MX-1: A New Multi-Modal Remote Sensing UAS Payload with High Accuracy GPS and IMU

Dr. Daniel S. Kaputa  
College of Engineering Technology  
Rochester Institute of Technology  
Rochester, USA  
dskiee@rit.edu

Timothy Bauch  
Center for Imaging Science  
Rochester Institute of Technology  
Rochester, USA  
tdbpci@cis.rit.edu

Dr. Carson Roberts  
Research and Development  
Headwall Photonics  
Bolton, USA  
croberts@headwallphotonics.com

Don McKeown  
Center for Imaging Science  
Rochester Institute of Technology  
Rochester, USA  
mckeown@cis.rit.edu

Mark Foote  
College of Engineering Technology  
Rochester Institute of Technology  
Rochester, USA  
mlf9871@rit.edu

Dr. Carl Salvaggio  
Center for Imaging Science  
Rochester Institute of Technology  
Rochester, USA  
salvaggio@cis.rit.edu

Abstract—Unmanned aerial vehicles, sometimes called UAVs or drones, have captured the imagination of a new generation of developers that see these systems as disruptive technologies that can completely transform entire markets. Due to their low cost, ease of use, and ability to carry sensors with unprecedented spectral, spatial, and temporal resolutions, remote sensing is one such market that is being transformed by these revolutionary new devices. As sensors become smaller and UAV payload capacities increase, the researcher has the ability to create various sensing payload combinations. This is very fortunate since many research projects require the simultaneous collection of multiple sensing modalities. By collecting all modalities simultaneously and in a single flight, one can collect data under the same weather conditions and illumination levels, thus increasing the veracity of the data. The multi-modal payload approach also eliminates the need to change gimbals in the field and reduces wear and tear on the equipment due to multiple payload changes. This article outlines the development of the MX-1 UAV-capable payload which was a joint development between the Rochester Institute of Technology Center for Imaging Science and Headwall Photonics. MX-1 is a revolutionary new multi-modal remote sensing UAV payload that allows for simultaneous collection of four different imaging modalities namely RGB, LWIR, LiDAR and hyperspectral.

Index Terms—multiple, modalities, UAV, payload, remote sensing, research

I. INTRODUCTION

As mentioned above the unprecedented spectral, spatial, and temporal resolutions that UAVs provide has ushered in a new era of remote sensing that has researchers scrambling to find ways to harness this veritable Pandora’s box of new sensing technology [1]. UAV-based remote sensing research is being conducted around the world using an assortment of imaging modalities to gather higher resolution data [1-5 cm] that is not possible or is cost prohibitive with other methods such as high altitude fixed wing aircraft [5-25 cm] or satellites [0.3 - 300 m] [2]. The astonishing capability of these systems is also being increased every couple years due to new UAV-targeted imaging sensors and advances in on-board processing. Our team has taken advantage of this confluence of sensor miniaturization and UAV technologies to develop the MX-1 system. Other remote sensing devices developed for fixed wing aircraft such as NASA Goddard’s LiDAR, Hyperspectral and Thermal g-LiHT airborne imager [3] are capable of multi-modal sensing, however to our knowledge there does not exist a UAV-based multi-modal sensing platform that can sense and log RGB, LWIR, LiDAR and hyperspectral imagery simultaneously. Our system, coined the MX-1, when mounted on a DJI Matrice 600 Pro, has a flight time of 18 minutes and is capable of a spatial resolution between 1-3 cm RMS [4]. The design and development of the MX-1 system is discussed at length in the sections below.

II. SYSTEM ARCHITECTURE

The MX-1 refers to the sensing payload however the total UAV system architecture needs to be taken into account in order to achieve the desired flight time. The system architecture of this unmanned aerial system [UAS] is split into two main functional units, namely the flight subsystem and the sensing subsystem. These two subsystems are completely separated with the exception that the flight batteries are also used to power the sensing subsystem. This design decision was made in order to eliminate the need for a separate sensing battery which would ultimately increase the weight and complexity of the system.

A. Flight Subsystem Selection

The flight subsystem is composed of a DJI Matrice 600 Pro UAV which has a weight of 10 kg, can carry a payload of 5.5 kg, and has a maximum controllable range of 5 km [5]. The Matrice 600 Pro was selected due to its lifting capability, design maturity, and affordable price. The Matrice 600 Pro has its own GPS/IMU and can be controlled through various flight planning software, such as UgCS, DJI Go, or Mission Planner. The system can be operated in either
autonomous mode or manual mode which can be determined by the user. A typical collection run is performed by first setting up a photogrammetry route, which is defined by a polygon bounding box that is used to determine flight lines based on proper overlap of imagery that will suit the desired experiment. Once the flight lines or waypoints are programmed into the software and uploaded into the UAV, upon starting the mission the system will automatically traverse the desired trajectory. The Matrice 600 Pro GPS/IMU combination only has an accuracy of around 1 meter [6] however it was determined that a separate sensing GPS/IMU was needed in order to achieve centimeter accuracy for sample placement on the ground. Our team selected the Applanix™ APX15 for the sensing GPS/IMU, however the Matrice 600 Pro GPS/IMU was still used for flight control. Once the main flight subsystem was selected, the task at hand was to select the proper sensing elements. When trying to determine the required size, weight, and power [SWaP] envelope for the sensing subsystem, the weight vs. flight time plot shown in Figure 1 was taken into consideration [5]. The data points on the figure depict flight times at given weights for payloads designed by DJI. The TB48S battery configuration was chosen for our design due to their longer flight numbers.

Since a flight time of over 18 minutes was desired, a payload weight requirement of 5 kg was set. One factor that is not represented in the above diagram is that the plot assumes no power is used from the main batteries to power the payload. This is not true in our case as both the flight and sensing subsystems are powered from the flight batteries. It was determined that as long as the sensing subsystem power draw was below five percent of the flight subsystem power draw, the flight duration would still be within a reasonable variance for the 18 minute flight time. The sensing subsystem and its associated power draw is discussed in the section below.

### B. Sensing Subsystem Component Selection

As mentioned above, the sensing subsystem is capable of sensing RGB, LWIR, LiDAR and hyperspectral modalities with a very high spatial resolution. For UAV applications the sensors not only need to have sufficient performance and connectivity, but they also need to have amenable size, weight, and power [SWaP] parameters. Both a power and weight budget analysis were performed on a variety of sensors in order to determine a subset of flight-worthy sensors. Figure 2 shows the sensors that were selected along with some of their key parameters. In order to obtain geo-location of the data, the APX15 is used for GPS/IMU information. The ground sampling distance [GSD] numbers shown in Figure 2 are for an altitude of 30 meters. On the MX-1 all sensors were mounted in a fixed position pointing nadir.

<table>
<thead>
<tr>
<th>Modality</th>
<th>Sensor</th>
<th># Bands</th>
<th>Spatial [px]</th>
<th>GSD [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyperspectral</td>
<td>Headwall Nano-Hyperspec*</td>
<td>270</td>
<td>640 x 1 *</td>
<td>1.88</td>
</tr>
<tr>
<td>RGB</td>
<td>Allied Vision Mako G-419</td>
<td>3</td>
<td>2048 x 2048</td>
<td>1.04</td>
</tr>
<tr>
<td>LWIR</td>
<td>DRS Tamarisk 640</td>
<td>1</td>
<td>640 x 480</td>
<td>3.09</td>
</tr>
<tr>
<td>LiDAR</td>
<td>Velodyne VLP-16</td>
<td>NA</td>
<td>NA</td>
<td>5.33 **</td>
</tr>
</tbody>
</table>

* Line scanner ** Approximate point spacing at 300 RPM

### III. PAYLOAD DESIGN

Once the functional elements [i.e., sensors] were determined, the task at hand was to develop a payload that would mate onto the undercarriage of the Matrice 600 Pro. The first step was to determine the physical and electrical interconnects between the various sensors and to understand how the data would be logged in a real-time fashion while being stamped with time and spatial identifiers. The block diagram of the sensor subsystem is shown below in Figure 5. The main flight batteries were accessed via the Matrice 600 Pro payload power jack and the power was regulated into clean 12 V.
and 5 V busses for the sensing electronics. Most of the data in the system is ferried around via an ethernet switch and the Applanix™ GPS/IMU acts as the main synchronization source. The Headwall HyperCore™ and Nano-Hyperspec®, as well as the Applanix™ GPS/IMU all perform data logging functions which are discussed in Section V below. A custom printed circuit board [PCB] was also developed to handle the various voltage levels required by the sensors and to implement a “hot swap” battery feature.

The “hot swap” feature allows the UAV to land when under a low battery condition and for the payload to be switched over to field power [typically from an external LiPo battery] so the payload never needs to be power cycled. This feature was found to be very beneficial as the GPS/IMU calibration was only needed to be performed a single time at the beginning of the day. If the payload was powered off after every flight, the Applanix™ GPS/IMU calibration procedure would need to be redone with every flight. Once the PCB was designed and fabricated, it was assembled into a 3D printed enclosure that also housed the ethernet switch, Applanix™ GPS/IMU, and various interfacing cables. An image of the entire electronics enclosure is shown in Figure 6. In addition to the electronics enclosure, an aluminum frame was constructed that holds the electronics enclosure as well as the sensing elements as shown in Figure 7. This frame was designed to be attached to the bottom of the Matrice 600 Pro as shown in Figure 8.

IV. APPLANIX CALIBRATION

It is noteworthy that the MX-1 uses the Applanix™ APX15 for the GPS/IMU. This device is the key component that gives the MX-1 system such a high geospatial accuracy. Without the APX15, the Matrice 600 Pro is only capable of around 1 meter resolution, however, the Applanix™ APX15 achieves an accuracy of 1-3 centimeters. One undesired feature of the APX15 is the somewhat cumbersome calibration procedure which requires the operator to power on, wait 5 minutes for warm up, and then to manually fly the drone in figure eights at high speed until an “aligned” status is achieved. The APX15 only needs to be calibrated one time per power cycle which was a main driver for the “hot swap” feature mentioned above. Once the APX15 is calibrated and flights are conducted, the APX15 data is offloaded via the ethernet switch and can
be post-processed into a smoothed best estimate trajectory [SBET] file to be used for post-processing the rest of the data.

V. DATA CAPTURE AND POST-PROCESSING

The data logging topology is quite complex since many systems are capable of logging their own data. The trick is to appropriately time stamp each isolated data set in order to enable data synchronization during data post-processing. The sensors that are capable of data logging are the Headwall HyperCore™ and Nano-Hyperspec®, as well as the Applanix™ GPS/IMU unit. The Applanix™ is the main synchronization agent in the system as it supplies both telemetry data and a pulse per second [PPS] signal to all other data logging units. The telemetry and PPS signals can be thought of as “primary keys” that can be used to sync up the data in the post-processing stage. After a collection flight, the HyperCore™, Nano-Hyperspec®, and Applanix™ datasets are downloaded via the ethernet switch to a local PC. Once the data has been downloaded the Applanix™ “primary key” is used to sync up the various data sets in order to achieve a time-synchronous multi-modal geo-rectified data set.

VI. RESULTS

The data collected by the MX-1 was used to generate the plot in Figure 9 which shows a set of high resolution multi-modal images. The end product level for processing is different for each modality and is determined based on the project and the end user’s desire. The total development time for the project was about four months and the system has been a workhorse for our research group and a true success story. Since its creation in May of 2017 it has flown over 400 flights all around the United States for studies ranging from forest density analysis, white mold detection, vegetative health, target detection, and calibration of sensors for various research projects at RIT.

VII. FUTURE WORK

Even though we believe the MX-1 mounted on the Matrice 600 Pro is a truly revolutionary sensing system, there are several updates that are being planned for the second generation system. In addition to longer flight times and a greater payload capacity, the second generation system will have a cooled longwave infrared imager for better thermal radiometric resolution as well as a downwelling light spectrometer for calibration purposes. Unfortunately the mantra “be careful what you wish for” has come true in this scenario, since instead of scrambling to find useful data sets for their research, our research team is drowning in geo-rectified high resolution data. For example, a typical 18 minute flight with all sensors running will typically generate about 30 GB of data which needs to be meticulously post-processed. A future improvement for the system would be to add some on-board data processing in order to automate data synthesis and to reduce the size of the logged data and consequently the required amount of post-processing.

VIII. ACKNOWLEDGEMENT

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