONE should have the capability to conduct linear measurements directly within the application. Linear measurements are a core task for imagery specialists and one of the most basic requirements in mission planning and execution. If the operator can calculate distances in the same screen that the video is viewed in, the software has added value in that it removes a step in the current process. Similar to MGRS grid generation, in order to conduct measurements, a still frame must be extracted from the video stream and matched against reference DPPDB imagery in a separate program resident to the geospatial workstation.

Storing and exporting aggregated measurement lists needs to be included. As an operator creates measurements, the software should store the endpoints and distance in a spreadsheet format, possibly comma separated value (CSV) that is readable in Microsoft Excel or a similar program. Mission planning products often require detailed information of this nature, and this is one way to create value for an operator by potentially making their job easier.

2. Annotations

FMV-ONE should have the capability to annotate the screen with comments and shapes and export that information. Naming points vice sequentially numbering them will make the point dropper a more user-friendly tool as well. Shapes, shading, and text should be integrated as a drawing toolkit. When a user creates any of the above annotations, the object should remain in place geospatially as the UAV orbit continues, thus enabling quick reference as the orbit or mission proceeds. These shapes should be able to be turned on and off to clean up the screen view if needed as well. Furthermore, a user should be able to export a screen capture of any frame to include the annotated overlay. The tool should allow the user to specify dimensions of a shape instead of relying solely upon the user's mouse inputs.

3. Export of Point-Dropper List

FMV-ONE should have the capability to export aggregate lists of generated MGRS points. Production of intelligence and mission support documents often requires lists of important grid locations. As an operator creates these grids within FMV-ONE, the program should store and allow for export via some spreadsheet format (e.g., CSV). Within the point-dropper capability, the user should be able to change the name of the point from a sequential number to text of his choosing. Naming a compound after the owner is more user friendly than labeling it "Point 1."

4. 3-Dimensional Model Generation

FMV-ONE should be able to create 3D models of the scene around which the platform flies. Visualizing terrain from different points of view aids mission planning significantly, and is particularly valuable for pilots and reconnaissance teams. DTED is useful in approximating an environment, but the integration of man-made objects is essential for a thorough product. In addition to creating its own elevation-inclusive data (in the absence of DTED, or in order to update DTED), FMV-ONE can bring the added benefit of including the necessary man-made objects. Once the model is constructed in near real time, the point of observation should be user-selectable with zoom capability once that reference point is established.

3D model generation should allow for route fly-through simulations. This function will support both ground and air operations. The point of view for the simulation should be altitude-adjustable so the user can tie it to ground level or any specific altitude to replicate a flight profile. Again, the simulation should be able to be paused at any point and the point of view manipulated in six degrees of motion to provide the planner/operator with maximum environmental considerations.

Line of sight studies should be incorporated into the model toolset as well. As a reconnaissance team is selecting their LP/OP position, they want to verify the fields of view it will offer them, as well as checking to see from what locations they are visible. Knowing not only what you can see, but what an adversary can see is essential to mission planning and force protection. Therefore, once a reference point is selected (i.e., the LP/OP), any other point in the environment should be able to be selected and evaluated for relative line of sight considerations. Additionally, once a point is selected, FMV-ONE should be able to create a shape representing the line of sight available from a given point with altitude and range specifications entered by the user. This is particularly useful for flight planning and threat avoidance.[31]

The model should also be exportable in a 3D printer-compatible format. The military is increasing its experimentation and fielding of additive printing devices, and although currently they are focused primarily on the supply and repair parts field, an

[31] Altitude and range dependent line of sight visualizations are offered in FalconView software loads. If FMV-ONE can offer similar toolsets, that would provide an additional enticement for users to adopt FMV-ONE. Replace an old capability with a similar or better one.

expansion to mission planning via 3D model creation would enhance the value of these devices for the MAGTF.

5. Separate Viewer Manipulation

Within the software GUI, a user should be able to manipulate one view option while the other three remain steaming in real time. Often times, ISR is used to conduct pattern of life (POL) studies on individuals or specific geographic areas (compounds, markets, etc.). Standard Operating Procedures (SOP) may require continuous observation and positive identification (PID) of the individuals or areas in question. If an event needs to be reviewed immediately by executing the live video rewind feature, the operator will lose PID on the target. This can be resolved by allowing the main view window to be manipulated while the side views continue to stream. Then, an additional person may temporarily be able to assist in maintaining "eyes on" the target while the other operator conducts the necessary video review.

Assuming the addition of the annotation/mark-up toolset recommended earlier, the view being manipulated would need to be paused to allow for accurate edits. In this case, as with the POL example, the other views should continue to stream live video to allow the operator to check the sensor as required. When the operator is finished with his annotations he should be able to return his main view window to live status.

6. Mensuration for Targeting

FMV-ONE should generate NGA-certified, mensurated, GPS-munition capable grids for precision targeting. This added capability would greatly expand the functionality and appeal of the software across multiple communities within the MAGTF. Aviation, artillery, and ground forces could not immediately generate targetable coordinates for GPS-guided munitions, allowing for near instantaneous weapons configuration. This would shorten the call for fire timeline by reducing the wait time for mensurated grids. In addition to supporting current operations, this capability would support deliberate JIPOE processes by allowing for target folder updates as needed.

F. EMPLOYMENT OF RECOMMENDED EXPANDED CAPABILITIES AND TOOLSETS

The expanded capabilities described above have the potential to impact numerous mission sets. Combining all of the recommended toolsets with expanded personnel and unit locations, FMV-ONE can represent the next evolutionary phase in full motion video exploitation and operational planning and execution. The expanded methods will integrate perfectly into the Marine Corps' *Expeditionary Force 21* vision, allowing for smaller, more capable teams to bring greater impact to the environment at reduced cost and risk to the nation.

1. Vignette Revisited, Part II

If the MSOC intelligence team had FMV-ONE at its location with the recommended toolsets available to it, the team could have overcome the mission planning obstacles with organic personnel and systems on hand. When the target location changed and a new raid package was required for mission re-approval, the work could have been completed rapidly on site. The entire intelligence team at company headquarters would have been cross-trained on the implementation of the FMV-ONE software and had the software loaded onto their individual workstations. The team could have had multiple users simultaneously exploiting the live video on their individual workstations. The school-trained Imagery Specialist would have directed the effort and assign tasks to individuals. He would have provided the quality control mechanism of the collateral employment to ensure standards were met.

Within a shorter time span, and with fewer personnel required than what actually transpired, the MSOC intelligence team could have provided an updated mission product for the operations teams. The team's immersion in the environment and familiarity with SOPs and targets would have allowed it to create more tailored products for the MSOC teams than a disparate unit may provide. This is not to say that the external product received was not sufficient, but the reality is that an on-scene unit simply has better SA of their environment. Furthermore, the company had trained and fought together for an extended period of time, so mutual trust was high and the operators were comfortable with exchanging ideas and immediate feedback with the intelligence personnel.

Through the distributed support model at the MSOC, JTACs or intelligence personnel accompanying the ground force on the mission could also carry and employ FMV-ONE throughout the operation. Thankfully no CAS was required on this mission, but had that been necessary, the software locally employed could facilitate its rapid employment. Furthermore, C2 personnel and ITC/STA personnel could relay information quickly to the ground force and know that they would understand the geospatial scenario described.

When mission planning details shift as significantly as in this scenario, lack of planning and rehearsal time can be compensated for with detailed visualization. The ability to construct 3D models of the compounds of interest for the GFC to review with his subordinate leaders would have been beneficial. The transition of shifting focus to an urban environment after weeks of planning for a rural one would have been eased by the use of detailed geospatial models that may be available in later releases of FMV-ONE.

2. 3D Model Generation

Geospatial and environmental visualization enhance mission planning and preparation. Sending ground forces into unknown territory contains inherent risk, but applied controls can reduce it to residual levels and facilitate mission accomplishment. 3D model analysis is one way to supplement mission planning in order to create enhanced environmental familiarity. With FMV-ONE's recommended 3D model functionality, a GFC could analyze his mission area with appropriate intelligence and operations planners. The intelligence personnel can identify adversary assets and likely courses of action within the environmental context, and the operations planners can assist in planning for risk mitigation and subsequent friendly actions.

3D models could be presented visually or physically. The visual representation on a computer screen or projector is the quickest and easiest method, but lacks the tangible effects that a physical model offers. The visual model also allows for more detailed zooming and holistic perspective appreciation and it can be presented to a large audience without concern for loss of fidelity. A physical model will be restricted by the 3D printing capabilities on hand, which may not produce a large enough physical object within the time constraints of the mission.

Helicopter landing zone (HLZ) studies can be enhanced by 3D model visualization. Though aviation planning typically includes primary, secondary, and tertiary landing zones, in the event that none of these are feasible, or the mission gets redirected, one orbit of a UAV can provide the detailed information required to make appropriate landing decisions. Obstacle identification is particularly important, and FMV-ONE would be able to identify and represent any man-made object with greater clarity than a sensor operator may be able to. In the event of darkness or cluttered visual environment, the value of computer vision only increases. This information could be gathered directly by a user on board the aircraft if appropriately linked to the FMV feed, or relayed by a ground station to the aircrew via radio transmission.

HLZ studies are important for casualty evacuation (CASEVAC) missions as well. Thorough planning identifies HLZ's by phase of operation, so that in theory, there is always an approved HLZ in the vicinity of friendly forces, but this is not always how events unfold. In the event that a CASEVAC must be conducted and it is out of the scope of the pre-mission planning, FMV-ONE would allow for an updated 3D analysis of a perspective zone. Currently, this process is completed visually by inbound aircrews and supported by ground forces, but if there is a UAV on station, it could accomplish this mission with greater fidelity while the CASEVAC flight is in the air, thus reducing timelines and increasing the likelihood for a prompt delivery of the casualty to a medical facility.

Marine Expeditionary Units (MEU) often respond to natural disaster environments to provide Humanitarian Aid and Disaster Relief (HA/DR). Post-disaster environments can be significantly different than they were prior to the event, thus negating the effectiveness of any geospatial database information. This is true particularly with respect to man-made structures, and depending on the level of event, even the earth's surface can be substantially changed (e.g., earthquake, mudslides, avalanche, tsunami). Furthermore, overhead collection assets may be unable to respond in a timely fashion to support operations. In this case, a MEU commander may fly organic UAVs or request theater assets to create his own updated database.

Evaluating the current condition of infrastructure is important in HA/DR planning. Knowing the status of hospitals, airfields, and bridges is crucial to getting aid on site quickly. FMV-ONE 3D models can reconstruct these structures for analysis before the MEU forces are ready to deploy, thus allowing for a more informed decision for initial actions on scene. This model generation can also be exported to experts offsite to allow for more thorough analysis as required by the MEU Commander.

3. Line of Sight Study

Knowledge of one's operating environment has always been a crucial element of military operations throughout history. Often times, engagements were determined by whichever side could discover the adversary first and get into an advantageous position. Though the means by which adversaries have discovered each other have become more technical through the centuries, the most basic element is still sight. Even with technologically advanced ISR systems, Marines still train and conduct visual reconnaissance, and use human visual input to make battlefield

The ability to know fields of view in an operating environment is a major advantage. One of the applications of an enhanced FMV-ONE should be to construct line of sight studies. Before a reconnaissance team embarks on a mission, they rigorously study their environment to select the most advantageous position both for their own fields of view, and to provide protection against adversary observation. Rotation and translation of vantage points would allow for a thorough understanding of the visual components of the environment.

Mobile device use would further enhance this capability. In the event that the software could be executed, or at least portions of it, on a mobile device, the reconnaissance team could dynamically assess new positions on a tablet. Given the input location from the device GPS, the software could automatically generate the model from their point of view and should allow for view rotation to evaluate their exposure from other designated points of interest.

Light condition visualizations are also valuable products in mission planning. The aviation and reconnaissance communities use these extensively. The ability to change the shading of the software view to match a corresponding light condition for a given time of day, including accurate astronomical data for sun and moon positions, would be the ideal configuration and implementation of this toolset expansion. Barring the actual astronomical data inclusion, user scaling of the light level to an approximate relative sun position would still be beneficial, as would a simple night vision simulation by applying a green filter.

Helicopter flight path visualizations with incorporated threat vulnerability rings can be built out of a combination of the 3D model and line of sight functionality. With route waypoints selected, a user can select potential threat engagement zones and specify weapons ranges and altitudes to be represented by object overlays in the view. The route can then be analyzed for threats and appropriate mitigations applied. This immediate threat representation can also be applied to HLZ studies as time permits.

4. GPS-Denied Navigation

Designed and envisioned for employment within the geospatial intelligence field, FMV-ONE will provide enhanced intelligence capabilities to the MAGTF. A broader employment of the software by other personnel and units will further expand its impact. If the development of the mathematical algorithms continue as the experts at MITRE suggest, then there is yet another application for the underlying image processing capabilities: navigation in GPS denied environments.

Application of navigational functions would be separate from the FMV-ONE GUI, but based upon the same mathematical backbone. Given one GPS location reference point at the launch position and a frame tracking initiation, the processor could rapidly calculate continuous location updates from its original position. This application is very much a theoretical concept at this point, but the potential exists.

G. SUMMARY

Full motion video from ISR platforms has become a staple of 21st century military operations for the United States. The enhanced situational awareness that "eyes in the sky" provide a commander helps to reduce the ever-present fog of war that disrupts plans and create confusion. Until now, video exploitation has not reached its full potential to support the warfighter. With FMV-ONE, Marines can begin to provide and use this support.

Operational acceptance of the software will be based upon what capabilities it provides. Understanding the potential behind the system's mathematical processing will only take FMV-ONE so far, it must provide tangible benefits to the user in order to be seen as value added. The initial fielding of the software will hopefully gain the interest of the target audience in the intelligence field, and as expanded toolsets and increased functionality are released in subsequent versions, the program reach its full operational potential across disciplines and units.

V. EMPLOYMENT METHODOLOGY COMPARISON AND RECOMMENDATION

A. DOCTRINAL FRAMING

Marine Corps Doctrinal Publication 1 (MCDP 1), *Warfighting*, lays out the theory behind the way the Marine Corps fights. It espouses maneuver warfare and mission tactics through centralized command and decentralized execution.[32] Coupled with the Marine Corps' capstone document *Expeditionary Force 21* (EF21) which details the Corps' strategic employment and development for the future, Marines are trained and challenged to have a bias for action and to be as capable a force as possible. The introduction of FMV-ONE into the toolset of the Marine Corps will enhance performance at all levels around the globe.

Centralized command and decentralized execution encapsulates the ethos of Marine Corps operations. The commander gives mission orders and trusts subordinates to achieve his intent. As the nation's crisis response force, the Marine Corps must be prepared to execute these orders anywhere in the world, at a moment's notice, without relying on robust external support. Being an expeditionary force in readiness implies that small units can have big impacts without a large footprint. To achieve this end state, Marines must train and deploy multi-functional, lightweight units.

FMV-ONE has the potential to be a major component in the Marine Corps' realization of *EF21.* If properly employed, it can support multi-functional requirements and enhance the capability of a small, deployed force to be the middleweight fighter that punches above its weight class. Integration across the force is essential for distributed operations at the small unit level, and FMV-ONE can provide part of the structure that integration requires. The employment options considered below are restricted fielding to the geospatial community (the current plan), unrestricted fielding to non-geospatial personnel, and a combination of the two.

[32] Department of the Navy, Headquarters United States Marine Corps, *Warfighting* (MCDP 1) (Washington, D. C., 1997), 87-96.

B. RESTRICTED GEOSPATIAL FIELDING

The current employment strategy for FMV-ONE is highly centralized. Fielding the software on geospatial workstations to be employed only by trained imagery specialists likely will ensure consistent performance parameters and set the conditions for reliable operation. Employment will be focused on intelligence processes and products that support commander's decision making. Ideally it should support current operations as well, but that will be unit and mission dependent. Retaining tools at higher echelons is the low risk employment model given the likelihood of stable operating conditions and availability of technical experts.

Geospatial restricted employment is the conventional, comfortable choice for the Marine Corps. Imagery specialists are well-versed in the aspects of imagery analysis and a sensible choice for early exposure to innovative tools. This familiarity may present a challenge as well, since the community will have high standards of past performance to compare FMV-ONE's interface toolset against. Only time will tell if professional appreciation for the capability FMV-ONE will be hindered by this history. I believe that after an initial learning and exposure period, the imagery community will adopt the software as a core toolset and support it's fielding to other functional areas. Acceptance within the geospatial and intelligence community is an important first step in potential force-wide fielding, but not prohibitive if it should not occur.

Geospatial employment will allow the Marine Corps to validate its original needs statements and continue the acquisitions and fielding process. Operational input from geospatial users will facilitate future iterations of software update releases, hopefully in concert with some recommendations presented here. Developing the toolsets with community-specific guidance can ensure tailored updates, but also risks stove-piping the program from widespread use and acceptance.

C. UNRESTRICTED FIELDING TO NON-GEOSPATIAL PERSONNEL

Unrestricted distribution of FMV-ONE is in keeping with the warfighting ethos of the Marine Corps and supports the tenets of *EF21*. Specific to intelligence capability, decentralized distribution will support: operations and intelligence integration, intelligence dissemination and utilization, and fusion and dissemination of timely intelligence to smaller and distributed units.[33] With respect to command and control, dispersed fielding will improve sharing situational awareness and address gaps in intelligence products based upon outdated imagery.[34] Lastly, as FMV-ONE applies to fires, wide distribution will support sensor capability to provide target location with high accuracy and enhance UAS platforms' ability to acquire targets and control fires.[35] With the potential for target mensuration in the developmental future, fires application of FMV-ONE only increases.

Collateral fielding of FMV-ONE will require trust and risk acceptance. The simplicity of the program and recommended toolsets should allow for functional employment after brief periods of OJT or MTT site visits. The risk acceptance pertains to the likely degraded individual performance of collateral workstations, since most Marine Corps computers do not meet the performance standards of the geospatial workstation. With the speed of technological advances, however, basic laptop computer performance will continue to advance and support increased complexity of workload and processing such that by the time future software releases are fielded, this collateral degradation may be reduced or negligible.

Initiative and imagination historically have been the bedrock of small unit problem solving and mission accomplishment. Enable the leader at the point of friction to overcome obstacles with organic solutions and overall unit effectiveness will increase. The recommended toolset expansions described previously are informed by work and experience in the intelligence field. Undoubtedly, there are many other potential uses that are as yet unthought-of of simply because the future innovator or user has not seen the capability yet. In order to realize these potential uses, the software must be distributed and tested by a wide variety of personnel in a myriad of situations.

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[33] Department of the Navy, Headquarters United States Marine Corps, *Expeditionary Force 21*. (Washington, D.C., 2014), 38.

[34] Ibid, 35.

[35] Ibid, 33.

The Marine Corps is working to implement C2-enhancing technology at the forward edge of the battlespace, and FMV-ONE should be no different. Beyond the decentralized deployment to additional functional fields, the software should be employed apart from anchoring Internet connections in COCs. The ability to receive the video and telemetry directly from an aircraft via some receiver device such as the Remotely Operated Video Enhanced Receiver (ROVER) or the One System Remote Video Terminal (OSRVT) expands its employment location and integrates its effects across the force. The processing power of tactical computers will limit the program's execution speed when compared against geospatial workstations, but just having the resource available is a benefit to small units. As improved computers are continually fielded, this processing power will increase and the limitations will be reduced. FMV-ONE fielding needs to capitalize on this technology-push and become part of the small unit tactical mission toolset.

D. COMBINATION FIELDING

FMV-ONE should be fielded in a widely distributed fashion, to both the geospatial and the non-intelligence communities. Solely employing the software in either method will limit its beneficial impact across the Marine Corps, but combining the two can yield the greatest effects. Technical expertise supporting deliberate mission planning and operational imagination achieving real time effects symbiotically realize the full potential of FMV that has eluded the Marine Corps for the past fourteen years of combat operations.

It is recommended that FMV-ONE not replace any current geospatial toolsets, but rather augment their performance. As the FMV-ONE toolsets are expanded and updated algorithms enhance accuracy and functionality, a deliberate replacement of existing programs may be in order. Using FMV-ONE to augment current geospatial processes will create a user-base appreciation among the imagery and intelligence fields until incremental releases yield an improved product capable of replacing legacy systems. For the collateral user, access to the basic functionality will represent a shift in organic capability that will build appreciation for the system's functionality and generate the imaginative recommendations for expanded operational uses.

Cooperative efforts will achieve greater aggregate results than singular employment. Geospatially-restricted employment may produce consistently high percentage solutions and product results, but the overall impact to the MAGTF will be limited by the number of imagery specialists and, ultimately, by the number of geospatial workstations available in the unit. Decentralized employment may result in diminished performance or solutions sets on an individual basis compared to the expert user and equipment employment, but aggregate percentages will yield higher overall impact. The combination of the two methods will create force-wide efficiency because small units can provide organic solutions to low level challenges while higher echelons can work on more complex obstacles and external unit coordination, as required.

Combined fielding will support MAGTF missions across the range of military operations (ROMO) [see Figure 9]. MEUs and Special Purpose-MAGTFs (SPMAGTF) are routinely tasked with initial response to global crises that span this continuum. Geospatial awareness and the ability to exploit FMV from the point of crisis through the command echelons in the cooperative manner described will enhance operational responsiveness. First-responder units in HA/DR scenarios can generate immediate on scene assessments in real time coordination with the COC afloat, allowing for more accurate recommendations and faster application of resources to specific needs. In combat operations, headquarters (HQ) elements can provide verification of grids and support situational awareness of GFC, who may or may not be under duress. HQ should never take the initiative from the unit at the point of friction, rather support their "on the ground decision" by relieving some of the external coordination that may be required for work. MAGTFs achieve their greatest potential when they employ their assets in a complementary fashion; combined fielding of FMV-ONE would create another complementary relationship at the MAGTF commander's disposal.

Figure 9. Range of Military Operations

E. COMMON BASELINE CAPITALIZATION

FMV-ONE directly supports the doctrinal geospatial intelligence mission set, but it can do so much more. Imaginatively employed, the software can have positive effects in nearly all major functional areas of command and operations. The Marine Corps' training and operational ethos and doctrine supports the creation of multi-functional units and personnel. In a crisis event, commanders need to have as many options at their disposal as possible.

Think of FMV-ONE like a rifle. The rifle is doctrinally intended to be used as the primary weapon by the infantryman in an infantry battalion. We train specialists in the rifle's employment to deliver precision fires; we call these specialists snipers. The Marine Corps also trains every Marine, regardless of MOS, on basic marksmanship and rifle functionality, creating a pool of capably trained riflemen if the situation demands it. The rifle may be most effective in the hands of a trained sniper, but we still issue them to all Marines, and as a service, benefit from the cooperative effects of common training. The MAGTF employs its rifle-wielding assets as the situation demands. Sometimes the precision fires of a sniper are required and sometimes it's the firepower of an infantry unit. In still other cases, as our recent operations in Iraq and Afghanistan have demonstrated, non-infantry units such as logistics convoys or aviation squadrons are required to employ their rifles. If these other functional units had to wait on the sniper or infantry battalion to respond to the threat, the results would have been catastrophic. By training every Marine on basic rifle marksmanship and platoon level tactics, we create an aggregate capability across the MAGTF that outstrips the singular capability of an infantry battalion and enable individual small units to respond to tactical challenges at their own level, thus preserving force-wide resources. FMV-ONE has the potential to be the rifle equivalent of geospatial tools.

FMV-ONE may be most effective in the hands of a trained specialist on an individual basis, but that should not preclude its distribution to and use by other units and personnel. Just as with the rifle, a combined fielding of FMV-ONE in both doctrinal and collateral employment methods will create the greatest force-wide effect and give the MAGTF commander the most value from his resource pool. FMV-ONE should be fielded in an incremental and deliberate fashion that starts with the geospatial field and expands to additional units.

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VI. CONCLUSION

A. PROBLEM RE-STATEMENT

Combat operations in support of the Global War on Terror have witnessed an exponential increase in the availability of FMV to tactical units via an ever increasing fleet of UAVs.[36] Even as the technical capabilities of the platforms and sensors expand, users will still require basic information in the form of geo-location information for objects of interest. The two current methods available to the warfighter are limited by time, personnel and equipment. Real time FMV exploitation via FMV-ONE can circumvent these deficiencies while also reducing the need to archive the gargantuan volumes of data collected each year, but what is the best way to employ this new software?

The critical point is that FMV-ONE allows rectification processes to be computed on a video stream in real time, not near real time, and not post-facto. This difference from current practice, though it appears slight, carries with it the potential for application across the spectrum of geospatial activities and the increase in speed of performance for all of them. Detailed imagery and video analysis has always been a post-processing task, but with FMV-ONE, the potential for real-time exploitation exists.

B. EMPLOYMENT RECOMMENDATION: UNRESTRICTED FIELDING

FMV-ONE presents a limited toolset when compared against current geospatial exploitation tools available to the Marine Corps' Imagery Analysis Specialists, but the underlying mathematic engines have the potential to expand toolsets and capabilities for previously unattainable real time video exploitation. Depending on the development and funding decisions of MCSC, FMV-ONE could be fielded in several fashions with varying degrees of success.

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[36] Vice Chairman of the Joint Chiefs of Staff and Under Secretary of Defense (AT&L), *Unmanned Systems Integrated Roadmap, FY2013-2038*, OSD Reference Number 14-S-0553, Washington, DC: Vice Chairman of the Joint Chiefs of Staff and Under Secretary of Defense (AT&L), 2011, 4.

To reach its full effect across the Marine Corps, MCSC should undertake unrestricted fielding of FMV-ONE beyond the scope of the intelligence community. In addition to the intelligence community, the limited capability initial releases (version 1.1) should be provided to operations, fires, and aviation communities across the Marine Corps, while subsequent, capability-enhanced versions should go solely to the Imagery Analysis Specialists. Depending upon feedback from the subsequent releases and the results of future testing on various systems, MCSC should retain the option to field the enhanced versions to the non-intelligence communities at a later date. A phased distribution of software versions with increasing capability will allow for a steady integration of FMV-ONE's real time applications. With full program maturity, FMV-ONE stands to be the primary real time exploitation tool in the Marine Corps' inventory, allowing for complete integration of ground forces, intelligence, and air and fires support.

C. RECOMMENDED AREAS OF FUTURE STUDY

FMV-ONE is a significant step forward in real time video exploitation, but there is still much work to be done to realize its full potential. This is not a derogatory assessment, but rather an identification of the underlying potential in the program and a strong recommendation for continued funding and development. FMV-ONE can be the next Marine Corps tool to cross the rigid functional boundaries that often restrict operational efficiency. There is a time, place, and necessity for hierarchical command and decision making, but "flattened" access to geospatial information should be the norm, not the exception. FMV-ONE can be a cornerstone in this architecture and key asset in the realization of the tenets of the Commandant's vision outlined in *Expeditionary Force 21*.

1. Remote Video Terminals & Distributed Employment

In order for the decentralized implementation of FMV-ONE to reach its full potential, it must be able to function apart from anchoring GCS or hard-wired intelligence shops within COCs. FMV-ONE should be tested across the spectrum of Remote Video Terminals (RVT) available within the Marine Corps and DOD, writ large. Various functional communities routinely employ these systems to connect directly to UAVs, specifically, fires personnel such as Forward Air Controllers (FACs) and JTACs. The systems, training, and corporate knowledge already exist within current infrastructure; FMV-ONE must capitalize on this opportunity.

As the standard RVT within the Marine Corps, the ROVER is a trusted, battle-proven system. Operating forces are familiar with its function and existence, so associating FMV-ONE's performance envelope with the device will enhance the prospects for acceptance of the software across the Corps. A separate video receiver, VideoScout, has been demonstrated in previous MCSC demonstrations, but only in a static, COC environment.[37] Proof of ROVER or OSRVT compatibility under mobile mission conditions will immediately expand the operational reach of FMV-ONE in both geography and functional application.

The processing power of the RVT computers is a key component that requires examination. Can the FMV-ONE software run on the organic RVT computer? If so, what are the second order effects to the system's performance in other aspects? If FMV-ONE cannot operate on the terminal in its own right, can the terminal output the necessary MPEG-2.ts video stream and KLV telemetry data via Ethernet or wireless means to a more powerful tactical computer? Under these circumstances, what are the impacts on the tactical computer's processor and parallel tasks with FMV-ONE running?

Human interface integration needs to be examined as well. The ROVER and OSRVT systems work well as an FMV viewer, and a standard laptop or geospatial workstation suits the employment of FMV-ONE, but what are the considerations for the human integration for a combination of FMV-ONE on an RVT? Assuming the RVT computer has enough processing power to add FMV-ONE on to, is it a viable option for a user in a tactical scenario? Considerations might include screen size and user input device in both permissive and simulated non-permissive environments. The technical combination may meet performance requirements, but if the human user does not integrate with the configuration, then the use case is not ready for implementation.

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[37]Marine Corps Systems Command PMMI RTI Team, *Full Motion Video Exploitation Demonstration Plan, Version 1.3*, 5.

2. Computer Configuration Optimization

MITRE designed FMV-ONE with the performance specifications of the standard Marine Corps geospatial workstation in mind. For the enabled missions sets and recommended distributed fielding employment scenario to be valid, FMV-ONE must be able to run on different computer configurations. To this end, the optimal hardware/software configurations for collateral employment should be examined. This configuration testing goes beyond the RVT computer, and includes the spectrum of government issued laptops found across functional areas on Marine staffs outside the Intelligence section.

a. Laptops

The main concern for collateral computer employment is the increased time-cost associated with the image processing of FMV streams. The software will run on less powerfully configured machines than the geospatial workstation, but so far there has been no deliberate measurement of the degradation of performance associated with various technical specifications. In order to implement distributed fielding recommendations, MCSC and unit commanders must accept risk in the performance degradation of the software, and scientific data relating to that threshold will allow them to make an informed risk decision. The degradation may be slight, but experimentally measuring that value to give a tangible representation of efficiency is essential.

b. Virtual Machines

Virtual machines (VM) are a potential performance enhancement option for collateral fielding. Once the performance spectrum of computers has been experimentally established, a unit can assess where their capability lies regarding FMV-ONE, based upon their computer inventory. If that happens to be less than optimal, then perhaps running the software on more powerful VMs may alleviate that risk. Establishing VMs with enhanced graphics processing power and dedicating them for FMV-ONE collateral employment can enable otherwise incapable or suboptimal computers to satisfactorily run the software.

A VM infrastructure implies a set of capabilities unto itself that must be managed. FMV-ONE integration into a notional VM architecture should be studied for both land based and embarked operations. What is the current state of VM architecture and usage within the Marine Corps? Can it support FMV-ONE employment? If not, what enhancements need to be made, and do we have the budget, ability, and desire to do so? First and foremost, however, FMV-ONE must be tested more thoroughly in a VM environment to determine if the subsequent infrastructure research is merited.

3. Group 1 UAV Incorporation

MCSC and MITRE have primarily tested FMV-ONE on Group 2 (Scan Eagle/Blackjack), Group 3 (Shadow) and non-standard ISR configurations, such as sensors mounted to manned aircraft in the early developmental days of the program.[38] Other test platforms include limited exposure to Group 3(Predator) and Group 1(Raven). For this software to realize its full potential, it must be able to work with the Group 1 UAVs. MCSC should conduct increased testing in this category for both terminal/computer performance and human factors integration.

a. Terminal and Computer Considerations

Depending on the receiving device configuration from the Group 1 UAVs, can a new system directly connect to the control computer, or should we use a ROVER system to run a separate workstation? Similar to configuration concerns for mobile ROVER employment, for Group 1 UAVs, is Ethernet output from the control system a reasonable solution to provide the video and telemetry data? Can a wireless relay replace physical wiring to extend the distance that an FMV-ONE operator may be from the UAV operator?

b. Human Factors Integration

Group 1 UAVs are operated by one person who flies the platform and operates the sensor simultaneously. For FMV-ONE integration, human factors should be studied for

[38] Scott Robbins and Kyle Fawcett, "FMV ON-Target, v 9.3a", 16-25.

task saturation concerns. A cursory analysis suggests that it is likely that a second a person will operate the FMV-ONE application on a separate computer. In this case task integration between the UAV operator and the FMV-ONE operator should be examined. Does this employment constitute a distinct mission crew, or can the FMV-ONE operator work in parallel, but without impact, upon the UAV operator, similar to larger UAV operations.

c. *Mechanical versus Digital Sensor Stabilization*

Group 1 UAVs use digital stabilization on their sensors owing to the lack of size and power to accommodate larger mechanical gyro-stabilization devices found in Group 2+ UAVs. MITRE has experimentally observed the degraded performance of combination digital-mechanical stabilization in the Group 2 RQ-21 Blackjack (Scan Eagle replacement) and recommended the sole use of mechanical methods if possible.[39] To this end, what is the effect on FMV-ONE accuracy under the conditions of solely digital stabilization associated with Group 1 UAVs? With the existence of image artifacts around stabilized frames, can the FMV-ONE feature detection algorithms maintain continuity to allow for sustained performance? At what error threshold will the software be unable to process the orbit for exploitation?

As with computer processing specifications, a spectrum of technical performance output from Group 1 UAVs should be compiled to assess the impact of digital stabilization on FMV-ONE's general functionality and specific grid accuracy. Assuming consistent grid generation is possible, what is the error ellipse envelope compared to mechanical stabilization?

4. Automatic Feature Detection Algorithms

Automated feature detection from video is a developing field. Can this capability be incorporated into FMV-ONE? Automation reduces individual human workload, and in keeping with the planning guidance from *EF21*, Marines must be prepared to deploy in

[39] Scott Robbins and Dale Herdegen, "Observations and Recommendations on Digital Stabilization for the RQ-21," (report, Stafford, VA: MITRE Corporation, 2015), 1-5.

lighter, smaller configurations. Every mechanism to assist in this end state should be employed. If automated feature detection is deemed reliable, and can be configured to support specific Marine Corps needs, then collateral employment of FMV-ONE can also expand to certain GEOINT specific tasks. Appropriate oversight may still be required by a trained 0241, but automated compound studies and object identification are two potential fields of study.

a. Automated Compound Studies

If automatic feature detection, as detailed by the user, can be implemented into FMV-ONE, then the software may be able to automatically generate the imagery support materials described in the various mission descriptions and vignette. Compound studies are time consuming, but if computer can identify some basic features such as windows and doors, and make measurements automatically, this could greatly reduce the time required to produce the materials. Is this technology mature enough to work and is it compatible with FMV-ONE? A phased implementation would allow the Marine Corps to go from man-in-the-loop work (currently) to man-on-the-loop for oversight purposes, and potentially even man-outside-the-loop once the confidence level and reliability of the tools are consistently demonstrated.

b. Object Identification

Absent a full automated compound study, could simple object identification be programmed into the software? Could FMV-ONE identify a tool versus a weapon in someone’s hand? Is this something that can be written directly into the program or would an additional toolset from an outside source work? Since weapons possession can carry hostile act/hostile intent implications for rules of engagement, further policy work will be required to determine if we are willing to accept automated object identification as an evidentiary equivalent to human identification.

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