An Airborne Gimballed Imaging System

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ABSTRACT

An airborne gimballed imaging system comprises an agile, accurate, efficient, and versatile gimbal machine. It drives a long range imaging sensor payload over wide roll, pitch, and yaw angular ranges. Together with an embedded instrument computer, the gimbal machine is precisely servo-actuated at a sub-pixel resolution and navigated by a GNSS-Aided Inertial Navigation System (INS) with a 1m geospatial accuracy for imaging payload stabilization and pointing and high resolution fast frame image collection.

A fast, high resolution and wide area mapping is one of the applications of the gimballed imaging system. It has been tested aboard Cessna 172 plane. It demonstrates: 1) a gimballed dual resolution fused imaging by adapting a pair of 47MP and 86MP mid-format cameras; 2) a fast wide swath mapping by using the gimballed imaging system, capable of collecting a 10cm Ground Sample Distance (GSD) geospatial data with a 3km swathwidth at a 12,000 ft Above Ground Level (AGL) by a single Cessna flypass.

Keywords: Remote Sensing, Gimbal, Photogrammetry, Robotics, Mapping.

1 INTRODUCTION

Space and/or airborne remote sensing systems today are still not good enough to provide the needed high resolution geospatial information quickly over a wide area to respond various real-time events. Particularly, for responding catastrophic disasters, searching disappeared airplanes/ aviators, or performing change detection, it demands geospatially precise high resolution remote sensing data rapidly collected over various sized Field of Regard (FOR).

Aerospace gimbal technologies have been used to increase imaging resolution and/or aera coverage by exploiting fast frame cameras. In Summer 2013, a collaboration of researchers from NGIT, GIA, AGC, and NASA demonstrated a pilot effort that adapts a gimballed imaging system aboard a US Navy research airship for a city scale thermal mapping over Baltimore, Maryland, USA[1]. The system utilizes a gimballed step-staring imaging to triple the swathwidth of a small format, 320 by 256 pixel, 30µm pitch, Quantum Well Infrared Photo-detector (QWIP) video camera with a 50mm lens. However, the reported gimbal system is limited by its speed, sensor loading capacity, angular ranges, etc., especially, when requiring hosting large, long-range multi-sensors for wider angular range operations aboard fast fixed-wing airplanes.

NGIT has recently developed a modularized roll, pitch, yaw gimballed imaging system motivated to have better agility, accuracy, efficiency and versatility to host larger sized multi-sensors for smart/programmable perspective imaging. The first application of the gimballed imaging system is to perform a fast airborne mapping test aboard a fixed-wing for simultaneous high resolution and wide area coverage. This NGIT's airborne test effort is subcontracted from IMSAR (https://www.imsar.com) as a part of a SBIR Phase III project supported and funded by the US Army Geospatial Research Laboratory (GRL).

2 AIRBORNE INSTRUMENT

NextGen Imaging Technologies (NGIT) Inc. designs and fabricates precise and high-performance gimballed imaging systems using NGIT's advanced technologies and innovations in the fields of modularized gimbal machines, advanced photogrammetry, and remote sensing system of systems. The gimbal machine is scalable in size and angular ranges. It is easily configurable to host various sensors for various operational scenarios, such as "roll, pitch, and yaw" or "full range pan and tilt" gimbal system for mission specific attitude controls.

A roll, pitch, yaw 3D gimbal machine is reported herein. Its angular ranges, resolutions, accuracy, and speed specified in **Table 1.** The gimballed imaging system is belly-mount on to a 10-inch in diameter camera port of a Cessna 172 airplane as shown in **Figure 1(a).**

Table 1: The 3D Gimbal Machine Specifications:

	Yaw	Pitch	Roll
Angular Range	+/-53°	+/- 36°	+/- 36°
Angular Resolution	$(2.02\text{x}10^{-5})°$	$(1.81\text{x}10^{-5})°$	$(3.38\text{x}10^{-5})°$
GPS/INS attitude accuracy(WGS84)	0.03°	0.01°	0.01°
Angular Speed Limit	322°/sec	360°/sec	360°/sec

The gimbal machine hosts interchangeable camera systems. Two mid-format cameras are selected as the gimballed payload for the airborne test. One is an SVS-Vistek 47 MegaPixel (MP; 8856 x 5280, 5.5µm pixels, 7fps) global shutter color CCD camera attached with a 210mm Mamiya lens. The other is a Teledyne DALSA

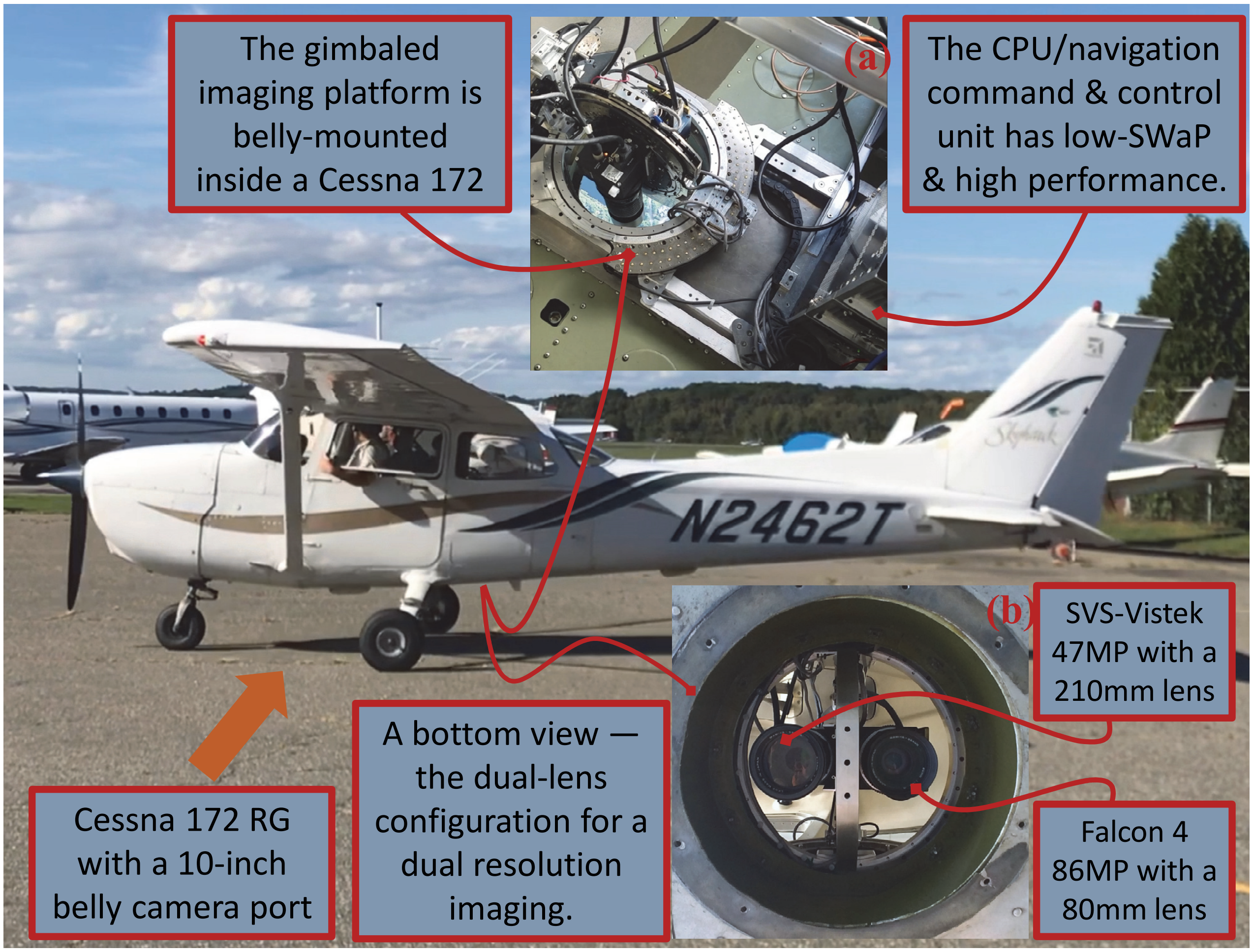

Figure 1: The Cessna 172 test airplane and the gimbaled imaging instrument setup.

86MP (10720x8064, 6μm pixels, 16fps) Falcon 4 global shutter CMOS camera attached with a 80mm lens as shown in **Figures 1(a) and (b)**. This sensor payload provides dual resolution imaging data sources motivated for more flexible mapping/ISR applications and more robust image geo-registration, while reducing data processing work.

The gimbaled imaging system comprises a modularized high performance command and control instrument as shown in **Figure 1(a).** The instrument tightly integrates a high performance CPU system, GPS-INS, servomotor drivers and controllers, along with two stackable high throughput imaging and data acquisition subsystems. One of the subsystems has a CameraLink data interface that connects to a SVS-Vistek 47MP camera. The other has a CameraLink HS™ (CLHS) interfaces connected to a Falcon 4 86MP camera. Combining a set of custom-built power and signal distribution circuits for all connected components, a fully functional, single-boxed low Size, Weight and Power (SWaP) command and control system has been made. This low-SWaP instrument system is battery or airplane power operational. It is compact and portable with significantly simplified system wiring for airborne deployment.

Embedded command and control software has been developed for the gimbal control, data collection, and imaging direct georeferencing. For simultaneous high resolution and wide area fast mapping, a multi-step Across-Track-Staring (ATS) imaging has been used. The software developed actuates the gimbal machine to do the multi-step ATS motion that orientates the telephoto to take multi-shots at ATS stabilized perspectives. The ATS multi-shots multiply the swathwidth of the telephoto field of view (FOV). For example, when a 10-step ATS is programmed with a step distance of 90% of the FOV, it generates a multiplied swath that is ~9 times of the FOV.

Dual-framerate synchronization is accomplished by a camera trigger circuit adapted to synchronize the frame captures over two acquisition paths. As an example, when 7-step ATS positioning events trigger a camera at 7Hz and the other at divided 3Hz, a set of frames exposed at 3Hz from two cameras are synchronized. Realtime GPS-INS and gimbal metadata are tagged to each frame at exposure time. With the precisely established timing, the integrated GPS-INS measurements can be utilized to actively navigate the programmed gimballing to stabilize and/or direct the aerial imaging accurately. The real-time direct georeferencing accuracy of imaging is about 1m.

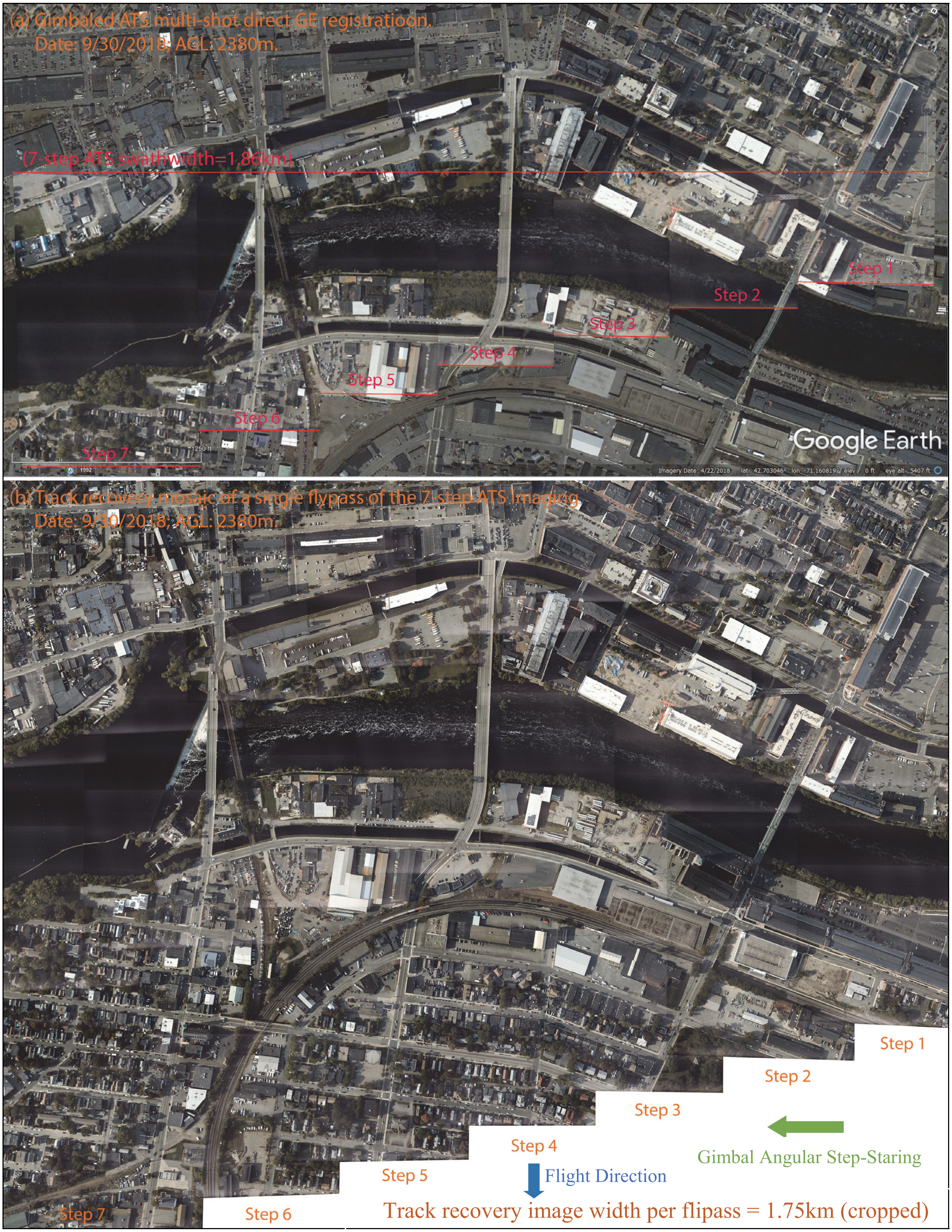

Figure 2: Illustration of the airborne 7-step ATS data sample collected by a 47MP camera.

4 AIRBORNE FAST MAPPING TEST

A fast mapping test of the gimballed imaging system was performed aboard the Cessna 172 Skyhawk airplane. To test the swathwidth multiplication, the imaging sensor payload was fast gimballed in a 7-step ATS mode. The programmed angular step is 5.937° that defines a 25% side-overlap between adjacent images of the ATS. It results in a total swathwidth 29,040 pixels across 43.9° FOR. The test was performed in the municipal area of Lawrence, Massachusetts, USA in September 2018.

The ATS-position-triggered frames were acquired and saved in both raw and JPEG files. The GPS-INS and gimbal positioning metadata were collected to index corresponding images for direct georeferencing.

For fast geospatial applications, a Keyhole Markup Language (KML) file that registers a JPEG image to map is calculated from the georeferencing metadata. NGIT's KML file is compatible to Open Geospatial Consortium (OGC) standard. It indexes a JPEG file to attach it to a digital globe map coordinate system. By openning a KML, a coresponding JPEG file is in turn openned as a geo-registered ground overlay image and displayed on the desktop of Google Earth or other compatible GIS.

Figure 2(a) shows that a set of 7-shots of ATS images are registered on to Google Earth as ground overlay images by calling NGIT's embedded KML files. These ATS images are geo-registered precisely as shown. The flying altitude is 2380m AGL. Using a 210mm lens, the ATS imaging has a GSD 6.23cm for near Nadir frames. The swathwidth of FOR is measured as 1.86km. The edge miss-registration among ground overlay frames meets instrument specification (~1m or less). The aerial image quality in terms of resolution, less geometric distortion, and less perspective variations are better than those of Google Earth base-images acquired on 4/22/2018.

Additional postprocessing mthods have been tested for the airborne data applications. Using aerotriangulation algorithms, the dual resolution multi-perspective imaging data can be exploited to reveal various terrain, 3D infrastructure, and plain metric map features.

An example postprocessing imagery is presented in **Figure 2(b).** It shows a mosaic composed from three rows of 7-step gimballed ATS images of a single flypass. The photogrammetric postprocessing uses GPS-INS & gimbal metadata to calculate the ATS image positions into a common coordinate system, in which all these frames are pre-aligned to speed up a fine registration calculation. A blending processing is used for the final mosaic generation, in which overlapping pixels are progressively blended to form a transitional portion. The processed data shows that the gimballing provides a reliably mapping coverage so that the mapping area underfly is completely covered by aerial images without data holidays. The edge miss-registration among these aerial frames is hardly noticeable in the mosaic. The mosaicked image has a cropped swathwidth about 1.75km as shown.

5 DISCUSSIONS

The swathwidth of FOR using the airborne gimballed imaging system aboard Cessna 172 can be further increased. For fast-stepped ATS mapping, ≤10% side-overlap is more efficient for swathwidth multiplication. Using 7-steps for the ATS operation with a side-overlap defined as 10%, an ATS step is 7.122°, giving a total swathwidth 33,792 pixels across 48.67°. A 3km imaging swathwidth with >30,000 pixels for <10cm GSD is obtainable using the Cessna 172 platform reported herein.

Having the instrument belly mounted as shown in **Figure 1**, the limiting factor for the payload angular imaging ranges is the small 10-inch in diameter and 6-inch deep camera port of Cessna 172. The gimbal machine roll and pitch angular range is 72° each. Supposing the FOV of a telephoto camera is 8°. The maximal ATS FOR swath will be 80° if the imaging is not limited by a camera port.

The gimballed imaging system is a multi-purpose remote sensing instrument. Its agile, precise, responsive, and programmable perspective can be adapted to exploit fast frames of modern imaging payload for fast throughput geospatial applications aboard various platforms operating from surface to orbits. A few potential applications of the instrument and/or its technology are considered: 1) Aerial multi-perspective imaging for accurate and high resolution 3D-modelling; 2) Multi-temeral imaging with perspective-controled-frame-matching motivated for efficient change detection; 3) mission-planned corridor remote sensing and border security; 4) emergent response & search and rescue.

6 CONCLUSIONS

An airborne gimballed imaging system has been proven operational for agile, accurate, and efficient data collections aboard Cessna 172. For a fast airborne mapping application, it provides a simultaneous high resolution and wide area coverage. Fast mapping with a 3km imaging swathwidth, >30,000 pixels for a <10cm GSD, is obtainable by a single flypass. Its gimballed aerial images are geo-registered for immediate Google Earth or other compatible GIS applications.

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