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# Interoperable Open-Source Sensor-Net Frameworks With Sensor-Package Workbench Capabilities: *Motivation, Survey of Resources, and Exploratory Results*

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**Abstract**—Low-cost sensor technologies, such as Micro-Aerial Vehicles (MAVs), present an opportunity to facilitate improved transformational Intelligence, Surveillance, Reconnaissance, Targeting, and Information Operations (ISRT/IO) capabilities in support of tactical network-centric ISRT/IO Warfighter and First-Responder operations. There is an exigency for realistic rehearsal frameworks to enable efficient and rapid deployment of MAVs in support of ISRT/IO; physics-based 3D simulation and modeling capabilities improve mission planning and efficiency. The incorporation of Free Open Source Software (FOSS) such as the Naval Postgraduate School (NPS) Autonomous Unmanned Vehicle (AUV) workbench into the Sensor-net Self-Organization and Control (SenSOC) initiative enables highly reconfigurable, realistic and dynamic mission planning capabilities thereby creating more responsive Systems-of-Systems Engineering (SOSE). The current work, reported herein, focuses on the incorporation of a scalable sensor-package in the NPS AUV platform-oriented modeling, simulation, and experimentation framework which would support operational use-cases and CONOPS (i.e. concepts of operation) for tactical ISRT/IO mission-threads and associated scenarios.

**Keywords** - MAV; UAV; micro-aerial vehicle; unmanned autonomous vehicle; sensor-net; image processing; mosaicking; georegistration; modeling and simulation; open source; X3D

## I. INTRODUCTION

Low-cost sensor technologies, such as Micro-Aerial Vehicles (MAVs), present an opportunity to facilitate improved transformational Intelligence, Surveillance, Reconnaissance, Targeting, and Information Operations (ISRT/IO) capabilities in support of tactical network-centric ISRT/IO Warfighter and First-Responder operations. Fig. 1 highlights only a few of the broad range of MAVs readily available for tactical ISRT/IO applications [1]-[3]. Note that the upper right image in the figure illustrates remote launch and recovery of MAVs from unmanned ground vehicles.

The figure also illustrates that MAVs enable man-packable sensor-net capabilities that, in principle, can provide organic ISRT/IO resources for individual stakeholders in the field.



Figure 1. Example Micro-Aerial Vehicles (MAVs) [1]-[3]

This tactical net-centric ISRT/IO effort, reported herein complements, and is working in collaboration with, robotics centers of excellence at SSC Pacific and elsewhere. Reviews and surveys of related robotics work are available [1]-[3]. A number of standardized and interoperable tactical robotics resources further motivate the development of interoperable open-source mission-driven sensor-net framework capabilities. For example, Fig. 2 is a screen-shot of the Multi-robot Operator Control Unit (MOCU) that supports video/imagery streams from multiple types of platforms (e.g. UAV/USV/UGV).

For rapid deployment and efficient utilization of such emerging technologies, especially in support of tactical network-centric ISRT/IO Warfighter and First-Responder operations, there is a critical need for highly reconfigurable and dynamic mission planning and rehearsal frameworks with highly-integrated workbench facilities.



Figure 2. Screen-Shot of MOCU Configured as A Multi-Vehicle (UAV/USV/UGV) Controller with Video From A Manportable UGV. [2]

The survey and initial results reported in this paper are in response to a need to utilize realistic physics-based 3D simulation and modeling capabilities to enable improved mission planning and support. The inclusion of Free Open Source Software (FOSS) such as the Naval Postgraduate School (NPS) Autonomous Unmanned Vehicle (AUV) workbench described in Section III into the Sensor-net Self-Organization and Control (SenSOC) initiative facilitates highly reconfigurable, realistic and dynamic mission planning capabilities thereby creating more responsive Systems-of-Systems Engineering (SOSE). The additional incorporation of a sensor-package in the integrated FOSS would support operational use-cases (i.e. concepts of operation) for tactical ISRT/IO mission-threads and associated scenarios.

Information interoperability (i.e. sharing) is also an inherent, key operational requirement for highly coordinated rapid responses, as typically needed for effective Network Centric Warfare (NCW) and First Responder missions [4]. As Fig. 3 illustrates, improvements in information sharing directly impact dependent activities such as shared situation awareness, collaboration and self-synchronization. Thus, more interoperable and seamless planning, rehearsal, and execution capabilities are expected to dramatically improve operational mission effectiveness for tactical ISRT/IO applications.

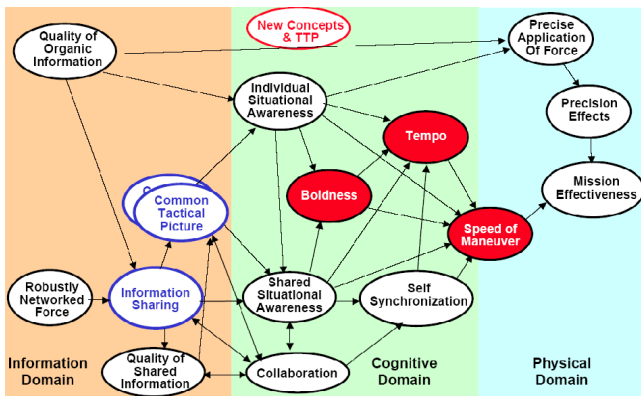


Figure 3. Tenets of Network-Centric Warfare (NCW) [4]

The SenSOC initiative focuses on developing seamless operational interoperability and self-organization capabilities that include heterogeneous ad-hoc subnets of both human and unmanned nodes within the networks of services provided by Enterprise Architecture (EA) and Service Oriented Architecture (SOA) frameworks. In other words, SenSOC concentrates on the spectrum of Research, Development, Acquisition, Test, and Evaluation/Experimentation (RDAT&E) challenges associated with sensor-net self-organization and control. Such challenges include multi-INT sensor data fusion, man-packable sensor-nets, self-synchronization, global MAV-based video reach-back, and most recently, semantically-enabled EA/SOA sensor-net capabilities [5]-[15].

Fig. 4 is a network diagram of a SenSOC-NPS experiment that demonstrated MAV global video reachback via the Internet and commercial SATCOM networking [15]. Thus, the results highlight the potential extent and range of networking capabilities that motivate the development of extensible open-source sensor-net frameworks that include seamless model driven mission planning, rehearsal, and experimentation.

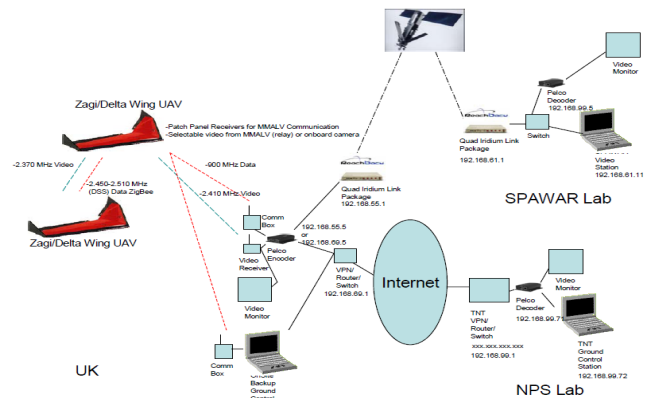


Figure 4. Network Diagram of Global Reachback Experiment [15]

In this paper, readily available open-source flight simulators and 3D modeling environments are investigated. The goal is to utilize multiple and independently developed platform frameworks to support mission needs and further enable information interoperability. A key component that is addressed includes a sensor-package workbench for facilitating the simulation of realistic mission-driven sensing capabilities, platforms/nodes, and communication networks that readily support operational use-cases (i.e. concepts of operation) for tactical ISRT/IO mission-threads and associated scenarios.

## II. NEEDS AND EMERGING CAPABILITIES

As the previous section illustrates, Warfighter and First Responder mission requirements necessitate dynamically reconfigurable sensor and communication networks that provide reliable information for improved situational awareness and rapid response. MAV technology is a high-payoff example of emerging disruptive technologies which help further enable such sensor-net capabilities. “The relatively low-cost, easy deployment, and low-detectability of MAVs provide viable next-generation NCW and first-responder solutions for mission-specific tactical ISRT/IO operations.

MAV-enabled sensor-nets provide much needed high-payoff next-generation ‘eyes and ears’ for Warfighters and First Responders, while keeping them out of harm’s way” [56]. Also, because of their small size, MAVs are of great interest for net-centric applications, where, if needed, more than one MAV can be deployed. Multiple MAVs enable swarms and other formations of MAVs to potentially self-organize and thus, more autonomously collaborate while collecting and communicating in the operational environment. UAV research continues to be an area of much research and interest. Summaries of relevant examples of emerging inter-dependent areas of UAV research are found below.

Cooperative MAV formations need to utilize global information, efficiently manage and allocate resources (MAVs and sensors), and be robust to changing environmental conditions or mission requirements [16]. Multi-UAV relative positions can be estimated based upon each UAV’s image of the scene and a derived motion field of common objects [57]-[58]. The motion fields then enable the relative displacements for each UAV to be calculated. Merino *et al.* utilize blob analysis to facilitate matching among the different UAV captured images [57]-[58]. In [17], Stolarik, Niland, and Givens studied improving the simulated MAV communications in the MultiUAV [18] multiple unmanned aerial vehicle (UAV) simulator developed by the Air Force which can simulate 8 UAVs and 10 targets. MultiUAV is a MATLAB based program. Niland discusses MultiUAV being used in the FLEXible Analysis Modeling and Exercise System (FLAMES) to facilitate more complex Suppression of Enemy Air Defense (SEAD) planning [19]. MAVs which are inherently small are greatly influenced by environmental disturbances such as wind, unlike the larger Predator for example. Research into MAV dynamics and control should investigate wind effects, both on control as well as data acquisition [20]-[21]. Yao-hung and Feng estimate the error in UAV position due to the wind field and use this to correct the UAV’s position [20]. Ceccarelli, Enright, Frazzoli, Rasmussen and Schumacher study target surveillance by MAVs under wind disturbances [21]. Göktoğan and Sukkariéh present a hardware in the loop (HIL) environment to further validate the simulated mission [22]. Sharma and Taylor studied multiple UAVs without GPS for navigation. Each MAV estimated its own as well as all other MAV locations and orientations. An extended Kalman filter was used to produce the position estimates [23]. Lin and Goodrich studied different algorithms for use in search and rescue path planning [24]. MAVs have also been studied for uses in environmental monitoring [25] wildlife population monitoring [26] and wildfire detection [27]. Thus, in addition to previous SenSOC related efforts, sensor-package and AUV workbench capabilities are needed to further enable environmental and wildlife monitoring and research, single and group based MAV path planning and coordination, as well as disaster management [16]-[28].

### III. FOSS AUV WORKBENCHES AND FLIGHT SIMULATORS

#### A. AUV Workbench

The Modeling, Virtual Environments and Simulation (MOVES) Institute and NPS Center for AUV Research, Naval

Postgraduate School, Monterey, California has created an XML based workbench called Autonomous Unmanned Vehicle (AUV) workbench [29]-[35]. This software workbench uses Autonomous Vehicle Control Language (AVCL). The AVCL includes definitions for pertinent mission data and parameters for mission simulations. AUV workbench simulations for vehicle dynamics are determined utilizing a 6 degree-of-freedom (DOF) model. The generic model can be easily changed to incorporate new vehicle dynamics or new vehicles. Background scenes during the simulation are created using Extensible 3D (X3D). Missions can also be mapped out using the 2D mission planner. Fig. 5 is a snapshot from the AUV workbench [29]-[35].

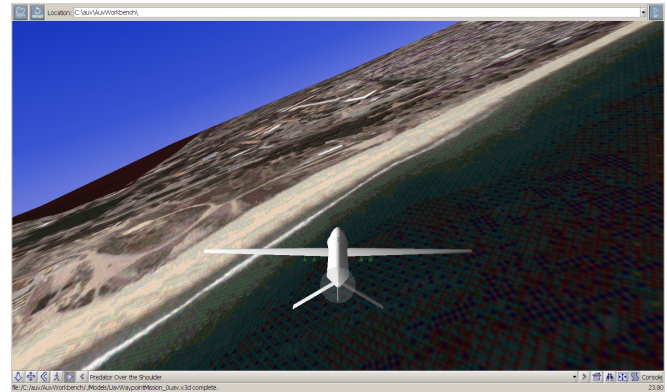


Figure 5. from MOVES AUV Workbench [29]

Fig. 6 depicts a two vehicle 3D mission planning simulation. This capability for multi-vehicle simulations is an advantage of AVCL. AVCL’s ontology defines common unmanned vehicle function relationships that in turn enable multiple vehicle interactions in a simulation. This capability as well as the generic vehicle model facilitates mission planning with different vehicles [29]-[35].

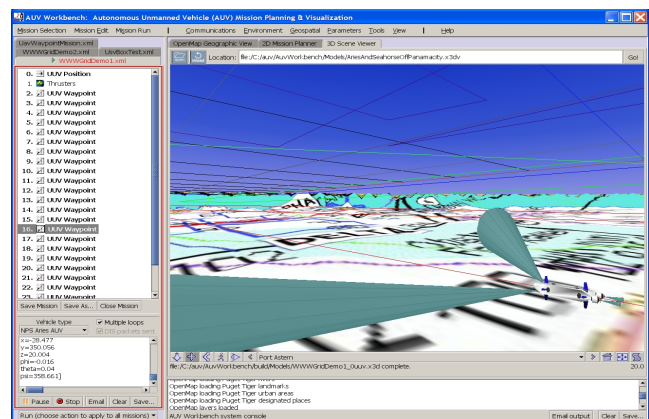


Figure 6. MOVES AUV Workbench Mission Planning Screen-Shot [29]

AVCL defines the mission using sequentially executed script commands or by defining goals which are interpreted in the form of a finite state machine (FSM). The 3D scene simulation is performed using a scene access interface (SAI) This allows the incorporation of different sensor packages. [29]-[35]. Camera models however are not included. This is a key component that needs to be addressed so that a sensor

package workbench capability incorporating camera models further enables realistic mission sensor imagery and communication data streams and their associated problems. Bandwidth limitations also play a crucial obstacle to full high resolution scene imagery being transmitted to the AUV's control station.

### B. *FlightGear Simulator*

Another open source simulator is FlightGear [36]. The simulator runs on many of the commonly used operating systems such as Windows and Linux. An important feature of FlightGear is that it includes modifiable flight dynamics models as AUV workbench similarly includes. Other options of interest available in FlightGear include such simulator features as weather, multi-player, and GPS. FlightGear is modified easily by the user by modifying XML files, similar to modifying the AVCL files in AUV workbench. This use of XML makes FlightGear readily extensible facilitating information interoperability across various platforms.

For initial proof-of-concept and exploratory assessment, FlightGear possesses a surprising amount of interoperability due to its utilization of XML. Additionally, this exploratory assessment showcased the compatibility of the FOSS simulator across different operating systems. Due to availability and more immediate ease of use, FlightGear was utilized for synthesizing framesets used for generating simulated mosaicking results [37]-[38], [56]. A more detailed summary and discussion of FlightGear can be found in [56].

These initial results have motivated continued follow-on efforts to develop interoperable open-source sensor-net frameworks that include extensible sensor-package capabilities. This sensor-package feature complements the platform-simulation capabilities currently within the NPS MOVES AUV Workbench and other simulators. The following section describes initial progress towards developing camera modeling capabilities as an initial example sensor-package component.

## IV. CAMERA MODEL - SENSOR PAYLOAD

As mentioned earlier, because of their small size and being relatively inexpensive, MAVs are of great interest for net-centric tactical ISRT/IO applications. Note that potentially, a significant number of MAVs can be deployed to create swarms or other large formations of MAVs that can rapidly collect and communicate data using sensor-net technology and smart cameras. Thus, multiple MAVs can cooperatively cover a large area of operation within a potentially much larger array of other fixed and mobile sensors.

Within this context, an important sensor capability is rapid collection and utilization of real time image or video scene data. Multiple scene images need to be mosaicked to produce a composite scene or aerial mosaic. Previous SenSOC experiments have demonstrated that mosaicking algorithms and software developed for larger platforms, cannot be readily applied to MAV applications. These earlier results motivate the development of camera modeling capabilities that help identify

and correct such mosaicking challenges that arise due to MAV platform dynamics and typical MAV camera characteristics. Thus, initial information interoperability experimentation explores the feasibility of creating synthesized video framesets for more controlled analysis of video mosaicking results. Initial mosaicking results from synthesized framesets created using the FlightGear simulator are found in [37]-[38], [56].

Photomosaics or image mosaicking continues to attract interest in the defense as well as research communities [39]-[44]. MAVs which are inherently small are greatly influenced by environmental perturbations and disturbances such as wind. As a result, quality of MAV captured video suffers due to these disturbances; this can lead to issues in reliably and consistently mosaicking MAV captured imagery. To facilitate consistent image mosaicking, Taylor and Andersen geo-register the images used in the mosaic [39]. With this geo-registration information, the authors' method tracks virtual points between captured frames [39]. Heiner and Taylor also geo-register the mosaicked MAV captured images. However, the authors utilize information from the MAV's Inertial Measurement Unit (IMU) and the Global Positioning System (GPS) to perform this geo-registration [40] by use of a common system of coordinates. Bulo and Birk demonstrate the use of an improved Fourier-Mellin Invariant (iFMI) for mosaicking in MAV as well as underwater imagery [43]. A common method being employed for image mosaicking is the use of the Scale Invariant Feature Transform (SIFT) to determine features [41]-[42]. The SIFT determined keypoint features are scale and rotation invariant. These examples illustrate some of the various techniques and methods employed in video and image mosaicking; this demonstrates the need for a sensor-net workbench capability which will enable and facilitate an improved mission analysis and optimization.

A camera model component in the workbench will enable realistic image acquisition planning and mission modeling. The camera model will need to incorporate various parameters of interest such as operational theater and mission specific values, camera system physical and electrical characteristics, and environmental conditions. To address this need, perspective effects on the image have been examined for a generic camera model. Perspective induced effects "affect the size and direction of patterns to be recognized" [45] and so must be accounted for [45]-[46]. Fig. 7 shows the effect of camera tilt along the X-Z plane on terrain area represented by each pixel [38]. The relative distance represented by each pixel is plotted in Figs. 8 and 9 [38]. To ensure correct image mosaicking or target identification, identification of objects or processing of pixels near image edges will need to account for this nonlinear distance representation as well as possible distortion due to the camera optics. Fig. 10 shows the percent overlap between successive frames as vehicle *speed* changes on a straight path at constant altitude with the imager held parallel to terrain [38]. These preliminary camera model results highlight the added value for including a sensor-package workbench capability in the FOSS or workbench.

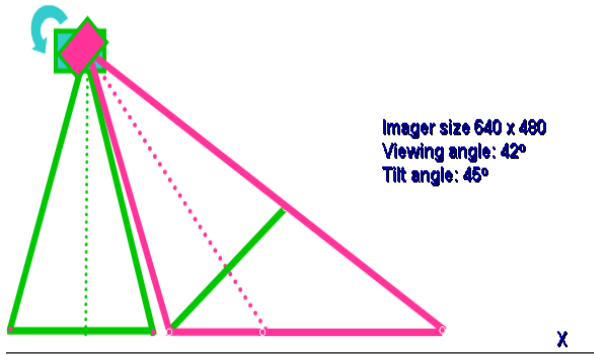


Figure 7. Effect of camera tilt along X-Z plane on terrain area represented by each pixel [38].

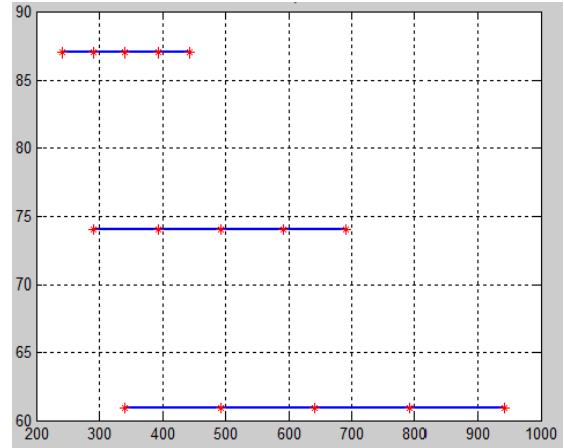


Figure 10. Percent overlap between successive frames as vehicle *speed* changes on a straight path at constant altitude (imager parallel to terrain) [38].

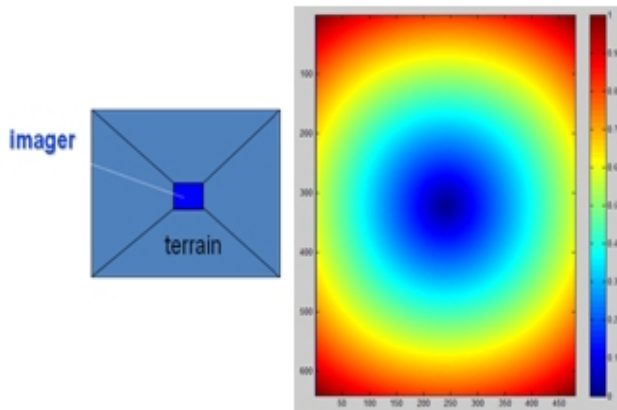


Figure 8. (Left) Camera imaging system parallel to the surface [38]. (Right) Relative distance represented by each pixel

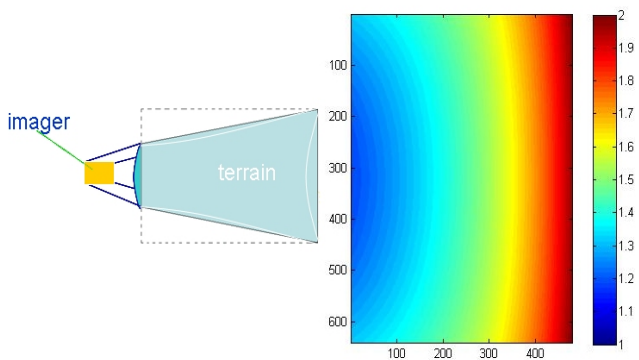


Figure 9. (Left) Flat Camera imaging system at angle to the surface [38]. (Right) Relative distance represented by each pixel.

## V. SUMMARY AND CONCLUSIONS

As discussed and highlighted in the previous sections, there is a critical need for highly reconfigurable and dynamic mission planning and rehearsal frameworks that are interoperable and support extensible sensor-workbench facilities. Such FOSS frameworks enable rapid deployment and efficient utilization of emerging disruptive sensor-net technologies. In particular, frameworks with sensor-packages that include camera modeling features, provide operationally realistic test beds that can be utilized for realistic MAV based image and sensor systems simulation and modeling development in support of tactical network-centric ISRT/IO Warfighter and First-Responder operations.

## VI. FUTURE WORK

In addition to further exploring FOSS video and image processing resources, such as OSSIM and other FOSS image/video processing resources [47]-[48], semantic features of the MOVES Military Scenario Definition Language, (MSDL), Coalition Battle Management Language (CBM-L) and other recently developed capabilities [49]-[53] are also of particular interest for integration with a companion SenSOC effort called Enterprise Lexicon Services (ELS) [8]-[9]. Semantic capabilities, such as MSDL, CBM-L, and others identified within the context of ELS, are of great interest due to potential improvements in information interoperability that, in turn, enable provenance and pedigree capabilities [54] for EA/SOA based sensor-nets and related services. Finally, a long-term goal includes incorporating multi-objective optimization tools [55] into interoperable sensor-net frameworks for best matching mission needs and resourcing constraints with sensor-packages, platform features, and the growing wealth of FOSS and commercial COTS/GOTS sensor-net related technologies.

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## REFERENCES

- [1] SPAWAR Robotics, <http://www.spawar.navy.mil/robots/> (acc'd 2009).
- [2] Nguyen, H.G., Laird, R.T., Kogut, G., Andrews, J., Fletcher, B., Webber, T., Arrieta, R., and H.R. Everett, "Land, Sea, and Air Unmanned Systems Research and Development at SPAWAR Systems Center Pacific", SPIE Proc. 7332: Unmanned Systems Technology XI, Orlando, FL, April 2009, [http://www.spawar.navy.mil/robots/pubs/SPIE\\_2009\\_SSC\\_Pacific\\_Unmanned\\_Systems.pdf](http://www.spawar.navy.mil/robots/pubs/SPIE_2009_SSC_Pacific_Unmanned_Systems.pdf) (acc'd Sept. 2009).
- [3] R. Vaidyanathan, "Morphing Micro Air-Land Vehicle," (acc'd 2009), [http://faculty.nps.edu/ravi/BioRobotics/MMALV\\_Summary.pdf](http://faculty.nps.edu/ravi/BioRobotics/MMALV_Summary.pdf)
- [4] J. Gartska, "Fighting the Networked Force," Network Centric Warfare, 2005, <http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA472041&Location=U2&doc=GetTRDoc.pdf> (last accessed Sept. 2009).
- [5] J. Durham, W. Torrez, and J. Manley, "Net-Centric Human-Robotics Operations: Integration of Business/Military Process Management," Grid Computing, and Robotics, 2004 IEEE International Conference on Web Services (ICWS 2004), San Diego, CA, 6-9 July 2004.
- [6] J. Durham, L. McLauchlan, and R. Yuster, "A Semantic alignment process for information interoperability: enabling more common and consistent enterprise-wide terminology," SPAWAR internal report, San Diego, July 2008.
- [7] J. Durham, L. McLauchlan, and R. Yuster, "Enabling a common and consistent enterprise-wide terminology: an initial assessment of available tools," Proc. of 2008 IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology, Sydney, Australia, pp. 544-548, Dec. 9-12, 2008.
- [8] J. Durham, "Enterprise Lexicon Services," Proc. of 11th International Business Rules Forum, Orlando, FL, 2008.
- [9] J. Durham, W. Anderson, and D. Zubrow, "Building net-ready information interoperability indicator widgets for DoDAF 2.0 dashboards," NDIA 2008 Systems Engineering Conference, 2008, <http://www.dtic.mil/ndia/2008systems/7105anderson.pdf> (ac'd 2009).
- [10] J. Durham and W. Torrez, "Monitoring of Natural Scenes for Feature Extraction and Tracking: An Independent Component Analysis (ICA) Approach," 2004 IEEE International Conference on Computational Intelligence for Measurement Systems and Applications (CIMSA 2004), Boston, MA, 14-16 July 2004.
- [11] W. Torrez and J. Durham, "Joint Composeable Human Robotics Operations (CmHRO)," 7<sup>th</sup> Annual Military Data Fusion Conf., 2005.
- [12] W. Torrez and J. Durham, "Vertical and Horizontal Fusion of Operational and Tactical Components Enabled by Networked ISR," MSS National Symposium on Sensor and Data Fusion, May 2005.
- [13] W. Torrez and J. Durham, "Data Fusion in the Bigger Tactical Picture," 8<sup>th</sup> Annual Military Data Fusion Conference, London UK, 27 Sep 2006.
- [14] W. Torrez and J. Durham, "Tactical Considerations for Using Man-Packable Sensor Nets," 3<sup>rd</sup> Ann. Sensor Fusion Conf., DC, Nov 2006.
- [15] R. Bledsoe, R. Vaidyanathan, J. Durham, and X. Yun, "Semi-autonomous micro air and ground vehicle control and video relay through internet and iridium networks." First Int. Conf. on Robot Communication and Coordination (Robocomm 2007), Athens, Oct 2007.
- [16] T. Shima and S. Rasmussen, "UAV Cooperative Decision and Control: Challenges and Practical Approaches," Advances in Design and Control, SIAM, 2009.
- [17] B. Stolarik, W. Niland, and B. Givens, "Multiple UAV communication modeling using the HLA," Simulation Interoperability Workshop, Arlington, VA, April 18-23, 2004.
- [18] S. Rasmussen and P. Chandler, "MultiUAV: A multiple UAV simulation for investigation of cooperative control," Proc. of the 2002 Winter Simulation Conference, San Diego, CA, Dec. 8-11, 2002, pp. 869-877.
- [19] W. Niland, "The migration of a collaborative UAV testbed into the Flames simulation environment," Proceedings of the 2006 Winter Simulation Conference, Monterey, CA, Dec. 3-6, 2006, pp. 1266-1272.
- [20] Q. Yao-hong and Liang Feng, "A method of wind field estimation and trajectory correction online in DR/GPS/RP integrated navigation of UAV," Automation and Logistics, 2008. ICAL 2008. IEEE International Conference on, Qingdao, China, pp. 1402-7, Sept. 1-3 2008.
- [21] N. Ceccarelli, J. Enright, E. Frazzoli, S. Rasmussen and C. Schumacher, "Micro UAV path planning for reconnaissance in wind," Proceedings of the 2007 American Control Conference, NY, July 2007.
- [22] A. Göktoğan and S. Sukkarieh, "Simulation of multi-UAV missions in a real-time distributed hardware-in-the-loop simulator," Proceeding of the 4th International Symposium on Mechatronics and its Applications, Sharjah, U.A.E. March 26-29, 2007, pp. ISMA07-1 - ISMA07-6.
- [23] R. Sharma and C. Taylor, "Cooperative navigation of MAVs in GPS denied areas," Proceedings of IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems, Seoul, Korea, August 20 - 22, 2008, pp. 481-486.
- [24] L. Lin and M. Goodrich, "UAV Intelligent Path Planning for Wilderness Search and Rescue," Proc. of 2009 IEEE/RSJ Int. Conference on Intelligent Robots and Systems, St. Louis, Missouri, USA pp. 709-714, Oct. 11 - 15, 2009.
- [25] A. Lomax, W. Corso, and J.F. Ebro, "Employing unmanned aerial vehicles (UAVs) as an element of the integrated ocean observing system," MTS/IEEE Oceans, 2005, pp. 1-7.
- [26] G. Jones, L.G. Pearlstine, and H.F. Percival, "An Assessment of small unmanned aerial vehicles for wildlife research," Wildlife Society Bulletin, 2006, vol. 34, no. 3, pp. 750-758.
- [27] L. Merino, F. Caballero, J. Dios, J. Ferruz, and A. Ollero, "A Cooperative perception system for multiple UAVs: Application to Automatic Detection of Forest Fires," Journal of Field Robotics, 2006
- [28] F. Bourgault, A.H. Göktoğan, et al., "Coordinated decentralized search for a lost target in a Bayesian world," Advanced Robotics, Special Issue on Selected Papers from IROS-2003, 2004
- [29] D. Brutzman, Presentation - "NPS AUV workbench: rehearsal, reality, replay for unmanned vehicle operations," NPS Technical Review and Update (TRAU), 25 April 2007, accessed September 10, 2009. [http://xmsf.cvs.sourceforge.net/\\*checkout\\*/xmsf/AuvWorkbench/documentation/presentations/presentations.html](http://xmsf.cvs.sourceforge.net/*checkout*/xmsf/AuvWorkbench/documentation/presentations/presentations.html)
- [30] D. Davis and D. Brutzman, "The Autonomous unmanned vehicle workbench: mission planning, mission rehearsal, and mission replay tool for physics-based X3D visualization," 14<sup>th</sup> International Symposium on Unmanned Untethered Submersible Technology (UUST), Autonomous Undersea Systems Institute (AUSI), Durham New Hampshire, 21-24 August 2005.
- [31] J. Weekley, D. Brutzman, A. Healey, D. Davis and D. Lee, "AUV workbench: integrated 3D for interoperable mission rehearsal, reality and replay," 2004 Mine Countermeasures & Demining Conference: Asia-Pacific Issues & Mine Countermeasures (MCM) in Wet Environments, Australian Defence Force Academy, Canberra Australia, 9-11 February 2004.
- [32] D. Brutzman, "Autonomous unmanned vehicle workbench (AUVW) rehearsal and replay: mapping diverse vehicle telemetry outputs to common XML data archives," 15<sup>th</sup> International Symposium on Unmanned Untethered Submersible Technology (UUST), Autonomous Undersea Systems Institute (AUSI), Durham New Hampshire, 19-22 August 2007.
- [33] B. Yoo and D. Brutzman, "X3D earth terrain-tile production chain for georeferenced simulation," Web 3D Sym., Darmstadt, June 2009.
- [34] D. Brutzman and L. Daly, X3D: Extensible 3D Graphics for Web Authors, M. Koffmann, 2007.
- [35] NPS Autonomous Unmanned Vehicle (AUV) Workbench, <https://savage.nps.edu/AuvWorkbench/> (accessed Sept 2009)
- [36] FlightGear Flight Simulator (Available: <http://www.flightgear.org>)

- [37] R. McBee, M. Mehrubeoglu, D. Carter and J. Durham, "Sensor-net information interoperability: trajectory and imagery support using free open-source software," poster presented at the Sensor-net Self-Organization and Control (SenSOC) Workshop, Mitre, San Diego, CA July 21-23, 2009.
- [38] M. Mehrubeoglu and J. Durham, "AUV Sensor-Payload Workbench: Exploratory Pilot for Image/Video Processing," presentation, Sensor-net Self-Organization and Control (SenSOC) Workshop, Mitre, San Diego, CA July 21-23, 2009.
- [39] C. Taylor and E. Anderson, "An automatic system for creating georeferenced mosaics from MAV video," 2008 IEEE/RSJ International conference on Intelligent Robots and Systems, Nice, France, 2008.
- [40] B. Heiner and C. Taylor, "Creation of Geo-Referenced Mosaics from MAV Video and Telemetry Using Constrained Optimization and Bundle Adjustment," *Proc. of 2009 IEEE/RSJ Int. Conference on Intelligent Robots and Systems*, St. Louis, Missouri, USA pp. 5173-5178, Oct. 11 – 15, 2009.
- [41] D. G. Lowe, "Distinctive image features from scale-invariant keypoints," *International Journal of Computer Vision*, vol. 60, no. 2, pp. 91–110, 2004.
- [42] D. G. Lowe, "Object recognition from local scale-invariant features," in *Proceedings of IEEE International Conference on Computer Vision, 1999*, vol. 2, pp.1150–1157, Sept. 20-27, 1999.
- [43] H. Bulo and A. Birk, "Fast and Robust Photomapping with an Unmanned Aerial Vehicle (UAV)," *Proc. of 2009 IEEE/RSJ Int. Conference on Intelligent Robots and Systems*, St. Louis, Missouri, USA pp. 5369-5375, Oct. 11 – 15, 2009.
- [44] Y. Lin and G. Medioni, "Map-enhanced UAV image sequence registration and synchronization of multiple image sequences," *Computer Vision and Pattern Recognition, 2007. CVPR '07.*, Minneapolis, MN, 2007, pp. 1-7.
- [45] M. Mehrubeoglu and L. McLauchlan, "Determination of traffic intensity from camera images using image processing and pattern recognition techniques," *Proc. of SPIE Volume 6063: Real Time Image Processing*, pp. 60630Q-1 -60630Q-12, Feb. 2006.
- [46] M. Mehrubeoglu and L. McLauchlan, "Determination of vehicle density from traffic images at day and nighttime," *Proc. of SPIE Volume 6496: Real Time Image Processing*, pp. 649603-1 – 649603-12, Feb. 2007.
- [47] OSSIM, [http://www.ossim.org/OSSIM/OSSIM\\_Home.html](http://www.ossim.org/OSSIM/OSSIM_Home.html) (ac'd 2009).
- [48] S. Steiniger and E. Bocher, "An Overview on Current Free and Open Source Desktop GIS Developments," *Int. J. of Geographical Information Science*, Sept. 2008, [http://terragis.net/docs/presentations/ssstein\\_foss\\_desktop\\_gis\\_overview.pdf](http://terragis.net/docs/presentations/ssstein_foss_desktop_gis_overview.pdf)
- [49] Whittington, E., and Blais, C., "Extending Capabilities of the Military Scenario Definition Language (MSDL) for Nontraditional Warfare Scenarios," Paper 09S-SIW-001, Proceedings of the Spring Simulation Interoperability Workshop, Simulation Interoperability Standards Organization, San Diego, March 2009.
- [50] Blais, C., Abbott, J., Diallo, S., Levine, S., Gustavsson, P. M., Nero, E., and Turnitsa, C., "Coalition Battle Management Language (C-BML) Phase 1 Specification Development: An Update to the M&S Community," Paper 09S-SIW-002, Proceedings of the Spring Simulation Interoperability Workshop, Simulation Interoperability Standards Organization, San Diego, March 2009.
- [51] Blais, C., Dodds, R., Pearman, J., and Baez, F., "Rapid Scenario Generation for Multiple Simulations: An Application of the Military Scenario Definition Language (MSDL)," Paper 09S-SIW-003, Proc. of the Spring Simulation Interoperability Workshop, Simulation Interoperability Standards Organization, San Diego, March 2009.
- [52] Gustavson, P., Nikolai, A., Scudder, R., Blais, C., and Daehler-Wilking, R., "Discovery and Reuse of Modeling and Simulation Assets," Paper 09S-SIW-076, Proc. of the Spring Simulation Interoperability Workshop, SISO, San Diego, March 2009.
- [53] Leong, H. W., Brutzman, D., McGregor, D., and Blais, C., "Web Services Integration On the Fly," Proceedings of the Spring Simulation Multi-Conference, San Diego, March 2009.
- [54] L. Seligman, B. Blaustein, P. Mork, K. Smith, N. Rothleder, "Information Interoperability and Provenance for Emergency Preparedness and Response," MITRE Report, 2009, [http://www.mitre.org/work/tech\\_papers/tech\\_papers\\_09/09\\_1337/09\\_1337.pdf](http://www.mitre.org/work/tech_papers/tech_papers_09/09_1337/09_1337.pdf) (last accessed Sept. 2009).
- [55] C. Coello, "Evolutionary Multi-Objective Optimization (EMOO) Home Page," <http://www.lania.mx/~ccoello/EMOO/> (accessed Sept. 2009).
- [56] J. Durham, M. Mehrubeoglu, D. Carter, R. McBee, and L. McLauchlan, "Support for Flight Trajectories and Video Capture: Initial Results Using a Free Open Source Flight Simulator," accepted *Earth & Space 2010 Conference – The 12th ASCE Aerospace Division Biennial International Conference on Engineering, Science, Construction and Operations in Challenging Environment*, Honolulu, HI, March 14-17, 2010.
- [57] K. Valavanis (editor), *Advances in Unmanned Aerial Vehicles – State of the Art and the Road to Autonomy*, Springer, The Netherlands, 2007.
- [58] L. Merino, F. Caballeros, P. Forssen, J. Wiklund, J. Ferruz, J. Martinez-de-Dios, A. Moe, K. Nordberg, and A. Ollero, "Vision-based multi-UAV position estimation - localization based on blob features for exploration missions," *IEEE Robotics and Automation Magazine*, vol. 13, no. 3, pp. 53-62, Sept. 2006.