LOW-COST MULTISPECTRAL AERIAL IMAGING USING AUTONOMOUS RUNWAY-FREE SMALL FLYING WING VEHICLES

Austin M. Jensen, Marc Baumann and YangQuan Chen

Utah State University
Center for Self-Organizing and Intelligent Systems (CSOIS)
Electrical and Computer Engineering Department
4120 Old Main Hill Logan, UT, USA
Austin.Jensen@aggiemail.usu.edu, yqchen@ieee.org

ABSTRACT

Aerial imaging has become very important to areas like remote sensing and surveying. However, it has remained expensive and difficult to obtain with high temporal and spatial resolutions. This paper presents a method to retrieve georeferenced aerial images by using a small UAV (unmanned aerial vehicle). Obtaining aerial images this way is inexpensive, easy-to-use and allows for high temporal and spatial resolutions. New and difficult problems are introduced by the small image footprint and the inherent errors from an inexpensive compact inertial measurement unit (IMU). The small image footprint prevents us from using the features from the images to help negate the errors from the IMU, which is done in conventional methods. Our method includes: using the data from the IMU to georeference the images, projecting the images on the earth and using a man-in-the-loop approach to minimize the error from the IMU. Sample results from our working system are presented for illustration.

Index Terms— Unmanned Aerial Vehicle, Multispectral Remote, Georeferencing, NASA World Wind.

1. INTRODUCTION

Some big challenges for remote sensing include: timeliness, frequency, spatial resolution and cost [1]. Many applications that would benefit greatly from remote sensing are nevertheless affected by the shortcomings of these challenges. Specifically in the agricultural application areas, Hunsaker et. al. [2] applied remote sensing to find the evapotranspiration of an area of interest to help with irrigation control. Similarly, Bajwa et. al. [3] used remote sensing techniques to find the water stress level of the crops to help with irrigation control as well. Both of these applications could help improve crop yield and save water. However due to the temporal resolution and cost, remote sensing has not been widely accepted for irrigation control [1]. In other applications, for example, Casbeer et. al. [4] introduced about how remote sensing could help combat forest fires, but the images cannot update fast enough to be effective.

Taking aerial images using UAVs has become a desirable way to overcome the above-mentioned remote sensing shortcomings. For example, Johnson et. al. [5] used a solar powered NASA UAV called Pathfinder to detect coffee field ripeness. Zhou and Zang [6] presented a low-cost UAV platform they used to record video from the air. The frames from the video are stitched together using common features from the overlap on the images. Another low-cost UAV platform was presented by Simpson et. al. [7]. They used a consumer digital still camera to take the images from the air. Once the plane landed, GIS software was used to georeference the images. All of these platforms use features from the images for georeferencing. Our experience has shown that in many cases, the small image footprint from a low altitude UAV makes it very hard to georeference only based on features. This is especially the case in featureless areas like fields and lakes. Moreover, each platform requires a runway and a long time for maintenance and repair. Depending on a runway is inconvenient and may prevent the UAV from flying in many remote areas and agriculture fields.

In this paper, we introduce a new system called gRIAD (Geo-Spatial Real-Time Aerial Image Display) which georeferences the aerial images using only the position and orientation of the UAV. gRAID is used with an economic, easy-to-use, flexible UAV platform for remote sensing with high temporal and spatial resolutions [8]. More information about our working system will be made available in [9].
2. UAV PLATFORM

All of the aircrafts in our collection are flying wings with wing span ranging from 48” to 100” (see Fig. 1). Currently, we only fly the 48” aircraft autonomously (Fig. 2), but plan on also using the larger frames to increase our flight time with better stability and larger payload. To avoid being dependent on a runway for take off and landing, all of our aircrafts can be hand-thrown at take-off and can easily skid land on any flat surface. In addition to hand-throwing the aircraft, we also routinely use a bungee (see Fig. 3) to launch the aircraft. Currently we use a robust and effective open source autopilot called Paparazzi [10] to fly our planes autonomously. For a survey of various autopilots, refer to [11]. The basic specifications of our more matured 48” UAV platform, known as CSOIS OSAM-UA V, are listed in Table 1.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>2.5 lb.</td>
</tr>
<tr>
<td>Max Height</td>
<td>300m.</td>
</tr>
<tr>
<td>Max Speed</td>
<td>20m/sec.</td>
</tr>
<tr>
<td>Max Communication Distance</td>
<td>16km</td>
</tr>
<tr>
<td>GPS Accuracy</td>
<td>3m - 5m</td>
</tr>
<tr>
<td>Batteries</td>
<td>3 Lipo</td>
</tr>
<tr>
<td>Flight Duration</td>
<td>45-50 minutes</td>
</tr>
</tbody>
</table>

3. LOW-COST MULTISPECTRAL IMAGERS

We have developed two different imaging systems from which we take the aerial photos. Both systems have the capability to cover the visual and the NIR bands of the spectrum. More information on the imaging hardware development is fully documented in [12].

Fig. 1. A sample collection of CSOIS OSAM UAVs

Fig. 2. Closeup of CSOIS OSAM-UA V (48”)

Fig. 3. Illustration of bungee launch of fixed-wing UAV

The first system is called GhostFinger (GF). GF is a consumer Pentax camera with some additional hardware which enables it to take pictures automatically at a specified frequency. Additionally, the GF also has the option to take a picture when triggered by an external signal source (another microcontroller or an RC controller). At 7 megapixels (MP), the GF camera can achieve centimeter resolution on the ground when flying at 200m. high. The GF is designed to accommodate additional sensors like a GPS module, altitude sensor and an inclinometer to georeference the images. Once an image is taken, the GF logs the data from the sensors onto an additional SD card. With the additional sensors, the images could be georeferenced and placed on a map using gRAID (see the next section for details). Although the inclinometer is not designed for dynamic uses and did not work well in dynamic flight, we were still able to obtain the roll and pitch of the UAV by roughly synchronizing the GF data with the datalog on the UAV. In the future, we will interface GF to the Paparazzi autopilot to georeference the images using the data from the IMU. By interfacing GF to Paparazzi, more accurate synchronization can be achieved with better georeferenced images.

The other system we have developed is called GhostFinger Video (GF-Video). The GF-Video is a small, 50 gram OEM camera with 640x480 resolution. The images from the camera are transmitted down to a frame grabber at the base station using a 50 gram, 500mW transmitter. Once the frame grabber records a picture, the position and orientation of the UAV are also recorded to synchronize the images for georeferencing. Before the images are georeferenced, they are corrected for barrel distortion and the noise is filtered. In addition to good ground resolution (0.5m), the GF-Video also gives us the opportunity to georeference and process the im-
ages in real-time with gRAID.

4. GEOREFERENCING AND STITCHING

To georeference the acquired aerial photos, we use the position and attitude data taken from the UAV. However due to the errors from the IMU, the georeferencing is not good enough. Normally, one would use a feature based stitching method to fix the errors. In our case, some applications require the images to be taken over a featureless area like a dirt field or a lake. In addition, the footprints of the aerial images are very small (50-150m width) and good ground control points are not always available. An example of the desired application where this would be a problem is remote sensing for irrigation control. These problems make it very hard to use features in the images to help with georeferencing.

To display the images, we use an open source 3D world viewer called World Wind (http://worldwind.arc.nasa.gov). World Wind was developed by NASA and is written in C#. It was chosen because it is open source, and it has a user friendly software development kit (SDK) for writing plug-ins. Our gRAID is a plug-in for World Wind and uses the 3D environment to render the images from the UAV. Image georeferencing can be done after the flight or in real-time during the flight. To improve the accuracy of the georeferencing, gRAID removes the barrel distortion from each image. To be compatible with other GIS software, gRAID can import and export world files (.JGW in our case). After the images are exported to world files, they can be stitched together using other software.

Fig. 4. World Wind with gRAID plug-in

To minimize the errors from the UAV sensors, gRAID provides a tool to easily manipulate the position and attitude of the UAV for each image. The accuracy of the image on the ground is related to the error from the sensor which is bounded. While staying within the boundaries of the sensor errors, the user can change the UAV sensor values and compare the rendered image with a background image. Even though this method still relies on features, by going man-in-the-loop, we can systematically understand where the errors are coming from. Once we know where the error is coming from, we can develop methods to correct the images by compensating the state estimates of the UAV.

5. RESULTS

A Utah State University owned farm is used to test the system (GPS: 41.8194 -111.9885, nearly 550 acres). Figure 5 shows the images taken with GF-Video after they have been processed and georeferenced. These images had an average error of about 40m. Figure 6 shows the images after the user made adjustments to the UAV data. By going the man-in-the-
loop way, we were able to conclude that the GPS module, the altitude sensor and the yaw are our biggest contributors to the resulted error. The yaw of the UAV is calculated using the course reported by the GPS module. The course is calculated using the current and previous position of the UAV. So if the UAV is not pointed in the direction it is moving, the yaw of the aircraft will be different than the course. The nice thing about the error in the yaw is that it seemed to be a bias error for each sweep which can be easily corrected. The altitude of the UAV was also a big problem since it is predicted by measuring the barometric pressure of the surrounding air. This allows the UAV to keep the same altitude by following the same gradient in the pressure. However, this altitude may not be the true altitude. To fix this problem the altitude could be calibrated for each flight. The last observation made with the man-in-the-loop method was regarding the GPS. The GPS error is found to be a consistent bias in the opposite direction of the flight. This may be caused by the slow update rate on the GPS module (1Hz) and the moving aircraft. If the GPS updates the position of the UAV a half second after, an image is taken, the position of the image could be off 7-10 m depending on the flying speed.

6. CONCLUSIONS AND FUTURE WORK

A system for processing, georeferencing and displaying aerial images in real-time called gRAID has been successfully developed and tested. With our current working system, future work will include:

- Differential GPS to improve GPS error
- Automatic altitude calibration to improve altitude error
- Adding magnetic compass to improve yaw error
- Adapting aircraft for a thermal infrared camera
- Adding real-time multispectral image processing to gRAID
- Adding open source GIS software OSSIM to gRAID for image stitching (http://www.ossim.org)

7. REFERENCES


