2015

Boresight Calibration for DMCii230 Serial #027

Peregrine Aerial Surveys
Leica Geosytems

Computation by
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1. Introduction

A “boresight calibration” is used to determine the differences in the rotations of the sensor rotational axes and the rotational axes of the Inertial Measurement Unit (IMU). The boresight parameters are determined by flying over a well controlled site (site with accurate ground controls) and then conducting aerial triangulation on the resulted imagery.

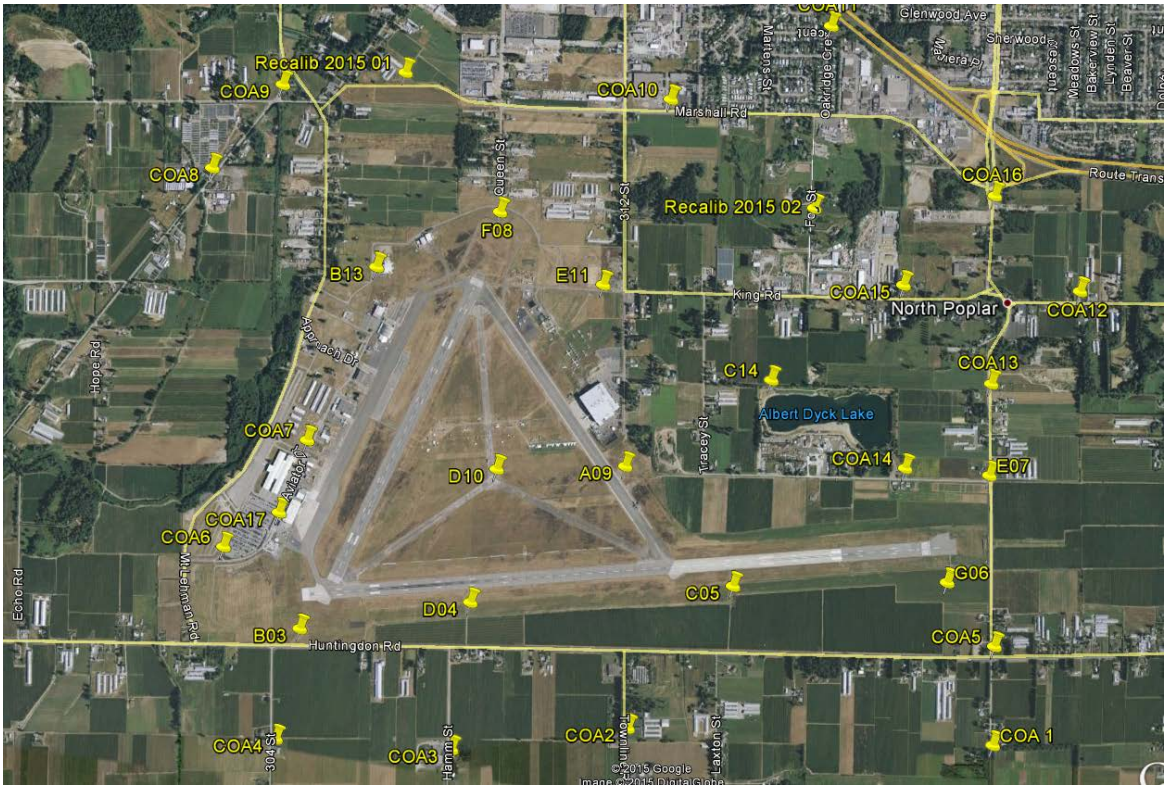
The aerial triangulation computes the six exterior orientation parameters (X, Y, Z, omega, phi, kappa) while the IMU measures the three orientation parameters' roll, pitch and heading (or yaw). Comparing the two sets of the orientation angles of the camera as computed by the aerial triangulation and measured by the IMU, establishes the differences in the rotations of the camera with respect to the inertial system (from the IMU). These differences (or offsets values) are then used to correct all subsequent IMU-derived orientation data.

2. Ground Control

Peregrine established and targeted a grid of 30 known points around Abbotsford Airport. These were of two types:

- 11 are monuments established and measured by Peregrine in 2012 (3 others placed in 2012 had been lost to new construction around the airport)
- 17 are MASCOT or City of Abbotsford monuments
- 2 were new points targeted and measured by Peregrine for the purpose of this calibration

The final target count was 29, since one point was lost to road construction between targeting and flying.



2.1.Ground Control Data

2.1.1. Peregrine-established monuments

The coordinates for the monuments established by Peregrine were determine using Leica 1230 GPS units maintained on location. Stations 3 to 11 were occupied for 7 to 10.25 hours, while 13 and 14 were occupied for 5 and 6 hours respectively. Data were then converted to RINEX and sent to CSRS for processing. The resulting data are shown in Table 1.

Point	UTM North-ing	UTM Easting	Ortho-metric Ht (m)	σ y	σ x	σ z (major)	σ z (minor)
B03	5429557.876	545310.271	50.155	0.004	0.007	0.009	0.005
D04	5429689.572	546339.41	52.947	0.007	0.015	0.019	0.008
C05	5429761.685	547259.083	55.696	0.004	0.007	0.009	0.005
G06	5429765.865	548220.533	59.390	0.008	0.016	0.020	0.008
E07	5430263.640	548408.913	60.605	0.008	0.016	0.021	0.009
F08	5431434.482	546197.399	56.326	0.005	0.008	0.010	0.006
A09	5430286.503	546184.861	53.35	0.005	0.008	0.010	0.006
D10	5430301.033	546766.335	54.617	0.005	0.008	0.010	0.006
E11	5431118.722	546664.530	56.857	0.006	0.009	0.011	0.007
B13	5430712.243	547416.420	53.266	0.008	0.016	0.021	0.008
C14	5431109.251	547928.792	59.592	0.007	0.013	0.017	0.008
2015-01	5432047.310	545746.304	57.470	0.005	0.007	0.019	0.008
2015-02	Lost to road construction						

2.1.2. MASCOT and City of Abbotsford monuments

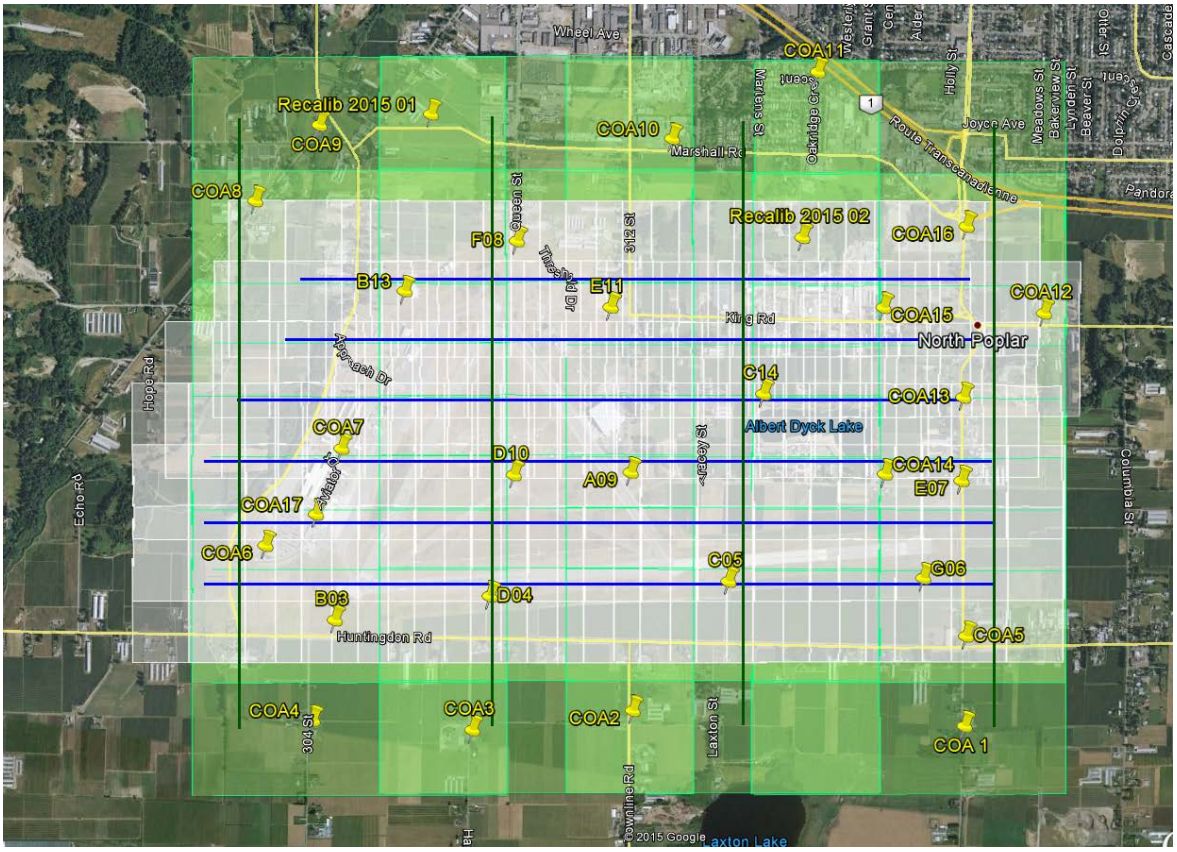
Monuments that would be in locations appropriate for the calibration were identified using the City of Abbotsford webmap facility. A ground control team located and targeted monuments. If a cover plate were in place, the vertical offset between the monument and the surface was determined by laying a steel straight edge across the opening, and measuring the distance between the monument and the surface to nearest the mm with a tape measure. The offset was added to the elevation. The elevation data was obtained by spirit level and all points are integrated with the provincial survey control system. Two points (*) had cover plates that could not be removed and height is estimated.

Point	MASCOT/COA Name	UTM North-ing	UTM East-ing	Orthometric Ht (m)	σ y	σ x
COA1	77H4233	548438.319	5429049.2	60.162	0.006	0.008
COA2	77H4200	546787.927	5429117.8	53.145	0.009	0.009
COA3	78H8293	545995.805	5429026.3	51.238	0.012	0.010
COA4	79H0826	545197.143	5429010.6	49.341	0.014	0.010
COA5 *	77H4202	548440.063	5429496.8	60.809 *	0.006	0.008
COA6	COA0164	544927.277	5429920.3	50.917		
COA7	COA0047	545343.826	5430401.9	53.796		
COA8	77H4279	544908.72	5431632.8	54.219	0.010	0.009
COA9	73H0642	545218.811	5431981.3	53.343	0.008	0.007
COA10	73H0614	547102.83	5431943.7	61.693	0.007	0.006
COA11	73H0611	547679.323	5432285.8	71.255	0.007	0.006
COA12	73H0639	548822.435	5431103.9	64.042	0.006	0.006
COA13 *	77H4380	548419.396	5430668.9	59.895 *	0.007	0.009
COA14	77H4373	547975.77	5430309.4	58.089	0.009	0.010
COA15	73H0620	548000.187	5431115.2	59.559	0.007	0.006
COA16	73H0622	548420.161	5431524.8	62.456	0.006	0.006
COA 17	COA0045	545209.426	5430080.9	52.968		

3. Flight Plan and Report

The flight was planned with 4 lines oriented north-south, with a GSD of 9.8 to 10.0 cm, and 6 lines oriented east-west, with a GSD of 5.1 to 5.4 cm, with 60% forward overlap and 30% sidelap. There were 28 photos at 10 cm GSD and 95 photos at 5 cm GSD. These GSDs were chosen to provide the greatest accuracy in the calibration.

North-south lines 10 cm GSD; East-west lines 5 cm GSD



- The flight occurred on June 7th 2015 between 2220Z and 2305Z, sun angle 52.9° to 46.3°. It was clear and sunny throughout
- The lines were flown in the following order and direction:
  - 104N, 103N, 102N, 101N, 1E, 4W, 2E, 5W, 3E, 6W.
- Processed photos and ABGPS were copied to a hard drive and shipped to Leica for calibration.

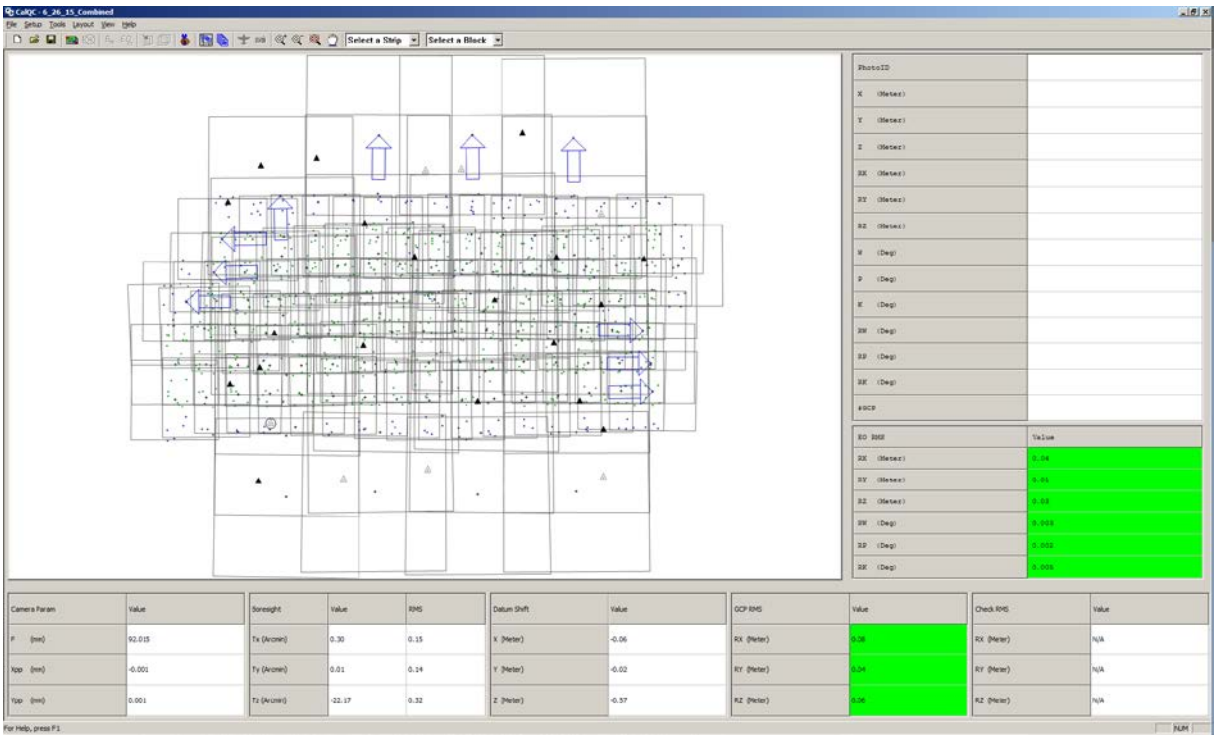
4. Aerial Triangulation

Aerial Triangulation and Boresight values were computed by Michael Reading of Leica Geosystems (Resume attached as Appendix A).

The Aerial Triangulation was processed using the following settings:

- Standard Deviation of image measurements - 4 um
- Standard Deviation of ground control (X, Y, Z) - .10 m, .10 m, .10 m
- Standard Deviation of GNSS / IMU Photo Positions (X, Y, Z) - 0.15 m, 0.15 m, 0.15 m
- Standard Deviation of GNSS / IMU Photo Attitude (omega, phi, kappa) - .01 deg, .01 deg, .01 deg
- The camera focal length and principal point was held fixed
- No camera self-calibration was enabled
- No GNSS / IMU shift or drift was enabled
- All control points and check points were targeted

The results of the aerial triangulation were generated with ImageStation Automatic Triangulation (ISAT) 2014, version 14.00.0533. The maximum RMS in the control points is $\leq$ 1.14 GSD for XY, and $\leq$ 1.04 GSD for Z. The maximum RMS for the check points was 1.04 GSD for XY and 1.13 GSD for Z



5. Boresight calibration results

The calibration was carried out on UTM, Zone 10 North, NAD83 (CSRS) coordinate system with heights on the CGVD28 vertical datum.

The boresight angles are: Tx (arcmin): 0.30
Ty (arcmin): 0.01
Tz (arcmin): -22.17

The Datum Shifts are: X (meter): -0.06
Y (meter): -0.02
Z (meter): -0.57

Boresight	Value	RMS
Tx (Arcmin)	0.30	0.15
Ty (Arcmin)	0.01	0.14
Tz (Arcmin)	-22.17	0.32

EO RMS	Value
RX (Meter)	0.04
RY (Meter)	0.01
RZ (Meter)	0.03
RW (Deg)	0.003
RP (Deg)	0.002
RK (Deg)	0.005

GCP RMS	Value
RX (Meter)	0.08
RY (Meter)	0.04
RZ (Meter)	0.06

Ground Control Point Residuals:

	Easting	Northing	Elevation	Rx	Ry	Rz
COA1	548438.32	5429049.24	60.595	N/A	N/A	N/A
COA2	546787.93	5429117.85	53.357	N/A	N/A	N/A
COA3	545995.81	5429026.30	51.563	N/A	N/A	N/A
COA4	545197.14	5429010.61	49.721	0.145	-0.005	-0.008
COA5	548440.06	5429496.84	60.808	0.007	0.088	0.144
COA6	544927.28	5429920.35	50.917	-0.067	0.067	-0.175
COA7	545343.83	5430401.94	53.796	-0.048	0.071	-0.1
COA8	544908.72	5431632.83	54.640	0.128	0.084	0.007
COA9	545218.81	5431981.30	53.592	0.07	0.034	0.021
COA10	547102.83	5431943.74	61.693	N/A	N/A	N/A
COA11	547679.32	5432285.75	71.522	0.139	0.123	0.071
COA12	548822.44	5431103.86	64.337	0.111	-0.005	-0.041
COA13	548419.40	5430668.92	59.895	0.065	0.024	0.043
COA14	547975.77	5430309.42	58.438	0.049	0.023	-0.01
COA15	548000.19	5431115.23	59.858	0.119	0.035	0.01
COA16	548420.16	5431524.80	62.456	N/A	N/A	N/A
COA 17	545209.43	5430080.91	52.967	-0.08	0.065	0.182
B03	545310.27	5429557.88	50.155	-0.14	-0.449	0.002
B04	564339.41	5429689.57	52.947	N/A	N/A	N/A
B05	547259.08	5429761.69	55.696	-0.111	-0.029	0.009
B06	548220.53	5429765.87	59.39	-0.118	-0.017	0.034
B08	546197.40	5431434.48	56.326	-0.016	-0.019	0.03
B09	546184.86	5430286.50	53.35	-0.082	-0.006	0.017
B10	546766.34	5431930.78	54.617	N/A	N/A	N/A
B11	546664.53	5431118.72	56.857	-0.03	-0.024	0.081
B13	547416.42	5430712.24	53.266	-0.071	-0.027	0.066
B14	547928.79	5431109.25	59.592	N/A	N/A	N/A
Recalib 2015 01	545746.30	5432047.31	57.47	-0.297	-0.02	-0.309

6. Summary

RMS Ground Control Point Residuals (meters)

X	0.08
Y	0.04
z	0.06

RMS GPS Residuals (meters)

X	0.041
Y	0.012
z	0.029

RMS IMU Observations (arcmin)

Omega	0.150
Phi	0.139
Kappa	0.320

Conclusion

Boresight AT results meet the required accuracy

Appendix A
Resume for Michael Reading

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SUMMARY

Over 29 years of experience in instruction, research, and application of the mapping and charting sciences to include: softcopy compilation and aerial triangulation, multi-spectral imagery analysis and digital image processing, acquisition of digital aerial imagery, acquisition and processing of Global Positioning System (GPS), and Inertial Measurement Unit (IMU) data, and acquisition, processing, adjustment, and feature extraction of mobile lidar data. Experience includes creating pre-sales materials, conducting product demonstrations and benchmarks, managing photogrammetric data acquisition and product generation, analyzing and improving production workflows, troubleshooting and resolving problems in day-to-day operations, and implementing new technology.

Professional Experience

Customer Services Consultant, Leica Geosystems 2002 – present

Provide pre-sales technical support for commercial photogrammetry and GIS Imaging products, training and post-sales support to customers on these products, and consultation on customer workflows and procedures. Conduct workshops, demonstrations, and benchmarks, and support the installation and daily operations of the Digital Mapping Camera (DMC) large format camera, RCD30 medium format camera, and Pegasus Mobile Mapping Lidar system.

Accomplishments

- Through pre-sales demonstrations, was instrumental in the sale of 10 Pegasus Mobile Mapping Lidar systems in North America over the first 18 months after introduction of the system. Sales of these systems exceeded $5,000,000.
- Developed and implemented the 2 week training module used for the operational training of the Pegasus Mobile Mapping Lidar system.
- Responsible for the installation and operational training of over 30 large format and medium format digital mapping cameras in North America using a variety of industry mission planning, flight navigation, and GNSS / IMU processing software and hardware.
- Created project plan for installation, testing, and training of the DMC large format camera. This became the standard operating procedure for every implementation in North America.
- Successfully processed and resolved an average of 500-customer service requests annually. Only analyst supporting the entire suite of commercial photogrammetry products, frame cameras, GNSS/IMU processing software, and Pegasus Mobile Mapping Lidar system.
- Evaluated Oklahoma Department of Transportation's production workflow and provided recommendations to improve production efficiency and quality. All recommendations were implemented.
- Conducted analysis of Tennessee Department of Transportation's production and implemented processes and training to support a new statewide digital orthophoto mapping initiative.
- Conducted analysis of Aerials Express production of commodity orthophoto products, and implemented new processes to streamline production and improve the quality of the products.
- Received Intergraph's Sapphire Circle Award, given to the top 1% performers in the company.

Division Manager, BAE Systems ADR 1996 – 2002

Managed day-to-day operations of the Image Technology Division. Supervised 12 technicians responsible for scanning and digital orthophoto production. Scheduled, allocated, and managed production resources, coordinated with other department managers, developed and refined production procedures, estimated and tracked production, managed subcontractor contracts and interfaced with clients on project status. Managed the division's Quality Assurance program, and developed technician training programs. Also assisted in pre-sales activities by developing marketing materials, providing technical reviews for proposals and contracts, and developing client presentations.

Accomplishments

- Managed over 40 digital orthophoto projects per year. These projects generated average annual revenue of over $2,500,000. Met schedules and budget in 98% of the projects.
- Developed ISO 9002 procedures and documents for the division and updated procedures on a regular basis. Efforts led to compliance on initial and all subsequent audits.
- Identified and implemented new procedures and equipment that reduced scanning costs by 67%
- Identified and implemented new software, equipment, and procedures that reduced digital orthophoto production costs by 50%
- Created new Quality Assurance procedures for Digital Orthophoto Quarter Quadrangle (DOQQ) production. Reduced product rejection rate from 90% to less than 2%.
- Designed digital archive procedures that allowed rapid recovery of raster imagery used in production. Reduced file management costs by 30%.
- Developed quality control procedures that cut the commercial digital orthophoto product rejection rate to less than 1%.
- Ran satellite production office in Colorado Springs for 4 years. Managed the closing of this production facility while ramping up a new production unit in Pittsburgh. Was able to successfully meet all project schedules during this transition.

Senior Photogrammetric Manager, MSE Corporation 1996 – 1997

Provided technical support to the Photogrammetry Department's softcopy and digital orthophoto production. Evaluated and refined workflows to streamline and enhance production, trained operators on software and techniques, and managed day-to-day softcopy compilation, aerial triangulation, and digital orthophoto production. Developed procedure manuals for production workflows and quality assurance.

Accomplishments

- Planned and implemented hardware/software procurement to enhance the department's capabilities to meet the current production backlog.
- Developed manpower plan to provide the proper mix of skills within the department in order to meet increasing production requirements.
- Enhanced digital terrain compilation techniques to incorporate automated software. These techniques saved over 400 hours in compilation time on a single project.
- Refined workflow used by operators for point transfer during aerial triangulation. These new procedures resulted in a threefold increase in the number of models processed per hour.
- Developed production techniques for reformatting digital orthophotos used by the company's Information Delivery Services branch. These procedures automated and standardized most of the process, cutting production costs by 50%.
- Developed UNIX programs to automate data conversions needed to input data into the production workflow or output data to specific formats required by clients.
- Put in place production manuals to standardize digital orthophoto, compilation, aerial triangulation, and quality assurance procedures.
- Managed projects for the City of Dubuque, Niagara Mohawk Electric, Johnson County, Virginia Natural Gas, and Fort Stewart projects

Application Software Support Analyst, Intergraph Corporation 1991 – 1996

Provided technical assistance for the development, marketing, training, documentation, and support of Intergraph's photogrammetry and image processing software. Developed Software Certification Test Plans and conducted testing to identify software design flaws and evaluate software performance. Assisted software core teams in designing requirements for new software releases and updates. Provided post sales support to customers on a daily basis. Developed training materials and presented instruction for all of Intergraph's digital photogrammetry courses. Reviewed and edited software reference documents. Conducted pre-sales workshops, demonstrations, and benchmarks.

Accomplishments

- Installed digital orthophoto production systems at over 20 customer sites worldwide.
- Implemented multi-sensor production systems for triangulation, compilation, and orthorectification of satellite imagery at 5 customer sites.
- Designed graphical interface to third-part multi-sensor triangulation and auto-mosaicking software.
- Assisted in defining requirements and software design for porting digital orthophoto production software to Windows NT platform.
- Developed course documents, data sets, and lab exercises for all of the department's photogrammetry courses.
- Successfully processed and resolved over 300-customer support calls annually.
- Designed and conducted workshops on geopositioning and orthorectification of satellite imagery for ASPRS, ISPRS, and EGIS conferences.
- Sole software analyst assigned to certify the orthorectification and third-party photogrammetry software. These products went out with less than 1 error per 100,000 lines of code.

Deputy Department Chief, Defense Mapping School 1986 – 1991

Provided logistic and administrative support to a department of 30 instructors that taught over 20 resident courses and 40 Mobile Training team (MTT) courses annually. Managed the department's training, travel, and capital expenditure programs. Was responsible for the school's Automated Information System (AIS) Security and Information Resource Management programs. Provided instruction to Department of Defense (DOD) and international students. Designed and managed resident courses, developed student materials, researched new technology to incorporate into the curriculum, and provided Mapping, Charting, and Geodesy (MC&G) support to military commands and other DOD organizations.

Accomplishments

- Designed and implemented a $250,000 hardware / software procurement to upgrade the department's image processing/Geographic Information System (GIS) computer lab.
- Initiated and directed a restructuring and update of the department's curriculum to stop a continuing decline in student enrollment. This effort led to over a 200% increase in student enrollment in one year.
- Established procedures for safeguarding the school's 150 plus AIS's and sensitive data. These procedures corrected an existing deficiency in control and accountability of these systems.
- Rated Master Instructor. Taught over 600 hours annually in 7 resident courses. Personally led over 20 Mobile Training Teams. Developed and documented over 200 hours of instructional manuals.
- Assisted designing and implementing the DOD's only GIS and digital image processing / remote sensing courses. These became the department's most popular courses.
- Incorporated GPS instruction into 5 resident courses. Assisted in developing specialized modules on differential and kinematic surveying, and integrating GPS and GIS technology.
- Assisted the Defense Intelligence Agency during the Persian Gulf War to develop operational target graphics and land cover thematic maps using satellite imagery.
- Presented several papers on cartographic and tactical applications of multi-spectral imagery and GIS at DOD sponsored symposiums.
- Conducted research on datum transformation software for the Army's Maneuver Control System. Results of this project were used to govern software development for the system.

Education

Master of Science, Business Management, Colorado Technical University
Master of Science, Project Management, Colorado Technical University
Project Management Certificate, Mount Royal College
Master of Science, Geodetic Science, The Ohio State University
Bachelor of Science, Geology, The Pennsylvania State University