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Final Report: High-Throughput Computing and Multi-Sensor Unmanned Aerial Systems in Support of Explosive Hazard Detection

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W911NF-19-1-0181

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
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6. AUTHORS

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES)
U.S. Army Research Office
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Research Triangle Park, NC 27709-2211

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14. ABSTRACT

15. SUBJECT TERMS

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a. REPORT	b. ABSTRACT	c. THIS PAGE			Derek Anderson
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RPPR Final Report
as of 26-Jan-2022

Agency Code: 21XD

Proposal Number: 73859CSRIP **Agreement Number: W911NF-19-1-0181**
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DUNS Number: 153890272 EIN: 436003859
Report Date: 24-Jun-2020 Date Received: 12-Apr-2021
Final Report for Period Beginning 25-Mar-2019 and Ending 24-Mar-2020
Title: High-Throughput Computing and Multi-Sensor Unmanned Aerial Systems in Support of Explosive Hazard Detection
Begin Performance Period: 25-Mar-2019 **End Performance Period:** 24-Mar-2020
Report Term: 0-Other

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Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: 1 **STEM Participants:** 30

Major Goals: This proposal is a two pronged request for high throughput computing (HTC) and multi-sensor unmanned aerial system (UAS) equipment in support of active U.S. Army Research Office (ARO) grants on machine learning and fusion for explosive hazard detection (EHD) (W911NF-18-1-0153, W911NF-17-1-0193, W911NF-10-1-0279) and an Army Research Laboratory (ARL) cooperative R&D agreement (CRADA) on wide area motion imagery (WAMI).

Investigators at the University of Missouri-Columbia have produced algorithms for the U.S. Army on EHD and WAMI within and across sensors and platforms for over 30 years. Whereas we have excellent resources, we lack the infrastructure capabilities outlined herein to make a leap (theory and application) and conduct more detailed, realistic, and repeatable platform/sensor/target experiments on past, current, and future Army data. Our HTC request is for data storage, a high-end server for compute-intensive offline experimentation, a development server, and mobile edge-computing for real-time UAS activities. The mobile edge-computing equipment is designed to also

be used in an offline capacity for additional day-to-day compute resources.

Our UAS/sensor request focuses on new U.S. Army capabilities. In EHD, existing platforms (e.g., hand-held, forward-looking, and side-looking (we have active research in all)) unfortunately put a human in harm's way; in close or direct proximity to threats. A UAS can mimic existing platforms and keep the human at a safe stand-off distance. Our UAS request consists of two copters and a fixed wing plane. These platforms allow us to investigate potential and best practices in collecting and processing data relative to metrics like task completion time/area covered. Our sensor request includes infrared, high resolution color, lidar, multispectral cameras, and positional sensors. These sensors have/are used in our Army research for WAMI and/or non-aerial EHD (hand-held and ground vehicle). Some sensors provide a direct way to sense and detect objects, e.g., explosive hazards. The remaining sensors facilitate registration of multi-sensor data and/or they can be used for scene understanding/context/tracking/etc.

In summary, the U.S. Army will see advancements in EHD and WAMI as a result of this DURIP. In addition, the various PIs/Co-PIs and Army projects involve overlapping topics like signal/image processing, registration, fusion, machine learning, etc. As such, the Army will get a value-add since this DURIP will bring together investigators/projects and allow for cross pollination of ideas and codes. Our team has demonstrated its ability to perform state-of-the-art research for the Army. If this DURIP is funded, we look forward to continuing our productivity and advancing the Army's mission on multiple fronts.

Accomplishments: See upload

Training Opportunities: Nothing to Report

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Results Dissemination: The following publications have been produced using resources from this project.

Evaluating deep road segmentation techniques for low-altitude UAS imagery

David Huangal, Jeffrey Dale, J Alex Hurt, Trevor M Bajkowski, James M Keller, Grant J Scott, Stanton R Price
Publication date: 2020/4/21
SPIE Defense and Commercial Sensing Conference: Artificial Intelligence and Machine Learning for Multi-Domain Operations Applications II

Maneuverability hazard detection and localization in low-altitude UAS imagery

J Alex Hurt, David Huangal, Jeffrey Dale, Trevor M Bajkowski, James M Keller, Grant J Scott, Stanton R Price
Publication date: 2020/4/21
SPIE Defense and Commercial Sensing Conference: Artificial Intelligence and Machine Learning for Multi-Domain Operations Applications II

Spatiotemporal Maneuverability Hazard Analytics from Low-Altitude UAS Sensors

Trevor M Bajkowski, David Huangal, J Alex Hurt, Jeffrey Dale, James M Keller, Grant J Scott, Stanton R Price
2020: IEEE Workshop on Applied Imagery and Pattern Recognition

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Detection of unknown maneuverability hazards in low-altitude UAS color imagery using linear features

Jeffrey Dale, David Huangal, J Alex Hurt, Trevor M Bajkowski, James M Keller, Grant J Scott, Stanton R Price
2020: IEEE Workshop on Applied Imagery and Pattern Recognition

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Koundinya Nouduri, Filiz Bunyak, Shizeng Yao, Hadi Aliakbarpour, Sanjeev Agarwal, Raghuveer Rao, Kannappan Palaniappan, “Deep learning based landmark matching for aerial geolocalization”, in Proceedings of the IEEE International Conference on Image Processing, 2020.

Gao, Ke, Hadi AliAkbarpour, Gunasekaran Seetharaman, and Kannappan Palaniappan. "DCT-Based Local Descriptor for Robust Matching and Feature Tracking in Wide Area Motion Imagery." IEEE Geoscience and Remote Sensing Letters (2020).

Koundinya Nouduri, Ke Gao, Joshua Fraser, Shizeng Yao, Hadi AliAkbarpour, Filiz Bunyak, Kannappan Palaniappan, "Deep Realistic Novel View Generation for City-scale Aerial Images", International Conference on Pattern Recognition, 2020, Submitted.

Dmitrii Chemodanov, Chengyi Qu, Osunkoya Opeoluwa, Songjie Wang, and Prasad Calyam. Policy-based function-centric computation offloading for real-time drone video analytics. IEEE Symposium on Local and Metropolitan Networks (LANMAN), 2019.

Rajeswara Rao Ramisetty, Chengyi Qu, Rumana Aktar, Songjie Wang, Prasad Calyam, and Kannappan Palaniappan. Dynamic computation o?-loading and control based on occlusion detection in drone video analytics. ACM Conference on Distributed Computing and Networking (ICDCN), 2020.

Chengyi Qu, Songjie Wang, and Prasad Calyam. Dycoco: A dynamic computation offloading and control framework for drone video analytics. In 27th IEEE International Conference on Network Protocols (ICNP), pages 1–2, 2019.

Jeromy Yu, Aditya Vandanapu, Chengyi Qu, Songjie Wang, and Prasad Calyam. Energy-aware dynamic computation o?oading for video analytics in multi-uav systems. IEEE International Conference on Computing, Networking and Communications (ICNC), 2020.

Chengyi Qu, Alicia Esquivel Morel, Drew Dahlquist, and Prasad Calyam. Design of tracebased NS-3 simulations for UAS video analytics with geospatial mobility. In Peter J. Doucette, Joshua D. Harguess, Kannappan Palaniappan, and Gunasekaran Seetharaman, editors, Geospatial Informatics X, volume 11398, pages 59 – 66. International Society for Optics and Photonics, SPIE, 2020.

Chengyi Qu, Alicia Esquivel Morel, Drew Dahlquist, and Prasad Calyam. Dronenet-sim: A learning-based trace simulation framework for control networking in drone video analytics. In Proceedings of the 6th ACM Workshop on Micro Aerial Vehicle Networks, Systems, and Applications, DroNet ’20, New York, NY, USA, 2020. Association for Computing Machinery.

Chengyi Qu, Alicia Esquivel, and Prasad Calyam. Dronenetsim. https://github.com/CaesarQu/DroneCOCoNet-Sim, 2020.

Honors and Awards: The 24th Conference on Neural and Information Processing Systems (NeurIPS2020) SpaceNet 7 competition, was about identifying and tracking building changes in 101 cities around the world using medium to low resolution (4m) satellite imagery. SpaceNet7 was organized by In-Q-Tel CosmiQ Works, Amazon Web Services, Maxar Technologies, Planet, Capella Space, IEEE GRSS and National Geospatial-Intelligence Agency (NGA). NeurIPS is one of the top artificial intelligence (AI) conferences and the University of Missouri Computational Imaging and VisAnalysis (CIVALab) team took 1st place in the graduate student competition, placed 8th overall among more than 300 entries and was the top ranked US team. The computational hardware from this DURIP was used to develop the winning technique.

Protocol Activity Status:

Technology Transfer: We constantly transfer codes, data, and information via biweekly presentations with our affiliated DoD laboratories (see write up).

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Project Contribution:
National Academy Member: N

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as of 26-Jan-2022

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ARTICLES:

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: IEEE Geoscience and Remote Sensing Letters
Publication Identifier Type: DOI Publication Identifier: 10.1109/LGRS.2020.3000762
Volume: Issue: First Page #: 1
Date Submitted: 3/16/21 12:00AM Date Published:
Publication Location:
Article Title: DCT-Based Local Descriptor for Robust Matching and Feature Tracking in Wide Area Motion Imagery
Authors: Ke Gao, Hadi AliAkbarpour, Gunasekaran Seetharaman, Kannappan Palaniappan
Keywords: Feature extraction , Discrete cosine transforms , Tracking , Agriculture , Detectors , Deep learning
Abstract: We introduce a novel discrete cosine transform-based feature (DCTF) descriptor designed for both robustly matching features in aerial video and tracking features across wide-baseline oblique views in aerial wide area motion imagery (WAMI). Our DCTF descriptor preserves local structure more compactly in the frequency domain by utilizing the mathematical properties of the discrete cosine transform (DCT) and outperforms widely used the spatial-domain feature extraction methods, such as speeded up robust features (SURF) and scale-invariant feature transform (SIFT). The DCTF descriptor can be used in combination with other feature detectors, such as SURF and features from accelerated segment test (FAST), for which we provide experimental results. The performance of DCTF for image matching and feature tracking is evaluated on two city-scale aerial WAMI data sets (ABQ-215 and LA-351) and a synthetic aerial drone video data set digital imaging and remote sensing image generation (Rochester In
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: IEEE Sensors Journal
Publication Identifier Type: DOI Publication Identifier: 10.1109/JSEN.2020.3042810
Volume: Issue: First Page #: 1
Date Submitted: 3/25/21 12:00AM Date Published: 12/7/20 6:00AM
Publication Location:
Article Title: Local Feature Performance Evaluation for Structure-from-Motion and Multi-View Stereo Using Simulated City-Scale Aerial Imagery
Authors: Ke Gao, Hadi Ali Akbarpour, Joshua Fraser, Koundinya Nouduri, Filiz Bunyak, Ricky Massaro, Guna Se
Keywords: Three-dimensional displays , Feature extraction , Cameras , Detectors , Pipelines , Sensors , Reliability
Abstract: Ubiquitous low cost multi-rotor and fixed wing drones or unmanned aerial vehicles (UAVs) have accelerated the need for reliable, robust, and scalable Structure-from-Motion (SfM) and Multi-View Stereo (MVS) pipelines suitable for a variety of flightpath trajectories especially in degraded environments. Feature tracking being a core part of SfM and MVS, is essential for multiview scene modeling and perception, but difficult to evaluate in large scale datasets due to the lack of sufficient ground-truth. For large-scale aerial imagery, accurate camera orientation and dense 3D point cloud accuracy can be used to assess the impact of accurate feature localization and track length. We propose a novel view simulation (or synthesis) framework which generates visually realistic new unseen camera views for feature detection using known high fidelity camera poses for modeling. Seven state-of-the-art local handcrafted and learning-based features are quantitatively evaluated for robustness and matc
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Acknowledged Federal Support: **Y**

CONFERENCE PAPERS:

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Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 2019 IEEE International Symposium on Local and Metropolitan Area Networks (LANMAN)
Date Received: 19-Jan-2021 Conference Date: 01-Jul-2019 Date Published:
Conference Location: Paris, France
Paper Title: Policy-Based Function-Centric Computation Offloading for Real-Time Drone Video Analytics
Authors: Dmitrii Chemodanov, Chengyi Qu, Osunkoya Opeoluwa, Songjie Wang, and Prasad Calyam
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: ICDCN 2020: 21st International Conference on Distributed Computing and Networking
Date Received: 19-Jan-2021 Conference Date: 04-Jan-2020 Date Published:
Conference Location: Kolkata India
Paper Title: Dynamic Computation Off-loading and Control based on Occlusion Detection in Drone Video Analytics
Authors: Rajeswara Rao Ramisetty, Chengyi Qu, Rumana Aktar, Songjie Wang, Prasad Calyam, and Kannappar
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 2019 IEEE 27th International Conference on Network Protocols (ICNP)
Date Received: 19-Jan-2021 Conference Date: 08-Oct-2019 Date Published:
Conference Location: Chicago, IL, USA
Paper Title: DyCOCo: A Dynamic Computation Offloading and Control Framework for Drone Video Analytics
Authors: Chengyi Qu, Songjie Wang, and Prasad Calyam
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 2020 International Conference on Computing, Networking and Communications & #x28;ICNC)
Date Received: 19-Jan-2021 Conference Date: 17-Feb-2020 Date Published:
Conference Location: Big Island, HI, USA
Paper Title: Energy-aware Dynamic Computation Offloading for Video Analytics in Multi-UAV Systems
Authors: Jeromy Yu, Aditya Vandanapu, Chengyi Qu, Songjie Wang, and Prasad Calyam
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: Geospatial Informatics X
Date Received: 19-Jan-2021 Conference Date: 27-Apr-2020 Date Published:
Conference Location: Online Only, United States
Paper Title: Design of trace-based NS-3 simulations for UAS video analytics with geospatial mobility
Authors: Chengyi Qu, Alicia Esquivel Morel, Drew Dahlquist, and Prasad Calyam
Acknowledged Federal Support: **Y**

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Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: MobiSys '20: The 18th Annual International Conference on Mobile Systems, Applications, and Services
Date Received: 19-Jan-2021 Conference Date: 19-Jun-2020 Date Published:
Conference Location: Toronto Ontario Canada
Paper Title: DroneNet-Sim
Authors: Chengyi Qu, Alicia Esquivel Morel, Drew Dahlquist, and Prasad Calyam
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: Artificial Intelligence and Machine Learning for Multi-Domain Operations Applications II
Date Received: 16-Mar-2021 Conference Date: 27-Apr-2020 Date Published:
Conference Location: Online Only, United States
Paper Title: Evaluating deep road segmentation techniques for low-altitude UAS imagery
Authors: David Huangal, Jeffrey Dale, J Alex Hurt, Trevor M Bajkowski, James M Keller, Grant J Scott, Stanton R
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: Artificial Intelligence and Machine Learning for Multi-Domain Operations Applications II
Date Received: 16-Mar-2021 Conference Date: 27-Apr-2020 Date Published:
Conference Location: Online Only, United States
Paper Title: Maneuverability hazard detection and localization in low-altitude UAS imagery
Authors: J Alex Hurt, David Huangal, Jeffrey Dale, Trevor M Bajkowski, James M Keller, Grant J Scott, Stanton R
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 2020: IEEE Workshop on Applied Imagery and Pattern Recognition, 2020
Date Received: 31-Mar-2021 Conference Date: 13-Oct-2020 Date Published:
Conference Location: Washington DC
Paper Title: Spatiotemporal Maneuverability Hazard Analytics from Low-Altitude UAS Sensors
Authors: Trevor M Bajkowski, David Huangal, J Alex Hurt, Jeffrey Dale, James M Keller, Grant J Scott, Stanton R
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 2020: IEEE Workshop on Applied Imagery and Pattern Recognition
Date Received: 31-Mar-2021 Conference Date: 13-Oct-2020 Date Published:
Conference Location: Washington DC
Paper Title: Detection of unknown maneuverability hazards in low-altitude UAS color imagery using linear features
Authors: Jeffrey Dale, David Huangal, J Alex Hurt, Trevor M Bajkowski, James M Keller, Grant J Scott, Stanton R
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: Detection and Sensing of Mines, Explosive Objects, and Obscured Targets XXV
Date Received: 16-Mar-2021 Conference Date: 27-Apr-2020 Date Published:
Conference Location: Online Only, United States
Paper Title: Doing more with less: similarity neural nets and metrics for small class imbalanced data sets
Authors: C. Veal, J. Schulz, A. Buck, D. T. Anderson, J. Keller, M. Popescu, G. Scott, D. Ho, T. Wilkin
Acknowledged Federal Support: **Y**

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Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: Detection and Sensing of Mines, Explosive Objects, and Obscured Targets XXV
Date Received: 16-Mar-2021 Conference Date: 27-Apr-2020 Date Published:
Conference Location: Online Only, United States
Paper Title: Extending deep learning to new classes without retraining
Authors: J. Schulz, C. Veal, A. Buck, D. T. Anderson, J. Keller, M. Popescu, G. Scott, D. Ho, T. Wilkin
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 2020 IEEE International Conference on Image Processing (ICIP)
Date Received: 16-Mar-2021 Conference Date: 25-Oct-2020 Date Published:
Conference Location: Abu Dhabi, United Arab Emirates
Paper Title: Deep Learning Based Landmark Matching For Aerial Geolocalization
Authors: Koundinya Nouduri, Filiz Bunyak, Shizeng Yao, Hadi Aliakbarpour, Sanjeev Agarwal, Raghuveer Rao, K
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: International Conference on Pattern Recognition, 2020
Date Received: Conference Date: 15-Jan-2021 Date Published:
Conference Location: Online
Paper Title: Deep Realistic Novel View Generation for City-scale Aerial Images
Authors: Koundinya Nouduri, Ke Gao, Joshua Fraser, Shizeng Yao, Hadi AliAkbarpour, Filiz Bunyak, Kannappan
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: Int. Conf. Pattern Recognition Workshop on Analysis of Aerial Motion Imagery
Date Received: 25-Mar-2021 Conference Date: 21-Feb-2021 Date Published:
Conference Location: Online
Paper Title: City-Scale Point Cloud Stitching Using 2D/3D Registration for Large Geographical Coverage
Authors: Shizeng Yao, Hadi AliAkbarpour, Guna Seetharaman, K. Palaniappan
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: International Conference on Pattern Recognition, 2020
Date Received: Conference Date: 13-Jan-2021 Date Published:
Conference Location: Online
Paper Title: Motion U-Net: Multi-Cue Encoder-Decoder Network for Motion Segmentation
Authors: Gani Rahmon, Filiz Bunyak, Kannappan Palaniappan
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: IEEE Applied Imagery Pattern Recognition (AIPR)
Date Received: Conference Date: 13-Oct-2020 Date Published:
Conference Location: Washington DC
Paper Title: SMVNet: Deep learning architectures for accurate and robust multi-view stereopsis
Authors: Shizeng Yao, Yangyang Wang, Hadi AliAkbarpour, Guna Seetharaman, Raghuveer Rao, and Kannappa
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Conference Name: IEEE Applied Imagery Pattern Recognition (AIPR)
Date Received: Conference Date: 13-Oct-2020 Date Published:
Conference Location: Washington DC
Paper Title: Semi-automatic system for rapid annotation of moving objects in surveillance videos using deep detection and multi-object tracking techniques
Authors: N.M. Al-Shakarji, E. Ufuktepe, F. Bunyak, H. AliAkbarpour, G. Seetharaman, K. Palaniappan
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: Geospatial Informatics X
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Authors: A. Nafis, E. Teters, R. Aktar, G. Seetharaman, and K. Palaniappan
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Partners

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I certify that the information in the report is complete and accurate:
Signature:
Signature Date:

2020 REPORT

High-Throughput Computing and Multi-Sensor Unmanned Aerial Systems in Support of Explosive Hazard Detection

Primary Investigator: Prof. Derek T. Anderson, University of Missouri (MU)
Co-Investigators: Prof. Prasad P. Calyam, MU; Prof. James M. Keller, MU; Prof. Kannappan Palaniappan, MU; Prof. Grant Scott, MU

Summary

Although 2020 was unusual in many ways, e.g., COVID, research has progressed on several fronts at the Univ. of Missouri related to this DURIP. The funds provided have contributed to a number of US Army projects. This report summarizes some of the research enhanced. More details can be provided upon request. This DURIP provided support for (1) computing and storage (algorithm development, evaluation, and real-time prototyping), (2) two drone platforms (one in support of structure from motion, the other for explosive hazard detection), (3) a mobile fog (for flexible real-time multi-sensor processing in theatre), and (4) a structure from motion visualization server. The University of Missouri is very grateful for this support, 2020 was our opportunity to set up and start to use the DURIP equipment, and in 2021 we anticipate more follow up success.

Dynamic Edge/Cloud Computation Offloading and Network Control for Drone Video Analytics

PI: Prasad Calyam

Unmanned Aerial Vehicles (UAVs), also known as drones, have been extensively used in urban and rural scenarios such as disaster response, border security, crime fighting and smart farming. Most commercially used drones are equipped with high-resolution cameras and sensors that are used to visualize and monitor target status, e.g., object recognition, counting and tracking purposes. State-of-the-art video analytics processing applications are increasing using drone video collection that requires high-performance computing resources and real-time network communications. The problems of insufficient computing resources and edge networking speeds can be addressed using computation off-loading to a Ground Control Station (GCS). However, traditional mobile edge computing (MEC) computation off-loading strategies cannot always be used for tactical drone computation and control due to the dynamic wireless channel and energy consumption constraints on the drone-edge computing for processing high-resolution images. In edge networks, a variety of environmental conditions may affect the performance of the video streaming between the drone and GCS. This in turn affects the performance of video streaming in terms of end-to-end delay, frame blurring, stalling and distortion. Given the above challenges, we have found that there is a clear lack of mechanisms to efficiently coordinate the networking protocols in conjunction with drone control orchestration and computation off-loading during drone video analytics. In this period-of-performance year of activities, we investigated and addressed the following problems in

drone video analytics as well as computation offloading considering Flying Ad-hoc Network (FANET) System applications:

- We developed a novel policy-based computational offloading scheme that facilitates tradeoffs in performance vs. cost factors (based on users' preferences) during real-time drone video analytics by utilizing Edge, Cloud and Function-Centric Computing architectures [1]. The Function-Centric Computing (FCC) architecture features decomposing applications into micro-service functions that can be deployed onto edge resources in conjunction with core cloud platforms.

- We designed a novel dynamic computation off-loading and control scheme that detects occlusions that impair user Quality of Experience (QoE), and coordinates intelligent processing in drone video analytics [2]. The intelligent processing considers the trade-o↵ in processing time vs. tracking/accuracy rate using the FCC architecture.

- To foster reproducibility in the real-world experiment of FCC and dynamic computation as well as control scheme, we proposed a demonstration through GENI and CloudLab [3]. Our demonstration had a set up of user requirements of latency and bandwidth to each function/task in the video analytics application. We showed how our framework identifies the pertinent network topology and allocates required resources with a novel service chaining and networking tool that we developed.

- By holistically considering FANET system energy consumption and resource allocation, we developed a novel energy-aware computation offloading scheme that minimizes the total energy consumption in the edge devices, while also achieving video processing time that fulfills a given set of FANET application requirements [4]. Our proposed scheme optimizes the tradeoffs in energy, processing latency, and task scheduling time among different FANET mobility settings used in different video processing applications (disaster response, border security, and smart farming).

- We addressed the challenges in executing high-scale drone video analytics experiments due to constraints in drone manufacturing, government regulation restrictions, and limited energy resources. Specifically, we developed algorithms with impact of network protocol selection to handle diverse UAV mobility models as well as dynamic network status during edge-network video processing. We also proposed simulations on both drone [5] and network [6] sides. Our simulation platform can process real-world drone traces that include various mobility models, geospatial link information and on-time network status obtained from real-world data-gathering efforts.

- We have developed open-source software for showing FCC capabilities and have demonstrated our simulator scripts using a map interface [7]. Our software can be configured with dynamic contextual markers functionality that help with the management of several UAVs in application scenarios relating to: (a) smart city traffic management, (b) border security monitoring, and (c) disaster incident management.

Publications

[1] Dmitrii Chemodanov, Chengyi Qu, Osunkoya Opeoluwa, Songjie Wang, and Prasad Calyam, "Policy-based function-centric computation offloading for real-time drone video analytics," IEEE Symposium on Local and Metropolitan Networks (LANMAN), 2019.

[2] Rajeswara Rao Ramisetty, Chengyi Qu, Rumana Aktar, Songjie Wang, Prasad Calyam, and Kannappan Palaniappan. Dynamic computation off-loading and control based on occlusion detection in drone video analytics," ACM Conference on Distributed Computing and Networking (ICDCN), 2020.

[3] Chengyi Qu, Songjie Wang, and Prasad Calyam, "Dycoco: A dynamic computation offloading and control framework for drone video analytics," in 27th IEEE International Conference on Network Protocols (ICNP), pages 1–2, 2019.

[4] Jeromy Yu, Aditya Vandanapu, Chengyi Qu, Songjie Wang, and Prasad Calyam, "Energy-aware dynamic computation offloading for video analytics in multi-uav systems," IEEE International Conference on Computing, Networking and Communications (ICNC), 2020.

[5] Chengyi Qu, Alicia Esquivel Morel, Drew Dahlquist, and Prasad Calyam, "Design of trace-based NS-3 simulations for UAS video analytics with geospatial mobility," in Peter J. Doucette, Joshua D. Harguess, Kannappan Palaniappan, and Gunasekaran Seetharaman, editors, Geospatial Informatics X, volume 11398, pages 59 – 66, International Society for Optics and Photonics, SPIE, 2020.

[6] Chengyi Qu, Alicia Esquivel Morel, Drew Dahlquist, and Prasad Calyam, "Dronenet-sim: A learning-based trace simulation framework for control networking in drone video analytics," in Proceedings of the 6th ACM Workshop on Micro Aerial Vehicle Networks, Systems, and Applications, DroNet '20, New York, NY, USA, 2020. Association for Computing Machinery.

[7] Chengyi Qu, Alicia Esquivel, and Prasad Calyam. Dronenetsim. https://github.com/CaesarQu/DroneCOCoNet-Sim, 2020.

Evaluation of State-of-the-Art Machine Learning Models Applied to Sensing Maneuverability Hazards using Multiple Phenomenologies and Platforms

Advanced Maneuver Technologies

Army Engineer Research and Development Center (ERDC)

PIs: Grant Scott & James Keller

This project aims to develop enhanced capabilities for the Next Generation Combat Vehicle (NGCV), in terms of maneuverability and survivability in hostile and dynamic environments. The hardware provided by the DURIP grant has assisted in the execution of this US Army ERDC

sponsored research project. Additionally, it has led to collaborative publications with research project agencies, such as detailed below. The high-performance computing equipment has been invaluable as we explore cutting edge machine learning techniques for data acquired from UAS, such as electro-optical, near infrared, and LIDAR systems. The mobile computing resources will be critical as we continue this research, as we are developing a distributed (multi-UAS and ground vehicle) sensor system to enable operational situational awareness of threats to maneuverability for ground vehicles.

Publications

[8] David Huangal, Jeffrey Dale, J Alex Hurt, Trevor M Bajkowski, James M Keller, Grant J Scott, Stanton R Price, "Evaluating deep road segmentation techniques for low-altitude UAS imagery," SPIE Defense and Commercial Sensing Conference: Artificial Intelligence and Machine Learning for Multi-Domain Operations Applications II, Apr. 2020.

Abstract: Semantic segmentation, the task of assigning a class label to each pixel within a given image, has applications in a wide variety of domains, ranging from medicine to self-driving vehicles. One successful deep neural network model that has been developed for semantic segmentation tasks is the U-Net architecture, a "U"-shaped neural network initially applied to segmentation of cell membranes in biomedical images. Additional variants of the U-Net have been developed within the research literature that incorporate new features such as residual layers and attention mechanisms. In this research, we evaluate various U-Net-based architectures on the task of segmenting the road and non-road in low-altitude UAS visible spectrum imagery. We show that these models can successfully extract the roads, detail a variety of performance metrics of the respective networks' segmentations, and show examples of successes and pending challenges using U.S. Army ERDC imagery collected from a variety of flight routes and altitudes in a complex environment.

[9] J Alex Hurt, David Huangal, Jeffrey Dale, Trevor M Bajkowski, James M Keller, Grant J Scott, Stanton R Price, "Maneuverability hazard detection and localization in low-altitude UAS imagery," SPIE Defense and Commercial Sensing Conference: Artificial Intelligence and Machine Learning for Multi-Domain Operations Applications II, Apr. 2020

Abstract: Object detection and localization is an important problem in computer vision and remote sensing. While there have been several techniques presented and used in recent years, the You Only Look Once (YOLO) and derivative architectures have gained popularity due to their ability to perform real-time object localization as well as achieve remarkable detection scores in ground-based applications. Here, we present methods and results for performing maneuverability hazard detection and localization in low-altitude unmanned aerial systems (UAS) imagery. Imagery is captured over a variety of flight routes and altitudes, and then analyzed with modern deep learning techniques to discover objects such as civilian and military vehicles, barriers, and related hindrances to navigating cluttered semi-urban environments. We present our findings for the deep learning architectures under a variety of training and validation parameters that include pre-trained weights from

benchmark public datasets, as well as training with a custom, mission-relevant dataset provided by U.S. Army ERDC.

[10] Trevor M Bajkowski, David Huangal, J Alex Hurt, Jeffrey Dale, James M Keller, Grant J Scott, Stanton R Price, "Spatiotemporal Maneuverability Hazard Analytics from Low-Altitude UAS Sensors," 2020: IEEE Workshop on Applied Imagery and Pattern Recognition, 2020.

Abstract: Low-altitude unmanned aerial systems (UAS) have a rapidly changing field of view for most sensor payloads, especially downward-looking high-resolution visual imagery. In this research, we explore visible-spectrum derived spatiotemporal awareness applied to companion sensor phenomenologies and computationally derived information, such as computer vision-based road extraction and maneuverability hazard localization. Specifically, short-span visual-temporal analysis is performed to understand the platform motion and therefore geospatial context of measurements, whether from sensors or analytical processes. The mathematical model of frame-to-frame platform motion is extracted as homographies and affine transformations that describe how one image "fits into" the next. By coupling these computed motion models with derived data, such as road segmentation and object localization, we show how this technique allows the development of temporal-confidence to aid scene understanding of a complex environment and results in more robust feature matching process. The resulting context-aware geospatial platform facilitates increasing complex spatiotemporal analytics for enhanced maneuverability and route planning for ground units from assistive low-altitude airborne platforms. The tools proposed show promise for increasing user security through spatial awareness in regions that are GPS-denied or unseen. In particular, these capabilities are demonstrated on a collection of sequential aerial images taken of a region with mixed use.

[11] Jeffrey Dale, David Huangal, J Alex Hurt, Trevor M Bajkowski, James M Keller, Grant J Scott, Stanton R Price, "Detection of unknown maneuverability hazards in low-altitude UAS color imagery using linear features," 2020: IEEE Workshop on Applied Imagery and Pattern Recognition, 2020.

Abstract: Deep learning approaches have very quickly become the most popular framework for both semantic segmentation and object detection/recognition tasks. Especially in object detection, however, supervised models like deep neural networks are inherently prone to find only classes from the training data in the testing set. In domains where the safety and security of operators are entrusted to machine learning algorithms, it is often infeasible or impossible to train supervised models on all possible classes; thus, a supplementary unsupervised approach is needed. For the specific problem of detecting potential maneuverability hazards within road segmentation networks, we propose an unsupervised solution using linear features with a voting scheme at each pixel within a pre-supplied road segmentation map, yielding a consensus-based confidence of how unlike a pixel is to surrounding road pixels. This approach is verified on UAS imagery collected by the U.S. Army ERDC.

Explainable Multi-Source Fusion in Deep Learning for Explosive Hazard Detection

PI: Derek Anderson
Co-PI: Grant Scott

This US Army research project, in support of NVESD, seeks to develop advanced explainable detection algorithms for explosive hazards using multiple sensor modalities from UAV platforms. The DURIP grant has enabled the purchasing of high-performance computing hardware, drones, and sensors that contributed to this research. We have used this equipment to investigate novel methods of data augmentation, object detection algorithms, and to develop and assess synthetic imagery. Specifically, the computing has allowed us to run more experiments and try more ideas. The edge computing hardware has also allowed us to develop real-time GPU codes in support of soldier touch point events. The drone has allowed us to collect data, refine our theories, and test ideas. It has helped support publications in 2020, and four more upcoming publications in 2021.

Publications

[12] C. Veal, J. Schulz, A. Buck, D. T. Anderson, J. Keller, M. Popescu, G. Scott, D. Ho, T. Wilkin, "Doing More With Less: Similarity Neural Nets and Metrics for Small Class Imbalanced Data Sets," SPIE 2020.

Abstract: The focus of this article is extending classifiers from N classes to N+1 classes without retraining for tasks like explosive hazard detection (EHD) and automatic target recognition (ATR). In recent years, deep learning has become state-of-the-art across domains. However, algorithms like convolutional neural networks (CNNs) suffer from the assumption of a closed-world model. That is, once a model is learned, a new class cannot usually be added without changes in the architecture and retraining. Herein, we put forth a way to extend a number of deep learning algorithms while keeping their features in a locked state; i.e., features are not retrained for the new N+1 class. Different feature transformations, metrics, and classifiers are explored to assess the degree to which a new sample belongs to one of the N classes and a decision rule is used for classification. Whereas this extends a deep learner, it does not tell us if a network with locked features has the potential to be extended. Therefore, we put forth a new method based on visually assessing cluster tendency to assess the degree to which a deep learner can be extended (or not). Lastly, while we are primarily focused on tasks like aerial EHD and ATR, experiments herein are for benchmark community data sets for sake of reproducible research.

[13] J. Schulz, C. Veal, A. Buck, D. T. Anderson, J. Keller, M. Popescu, G. Scott, D. Ho, T. Wilkin, "Extending Deep Learning to New Classes without Retraining,", SPIE 2020.

Abstract: The focus of this article is extending classifiers from N classes to N+1 classes without retraining for tasks like explosive hazard detection (EHD) and automatic target recognition (ATR). In recent years, deep learning has become state-of-the-art across domains. However, algorithms like convolutional neural networks (CNNs) suffer from the

assumption of a closed-world model. That is, once a model is learned, a new class cannot usually be added without changes in the architecture and retraining. Herein, we put forth a way to extend a number of deep learning algorithms while keeping their features in a locked state; i.e., features are not retrained for the new N+1 class. Different feature transformations, metrics, and classifiers are explored to assess the degree to which a new sample belongs to one of the N classes and a decision rule is used for classification. Whereas this extends a deep learner, it does not tell us if a network with locked features has the potential to be extended. Therefore, we put forth a new method based on visually assessing cluster tendency to assess the degree to which a deep learner can be extended (or not). Lastly, while we are primarily focused on tasks like aerial EHD and ATR, experiments herein are for benchmark community data sets for sake of reproducible research.

High-Throughput Computing and UAS with Sensors for WAMI Processing

The hardware purchased under the DURIP including drone, sensors and visualization system enabled progress on three projects related to improvements in wide area motion imagery 3D scene perception, target tracking, coordinating multiple UAVs and drone network security. Over 12 papers were published with support from the DURIP award for both HTC and UAS with Sensors. Publication list at the end of the report.

ARL: (PI Kannappan Palaniappan)
Video Analytics and Image Processing for Multiview Scene Understanding

AFRL: (PI Kannappan Palaniappan)
3D Urban Modeling Using Coordinated UAV Platforms and Embedded FABRIC Architectures

NSF REU SITE: (PI Prasad Calyam)
Research in Consumer Networking Technologies

Request 1 High-Throughput Computing

The visualization server, GPU accelerators, and embedded GPUs were successfully purchased, installed and tested for developing ML and Fusion software for algorithms, codes, and experimental results for processing WAMI datasets. The DURIP HTC hardware resources with CPU and GPU clusters enabled us to successfully extend our object detection algorithms developed for aerial imagery to small object detection in satellite imagery for competing in the SpaceNet7 challenge. The 24th Conference on Neural and Information Processing Systems (NeurIPS2020) SpaceNet 7 competition, was about identifying and tracking building changes in 101 cities around the world using medium to low resolution (4m) satellite imagery. SpaceNet7 was

organized by In-Q-Tel CosmiQ Works, Amazon Web Services, Maxar Technologies, Planet, Capella Space, IEEE GRSS and National Geospatial-Intelligence Agency (NGA). NeurIPS is one of the top artificial intelligence (AI) conferences and the University of Missouri Computational Imaging and VisAnalysis (CIVALab) team took 1st place in the graduate student competition, placed 8th overall among more than 300 entries and was the top ranked US team.

https://engineering.missouri.edu/2021/03/mapping-the-cities-of-the-world-one-building-at-a-time-from-space/

Request 2 UASs and Sensors

The VTOL UAS and combination gimbal plus sensor with EO, thermal IR and LiDAR was successfully designed, assembled and tested. This enabled testing embedded processing of the tracking algorithms including PFluxTracker on ARL custom built drone systems (IMPERIAL). The University of Missouri tracking algorithms including PFlux Tracker were demonstrated in early 2020 on embedded GPUs for onboard UAS processing, to then Army Undersecretary James McPherson as part of Project X-Convergence and in 2019 as part of the Army Small Intelligent UAS (SIUAS) program. Some initial data has been collected with the DURIP sensors mounted on the FreeFly ALTA-6 upgraded drone plus sensors. This UAS has been approved (AWR, Level 3 Airworthiness) for onsite data collection. The UAS received preliminary approval for the 2020 C5ISR NVESD at Yuma Proving Ground (YPG), AZ but the data collection was cancelled due to the covid pandemic. We have completed an updated AWR application request for the YPG aerial imagery data collection as part of the Advanced Targeting and Lethality Automated System (ATLAS) Aided Target Recognition (AiTR) Data Collection Rodeo.

At the edge-cloud processing UAV tracking testbed was developed using embedded GPUs and a ROS Node. In the SIUAS program and Army Modernization Priorities Essential Research Program (ERP) collaboration with ARL we developed algorithms to obtain 3D situational awareness and common operating picture (COP) using real-time onboard AI & ML onboard for developing autonomous capabilities.

Publications

[14] Ke Gao, Hadi AliAkbarpour, Joshua Fraser, Koundinya Nouduri, Filiz Bunyak, Ricky Massaro, G. Seetharaman, K. Palaniappan, “Local feature performance evaluation for structure-from-motion and multi-view stereo using simulated city-scale aerial imagery”, *IEEE Sensors Journal*, 2020, Online.

[15] Ke Gao, Hadi AliAkbarpour, G. Seetharaman, K. Palaniappan, “DCT-based local descriptor for robust matching and feature tracking in wide area motion imagery”, *IEEE Geoscience and Remote Sensing Letters*, 2020, Online.

[16] Gani Rahmon, Filiz Bunyak, Guna Seetharaman, K. Palaniappan, “Motion U-Net: Multi-cue encoder-decoder network for motion segmentation”, *Int. Conf. Pattern Recognition,* 2020.

[17] Koundinya Rohit Nouduri, F. Bunyak, Shizeng Yao, Hadi AliAkbarpour, Sanjeev Agarwal, Raghuveer Rao, K. Palaniappan, “Deep learning-based landmark matching for aerial

geolocalization", *IEEE International Conference on Image Processing (ICIP),* pp. 1911—1915, 2020.

[18] Koundinya Nouduri, Ke Gao, Joshua Fraser, Shizeng Yao, Hadi AliAkbarpour, Filiz Bunyak, Kannappan Palaniappan, "Deep realistic novel view generation for city-scale aerial images", *Int. Conf. Pattern Recognition,* 2020.

[19] Shizeng Yao, Hadi AliAkbarpour, Guna Seetharaman, K. Palaniappan, "City-scale point cloud stitching using 2D/3D registration for large geographical coverage", *Int. Conf. Pattern Recognition Workshop on Analysis of Aerial Motion Imagery*, 2020.

[20] Koundinya Rohit Nouduri, F. Bunyak, Shizeng Yao, Hadi AliAkbarpour, Sanjeev Agarwal, Raghuveer Rao, K. Palaniappan, "Deep learning-based landmark matching for aerial geolocalization", *IEEE International Conference on Image Processing (ICIP),* pp. 1911—1915, 2020.

[21] Shizeng Yao, Yangyang Wang, Hadi AliAkbarpour, Guna Seetharaman, Raghuveer Rao, and Kannappan Palaniappan "SMVNet: Deep learning architectures for accurate and robust multi-view stereopsis", *IEEE Applied Imagery Pattern Recognition (AIPR),* 2020.

[22] N.M. Al-Shakarji, E. Ufuktepe, F. Bunyak, H. AliAkbarpour, G. Seetharaman, K. Palaniappan, "Semi-automatic system for rapid annotation of moving objects in surveillance videos using deep detection and multi-object tracking techniques", *IEEE Applied Imagery Pattern Recognition (AIPR),* 2020.

[23] Ekincan Ufuktepe, Vipul Ramtekkar, Ke Gao, Noor Al-Shakarji, Joshua Fraser, Hadi AliAkbarpour, Guna Seetharaman, and Kannappan Palaniappan "pyTAG: Python-based interactive training data generation for visual tracking algorithms", *Proc. SPIE Geospatial Informatics X,* Vol. 11398, 113980D, 2020.

[24] A. Nafis, E. Teters, R. Aktar, G. Seetharaman, and K. Palaniappan. GPU and multi-threaded CPU enabled normalized cross correlation. In *Proc. SPIE Geospatial Informatics X* (Defense + Commercial Sensing), Vol. 11398, 2020.

[25] Rajeswara Rao Ramisetty, Chengyi Du, Rumana Aktar, Songji Wang, Prasad Calyam, K. Palaniappan, "Dynamic computation off-loading and control based on occlusion detection in drone video analytics", ACM *21st International Conference on Distributed Computing and Networking (ICDCN),* Kolkatta, India, 10 pages, 2020.