A REAL-TIME PHOTOGRAMMETRIC MAPPING SYSTEM

S. S. C. Wu [a, *], J. Hutton [b], B. Kletzli [c], H. M. Noto [a], S. S. Wang [d], Z. H. Wang [d]

[a] United States Department of Energy's Remote Sensing Laboratory operated by Bechtel Nevada, 4600 N. Hollywood Blvd., Bldg. 2211, Las Vegas, NV 89191-8403, U.S.A. - (wusc, notohm)@nv.doe.gov
[b] Applanix Corporation, 550 Alden Rd. Unit 112, Markhan, Ontario, Canada L3R6A8 – jhutton@applanix.com
[c] Spectrum Mapping, LLC, 7500 Jefferson Street NE, Courtyard II, Suite 101, Albuquerque, NM, 87108, U.S.A. – bkletzli@specmap.com
[d] Mira Solutions, Inc., 39176 State St., Suite C, Fremont, CA, 44538, U.S.A – (swang, zhihong)@mirasolutions.com

Commission II, WG II/1

KEY WORDS: Photogrammetry, Real-time, automation, on-line, digital

ABSTRACT:

A Real-Time Photogrammetric Mapping System (RTPMS) is being developed at the U. S. Department of Energy's Remote Sensing Laboratory. The RTPMS integrates a 4k by 4k color digital frame camera, a Position and Orientation System, and an Aerial Survey Control Tool (ASCOT) navigation system, with the newly developed One-Path Photogrammetric Program (OPPP). It automatically processes Digital Elevation Models (DEM), ortho-images, and contour lines on-board the acquisition platform and in real-time. The OPPP has been successfully tested on various sources of digital image data, including scanned aerial photography from an RC-30 camera and digital imagery from a Digital Frame Camera (DFC). A laptop computer takes 12 minutes to process a single strip of four models, producing an ortho-image, DEM, and contour line map, and only 42 minutes to process a block of three-strips of 12 models. An elevation precision of approximately 1/7,000 of the flight height has been achieved by the OPPP software. Hardware and software integration has been completed and we are currently in the final stages of the development, i.e. testing and implementation of the RTPMS in the air. Once tested, the RTPMS will be able to produce a mosaicked DEM, ortho-image map, and contour map, on-board, in real-time, and without ground control or without operator intervention. Results from airborne testing will be presented at the 20th ISPRS Congress. The next step of this endeavour is to incorporate the ability to transmit processed photogrammetric products to the ground before the aircraft lands, and ultimately being able to mount the system on an unmanned aerial vehicle to automatically generate photogrammetric products without operator intervention.

1. INTRODUCTION

State-of-the-art photogrammetry involves the use of image data that are mostly in digital form acquired by cameras as well as by a broad spectrum of other sensors, including optical, lidar, radar, and interferometers. The data, which may be processed automatically, are used for making maps and for military, scientific, and industrial applications. The Remote Sensing Laboratory of the Department of Energy (RSL/DOE) in Las Vegas, Nevada, maintains some of these cutting-edge mapping technologies. In support of the time-sensitive national emergency response and consequence management missions at the RSL/DOE, we are currently developing a Real-Time Photogrammetric Mapping System (RTPMS). The RTPMS is a system that can input digital image data (DID) from a digital frame camera (DFC) directly into photogrammetric software for automatic processing of digital elevation models (DEM), ortho-images, and contour lines, on-board the acquisition platform in real-time. The ultimate goal of this development is to transmit the photogrammetric products processed on-board to the ground before the aircraft lands and eventually mount the system on an unmanned aerial vehicle.

2. DEVELOPMENT

The RTPMS is being developed in three phases. During Phase I, a pilot study was conducted to develop the real-time photogrammetric processing software, called One-Path Photogrammetric Program (OPPP). Phase II integrated the OPPP software with a DFC, Position and Orientation System (POS), and ASCOT navigation system. Phase III, the testing and implementation of the RTPMS in the air, is currently underway with a flight over a calibration range scheduled for mid-May 2004.

2.1 Phase I

In Phase I, we developed the OPPP software, a real-time DEM/orthophoto processing program derived from several programs that provide automatic functions, including interior- and exterior- orientation, DEM generation, ortho-image rectification, contour-line generation, block adjustment, and mosaicking with color balance. The size of the program, written in C-plus, is about 3 MB and can be run on a standard PC with disk space for the raw and processed imagery being the primary resource requirement. OPPP requires a pre-defined flight plan as input, in addition to camera calibration parameters and photo position and orientation data. An ortho-rectified photo mosaic of a single strip processed through OPPP is shown in Figure 1. The mosaic on the left in Figure 1 was not color balanced while

* Corresponding author.

the mosaic on the right was processed with OPPP's automatic color balancing feature.

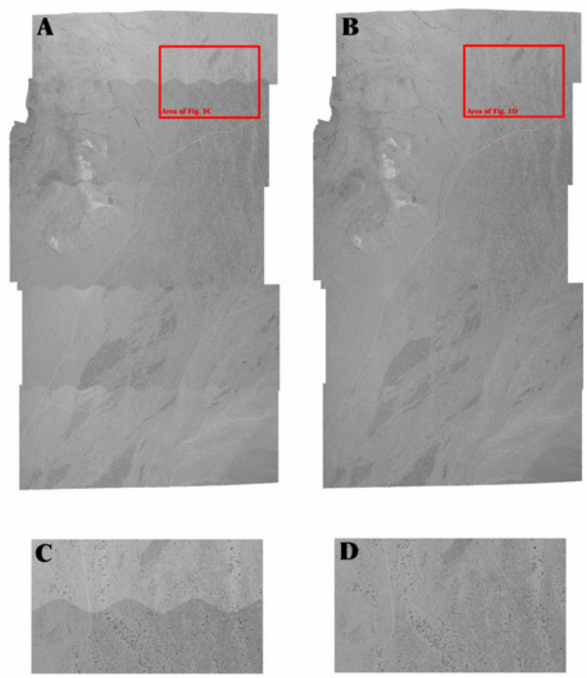

Figure 1. Orthophoto mosaic generated by the OPPP software using scanned RC-30 photographs. A & C – Color unbalanced; B & D – Color balanced.

2.2 Phase II

During phase II the integration of the RTPMS hardware and software components was completed and an assessment of the OPPP software performance was conducted.

Hardware/Software Integration

As part of phase II, a 4k × 4k DFC with an exposure-time rate of 1.5 seconds was acquired from Spectrum Mapping, LLC (Figure 2). The DFC has a format of 4,096 x 4,096 pixels with a pixel size of 9 micrometers and two lenses with focal lengths of 90-mm and 50-mm. In order to achieve the real-time processing capability, the DFC and POS software were modified for integration with the OPPP. The DFC acquisition software was modified to output digital images directly in TIF format, and incorporated a DLL version of the Applanix POSEO software.

Figure 3 outlines the general processing flow for the RTPMS. A pre-defined flight plan is generated identifying flight lines and photo numbers, with pre-determined photo-center locations. The flight plan is input into the ASCOT. The ASCOT navigates to each photo center and triggers the DFC at each pre-determined photo-center according to the flight plan. Using precise time, each photo is associated with position and orientation parameters acquired by the POS. A real-time smoothed best-estimate trajectory (SBET) is generated based on the time-tagged photo events. A DLL version of POSEO computes the orientation parameters (x, y, z, ω, ϕ, κ) for each photo center and an orientation file is generated. The digital image data, camera calibration parameters, and the position and orientation data are input into the OPPP and a DEM, orthophoto, and contour map are generated for each model, followed by a mosaic of the entire block.

Figure 2. The Spectrum Mapping, LLC 4096 × 4096 color digital frame camera has two lenses with focal lengths of 50 mm and 90 mm.

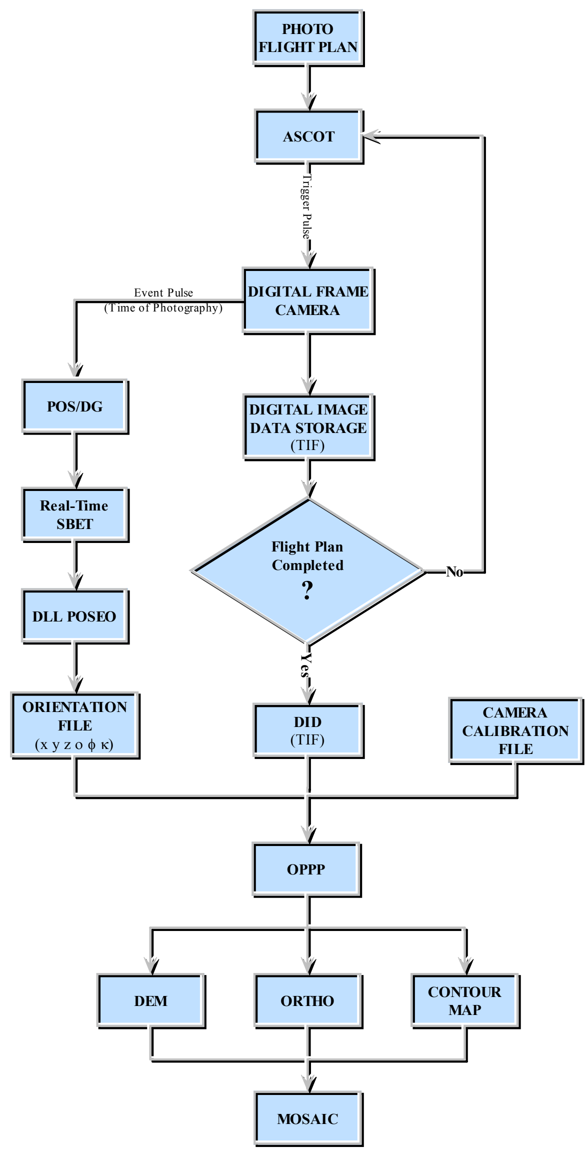

Figure 3. RTPMS general processing flow.

The hardware configuration is shown in Figure 4. The ASCOT sends a trigger pulse through the Camera Controller (a 3-GHz computer with 500 MB of RAM and two 68-GB removable hard-drives) to the DFC. The DFC triggers a picture and sends a signal to the ASCOT and the POS, simultaneously, using precise time to relate each photo with the position and orientation of the acquisition platform at the time of exposure. All data is stored on the Camera Controller where the OPPP resides. The OPPP processing is conducted on the Camera Controller and output products are stored on one of the removable hard drives.

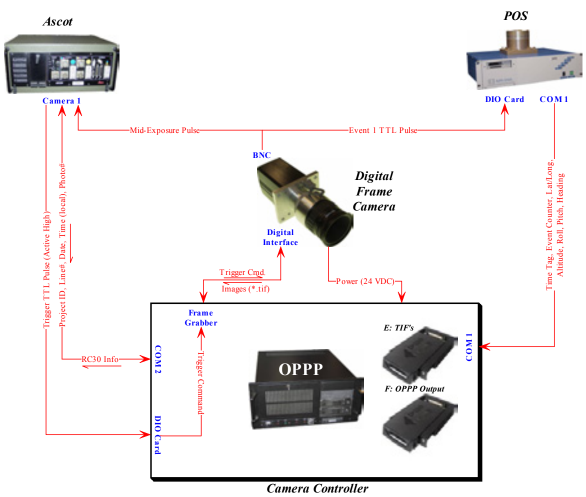

Figure 4. Hardware integration of the OPPP with the DFC, POS, and ASCOT.

Figure 5 is the integrated RTPMS as designed for installation in a B-200 fixed-wing aircraft. The figure shows the 4k x 4k digital camera mounted together with an Initial Measurement Unit (IMU) on a PAV-20 mount for the RC-30 camera base. The electronics rack holds the camera and the POS controllers.

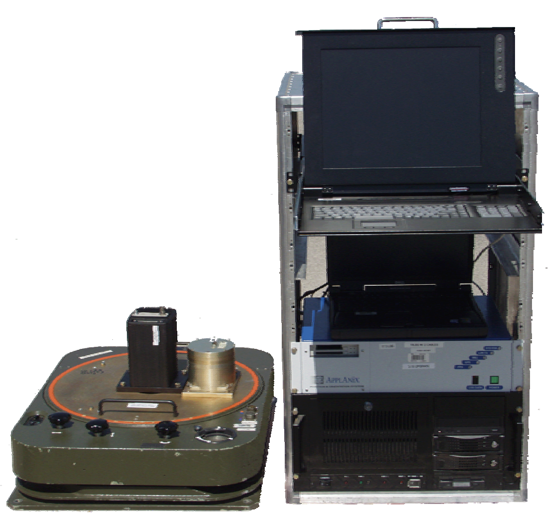

Figure 5 Integrated RTPMS consisting of a DFC, POS, PAV-20 mount and a computer with the OPPP software.

Test Results of OPPP Software

The newly developed OPPP has been successfully tested with both scanned aerial photography from an RC-30 film camera and DID from a DFC. Using scanned DID from RC-30 photographs, a single strip of five images (4 models) and a block of three strips of 15 images (12 models) were tested. Together with orientation data from the POS, and without ground control or operator intervention, the OPPP produced a mosaicked DEM, ortho-image map, and contour map. Figure 6 shows the contour map generated for the three-strip block. On a laptop computer, processing of the single strip of four models took 12 minutes and the processing of the block of three strips of 12 models completed in 42 minutes.

Figure 6. Contour map generated from a block of three strips with 15 images. Contour interval is 1 meter.

Aerial photographs were taken at a calibration range by an RC-30 camera (6-inch lens) with a POS device at a flight height of 3,000 feet above ground level. The ground-targeted control points within the calibration range have a 2-cm relative precision and a 25-cm accuracy relative to the WGS-84 Geodetic reference system. The POS has a precision of 20 arc seconds for the roll and pitch, and 30 arc seconds for the yaw. A total of 13 ground-control points of the calibration range were within the area encompassed by the single strip test. Results from the 13 ground control points are given in Table 1.

Ground Coordinates (in cm)	X	Y	Height
Arithmetic Mean Error	-8.6	-17.7	-6.0
Absolute Mean Error	10.2	17.7	12.2
RMS Error	9.8	9.6	16.1

Table 1. Comparison of processed data from a single strip with 13 target points on the calibration range.

For the three-strip test, 36 ground-control points measured on the OPPP-generated DEM were compared with the corresponding 36 ground-control points from the calibration range. Results for the three-strip block are provided in Table 2.

Ground Coordinates (in cm)	X	Y	Height
Arithmetic Mean Error	-0.8	-0.1	-22.2
Absolute Mean Error	14.6	7.7	22.3
RMS Error	18.0	10.1	13.4

Table 2. Comparison of processed data from 3 strips with 36 target points on the calibration range.

The statistics given in tables 1 and 2 show that the elevation measurements have a precision of approximately 1/7,000 of the flight height. Accuracy was also assessed by comparing more than 20 million points of DEM data processed from the OPPP with DEM data of the calibration range. 68.3% of the elevation differences are better than 16 cm, and 90% have elevation differences of 27.5 cm. These test results indicate that the OPPP has a processing accuracy within the accuracy of the ground-targeted points of the calibration range.

In a separate experiment using DID from the 4k x 4k DFC, a block of 5 strips comprised of 65 images was used to evaluate OPPP. Automatic processing of the DEM, orthophotos, and contour lines required 150 minutes on the same laptop computer but only 75 minutes on a PC with a 3-GHz processor. The ortho-image map generated by OPPP from the 65 digital images is shown in Figure 7.

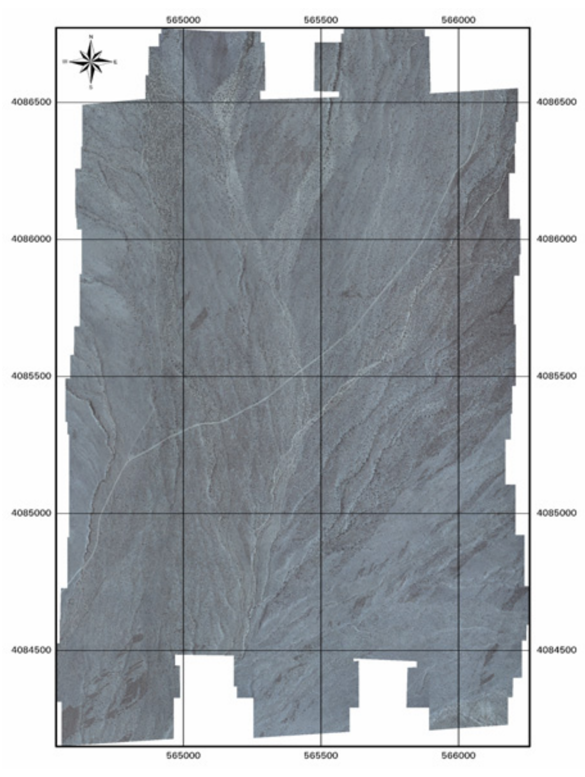

Figure 7. Mosaicked orthophoto map processed from 65 images using a DEM from 60 models.

2.3 Phase III

Phase III, the testing and implementation of the RTPMS in the air, is in progress. A test will be conducted over the calibration range described above in order to provide an accurate assessment of the results. The test will consist of four flight-lines, as shown in Figure 8, flown in opposite directions, with five images in each strip. It is planned to use the 90-mm lens to collect imagery at a photo scale of 1:18,000. Thirty-three targeted ground control points will be used for the evaluation and the results will be presented at the ISPRS 20th Congress.

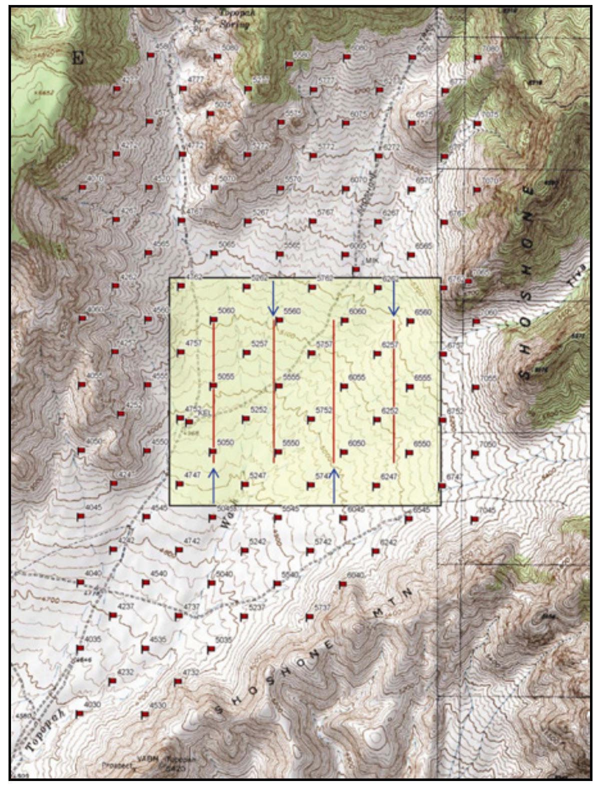

Figure 8. Flight plan with four strips of 25 images to be tested. Image scale will be 1:18,000.

3. CONCLUSIONS

Upon completion of Phase III, a RTPMS that inputs digital image data from a digital frame camera directly into photogrammetric software, processes DEM orthophotos and contour lines on the aircraft in real time without ground-control points or operator intervention will come to fruition. This development will prove to be a landmark achievement for the photogrammetric mapping community.

REFERENCE

Wu, S. S. C., 2004, Real-Time Photogrammetric Mapping System, Bechtel Nevada Annual Project Report (in press).

ACKNOWLEDGEMENTS

The authors wish to express their special thanks to Marc Rivera of Bechtel Nevada Corporation at the DOE/RSL for his dedicated work on the RTPMS hardware integration, flight planning, and acquisition of the image data. Also, we would like to acknowledge the invaluable contributions of Charles Golanics and Jon Leander of Bechtel Nevada Corporation to the hardware integration. Our sincerest gratitude and appreciation goes to Philip T. Thayer for his dedicated assistance in software integration. Finally, we would like to thank Hani Mourra of Applanix Corporation for his contributions to the integration of the POS system into the RTPMS.