2021

# Assessment of Multispectral Imaging System for UAS Navigation in a GPS-denied Environment

Yakimenko, Oleg A.

Monterey, California: Naval Postgraduate School

https://hdl.handle.net/10945/69767

NAVAL RESEARCH PROGRAM
NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

# ASSESSMENT OF MULTISPECTRAL IMAGING SYSTEM FOR UAS NAVIGATION IN A GPS-DENIED ENVIRONMENT

## EXECUTIVE SUMMARY

**Principal Investigator (PI):** Prof. Oleg Yakimenko, Graduate School of Engineering & Applied Science (GSEAS), Systems Engineering (SE)

**Additional Researcher(s):** No additional researchers participated in this research project

**Student Participation:** Seungwan Cho, Systems Engineering, Joel Li, Systems Engineering

**Prepared for:**
Topic Sponsor Lead Organization: N8 - Integration of Capabilities & Resources
Topic Sponsor Organization(s): NAVSPECWARCOM
Topic Sponsor Name(s): Mr. Peter Dimitruk, NAVSPECWARCOM
Topic Sponsor Contact Information: peter.dimitruk.mil@socom.mil, 858-349-2707

This research is supported by funding from the
Naval Postgraduate School, Naval Research Program (PE 0605853N/2098).

**Project Summary**
This study assessed applicability and benefits of using a multispectral (MS) sensor (as opposed to or in addition to a standard electro-optical (EO) and/or infrared (IR) sensors) on board of small unmanned aerial systems (sUAS) for enhancing accuracy and precision of object detection (identification), classification and tracking (DCT) that may contribute to a variety of downstream applications including threat detection, forensics, battle damage-assessment, additional/alternative aid to navigation (ATON) in the GPS-degraded or GPS-denied environments. It also includes an assessment of the computer-vision and artificial intelligence algorithms to process the MS sensor output quickly and reliably. The overall conclusion is that the usage of multi-band MS sensors instead of EO or EO/IR sensors represents a feasible enhancement / alternative. Further assessment should include investigation of the effects of operating environment (including meteorological factors and sUAS mission parameters) to determine limitations of the MS-based DCT and ATON.

**Keywords:** *sUAS, MS sensor, unexploded ordinance detection, machine learning, GPS-denied navigation, navigational aid, feature extraction and matching, vision odometry*

**Background**
These days, an integrated EO/IR sensor and its associated signal or image processing, tightly integrated in form and function, is a standard payload for manned and unmanned aerial systems (UAS) of Group 1 and higher. Specifically, Group 3 - Group 5 UAS use numerous sensor technologies that span from ultraviolet to far infrared. EO/IR sensors are used to detect and identify targets, track moving targets, and assess threats from a distance and in challenging environmental conditions. Common applications of EO/IR systems include airborne homeland security, combat, patrol, surveillance, reconnaissance, search and rescue programs.

For most gimbal pointing applications, including geo-referencing, the gimbal control system requires position data, which precludes a solution provided by Inertial Navigation System (INS) and requires a GPS-aided option. In order to operate in GPS-denied environments, which is becoming a growing concern as peer-state rivals continue to advance GPS spoofing and denial techniques, new technologies are being explored / developed. Particularly, Vision Navigation is considered to be one of the most rudimentary forms of navigation and involves building a database of terrain features or landmarks that can then be tracked by onboard sensors in order to calculate a vehicle's position, velocity and altitude to provide a Precision, Navigation and Timing (PNT) solution.

Multispectral (MS) imagery is a relatively new technology. The difference compared to the EO and infrared IR sensors is that MS sensors capture reflected light/energy in the number of bands rather than in a single narrow band. Because MS and HS imaging captures information that cannot be seen with the human eye and presents a more data-rich mosaic for scientists, it has become a highly desired technology for applications within the remote-sensing realm. These applications include crop science, precision agriculture, mining and mineral exploration, petroleum exploration, ecology, disaster mitigation, and others. Typically, these applications are most efficiently done from the air.

The research questions addressed in this study included the following:

- Whether using multiple spectral bands has any benefits compared to a standard EO sensor or EO sensor combined with IR sensor. That includes benefits of having a spectral profile of surrounding background area and objects from the standpoint of more reliable/precise DCT.
- What are the limitations of using MS sensors and computer vision / artificial intelligence (CV/AI) algorithms to process data?
- What computational resources would be required to enable DCT capability on board of commercial off-the-shelf sUAS?
- Whether an onboard MS sensor and available feature-finding and matching techniques can contribute to enabling GPS-free navigation for aerial vehicles.

To address these research questions, this study dealt with two applications. One was related to the DCT problem, specifically it dealt with detecting unexploded ordinances (UXOs) with the help of sUAS equipped with a 5-band MS. Thousands of images were obtained using both EO and MS sensors. Artificial convolutional neural network (CNN) was designed and trained for EO and each spectrum of MS sensors. The second application dealt with visual odometry. A limited set of 2-band MS sensor imagery was used for the analysis. Different feature-finding algorithms were tried.

**Findings and Conclusions**

The key findings for the MS-based detection of UXOs problem are as follows:

- The AI-based UXO detection system seems to be a good representative application where MS sensor could reveal its potential to contribute to the solution of DCT problems.
- As anticipated, the UXO detection capability by individual spectrum detectors is lower compared to that of EO sensor. However, it was found that they are complimentary to each other.
- By applying the two-step integration process, the overall UXO detection capability of MS detector exceeds that of EO sensor by about 13%.
- Using more than one spectral band makes a detection process more reliable. For example, while in some cases Blue and Green detectors were able to detect UXO, other band detectors were not. In some other cases, only the NIR detector was able to detect UXO while all other detectors failed to do so.
- All detectors detecting UXO in their own spectrum band feature a different size of the bounding box and different detection confidence score (i.e., some spectrum detectors detect UXO more precisely than others). For instance, in some cases, the Blue and Green detectors detected UXO more precisely than other detectors. In some other cases, it was the Red and NIR detectors that detected UXO more precisely than the others.

The key findings for the MS-based visual odometry problem are as follows:

- Three feature finding methods (out of eight explored), specifically, ORB, FAST and SURF, seem to provide the best feature finding results for both EO and NIR spectra.

- Features found by EO and NIR sensors, seem to be complimentary (not necessarily the same).
- If two consecutive images feature about the same scene, many features can be matched between the images, even though they are far apart (slow flight, high altitude flight, high sampling rate). Even for the specific set of data obtained by a low-flying sUAS when images were taken 10 or even 20 seconds apart, there was a healthy number of the matching features and inliers to produce a compute transformation.

For both applications considered in this study (object detection and vision-aided navigation), the CV/AI algorithms that were developed in the MATLAB development environment worked reliably and did not take more resources than it would be required for processing a standard EO and/or IR sensor output.

**Recommendations for Further Research**

The overall conclusion from this study is that utilizing small unmanned aerial systems (sUAS) equipped with multispectral sensor (MS) and computer vision / artificial intelligence (CV/AI) algorithms may be very beneficial to Department of Defense and Department of the Navy offering new and enhancing existing capabilities. As such, the recommendation is to continue the assessment of technologies discussed in this study. Further development would involve

- Using a fully equipped sUAS, recording unmammed aerial systems‘(UAS) / sensor position and attitude while taking MS imagery
- Tuning the visual odometry algorithms to match true data provided by the inertial navigation system/global positioning system (INS/GPS)
- Studying effects of operating environment, terrain, altitudes, object size and material, time of the day, weather, number of spectral bands, resolution, narrow field of view.

**Acronyms**

| | |
|---|---|
| AI | artificial intelligence |
| ATON | additional/alternative aid to navigation |
| CV | computer vision |
| DCT | detection (identification), classification and tracking |
| EO | electro-optical |
| GPS | Global Positioning System |
| HS | hyperspectral |
| INS | Inertial Navigation System |
| IR | Infrared |
| MS | multispectral |
| NIR | near infrared |
| PNT | precision, navigation and timing |
| sUAS | small unmanned aerial system |
| UAS | unmanned aerial system |
| UXO | unexploded ordinance |

| | |
|---|---|
| VNIR | visible and NIR |