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System Architecture

GXL System Overview

The following figure provides an example of how the different hardware components fit together for the advanced GXL System deployment. In the simple deployment model, all of the GXL software components are installed on a single desktop computer. Different deployment models allow the GXL to be very flexible and scalable, in order to meet the processing demands of our customers.

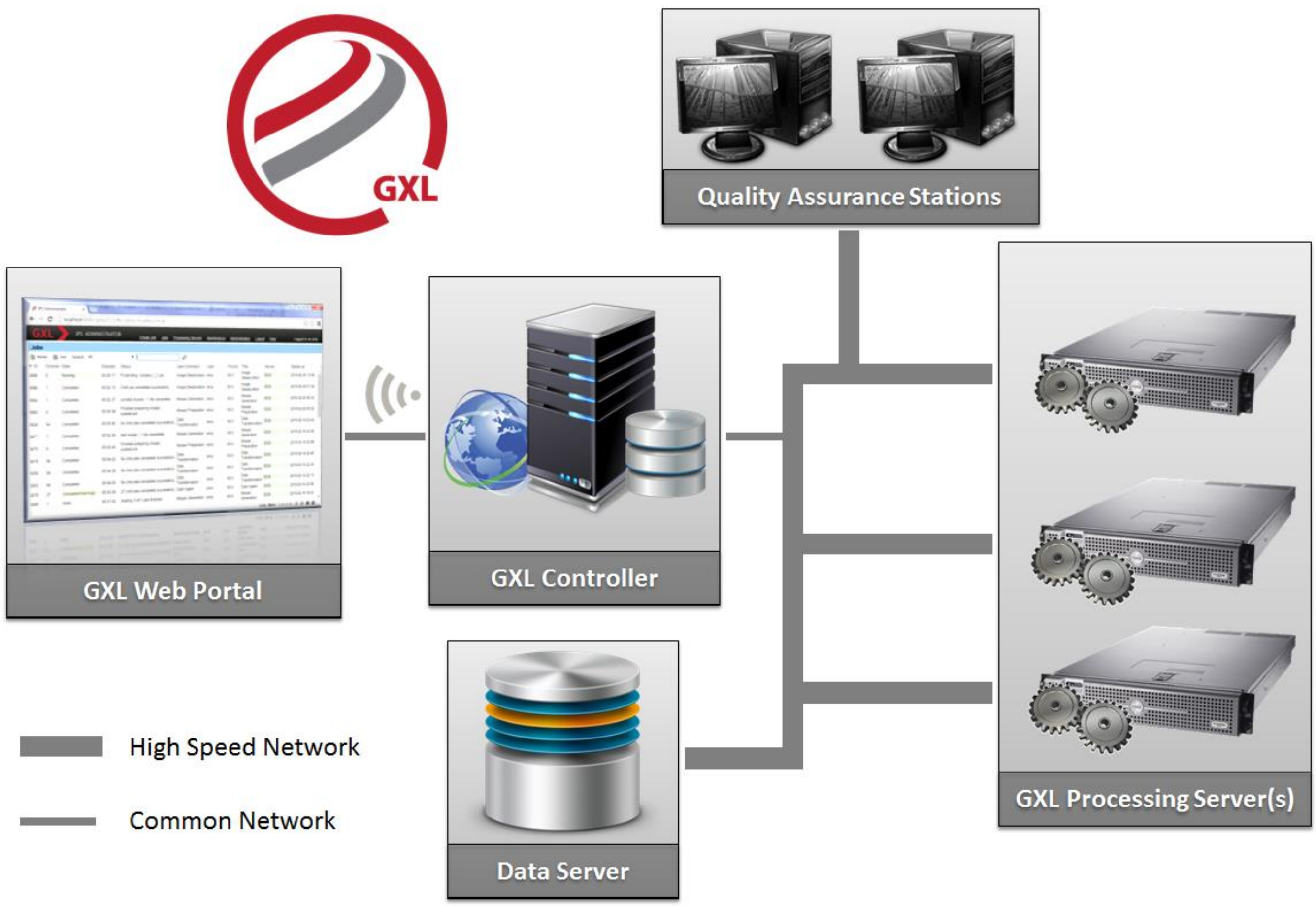


Figure: Hardware configuration for the advanced deployment model for the GXL System

As described in the above figure, the GXL consists of five primary components: Processing servers, controller system, web portal (thin client) interface, quality assurance computers and the data server. These five components work seamlessly together to perform efficient, high-speed, autonomous, distributed, batch geo-processing tasks.

GXL System Components

GXL Processing Server(s)

The processing servers represent the primary engines that drive the GXL system. PCI's advanced geo-image processing algorithms and workflows are installed directly on each processing server. The GXL processing servers are responsible for processing each individual job in the batch project, submitted through the GXL's web interface and distributed autonomously by the GXL controller.

The GXL system is readily scalable; any number of additional processing servers can be easily added to meet increasing throughput demands. The processing servers are autonomous and can be added without taking the system offline. Furthermore, newly added processing servers will immediately start accepting processing jobs queued in the controller's database, once it is detected.

The processing servers are built using state-of-the-art commercial off-the-shelf (COTS) hardware, such as: Multi-core hyper-threaded processors, NVIDIA Graphical Processing Units (GPUs), high performance disk drives and more. There are no limits on the number of cores that the GXL processing servers can take advantage of.

Furthermore, PCI's industry leading geo-image processing algorithms were re-engineered for the GXL using standard architectures like OpenMP and CUDA, in order to take advantage of multi-threaded and GPU processing, respectively.

GXL Controller

The controller houses the GXL's webserver (Apache Tomcat), database (PostgreSQL), license server and distributed processing engine.

The controller is responsible for handling system requests and managing resource allocation. PCI has developed proprietary software that allows the controller to automatically and efficiently distribute processing tasks between multiple processing servers, which is based on a load balancing methodology. This helps to ensure that processing server resources are maximized, but never overloaded.

In addition to controlling processing traffic, the controller is also responsible for serving the GXL web-portal interface, as well as serving the floating licenses required by the processing servers and QA computers connected to the GXL system.

GXL Interface (thin Client)

One of the advantages of the GXL is that it does not require that any thick-client software be installed. GXL operators can access the operator interface (JPS Administrator) through any supported web browser on any workstation that has network access to the GXL's web server. Depending on how the GXL is deployed, users may be restricted to computers on the local area network (LAN) or through any computer connected to the internet (WAN).

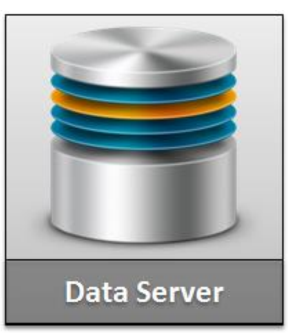
The GXL's operator interface (JPS Administrator) is where users can submit and actively monitor processing jobs. Multiple users can connect to the JPS Administrator at any time.

GXL Quality Assurance (QA)

The QA Tools that come with the GXL system are used to visually inspect and if required, manually edit the output of different geo-processing workflows (i.e. GCPs, tie points, DEMs, and ortho-mosaics).

The GXL contains automated methods for removing blunder GCPs and tie points, converting DSMs to DTMs, evaluating the accuracy of ortho images and creating seamless mosaics. However, sometimes a manual or interactive approach is required to ensure the level of quality meets or exceeds expectations.

GXL Data Server



The data servers or SAN (Storage Area Network) are not delivered with the GXL. The GXL interfaces with the customer's data server so that the processing servers can read input data required for processing and conversely, store output data back onto the data server once the process has completed. The GXL never modifies the input data directly, which eliminates the chance of the GXL corrupting input data due to unforeseen circumstances (i.e. power failure, network failure, etc.)

Processing Architectures

General

The GXL system contains three primary architectures that are used to maximize throughput of the geo-image processing projects, which include: OpenMP, CUDA and a proprietary distributed processing architecture.

- The **OpenMP** architecture is used for lower level multi-thread parallel CPU processing of the GXL's geospatial algorithms.
- The **CUDA** architecture is NVIDIA's proprietary architecture for performing processes with NVIDIA Graphical Processing Units (GPUs).
- **PCI Geomatics** has created a **proprietary** architecture for high-level job distribution and management on a single computer or between multiple processing servers connected together on a network.

Multi-thread Parallel Processing

OpenMP is a multi-threaded parallel processing architecture for CPU processing. The geo-processing functions installed on the GXL's processing servers are developed with OpenMP architecture so that independent parts of a workflow or algorithm can be processed in parallel on different processing cores or threads. Enabling the OpenMP architecture has allowed many of the GXL's process intensive algorithms to experience considerable performance boosts.

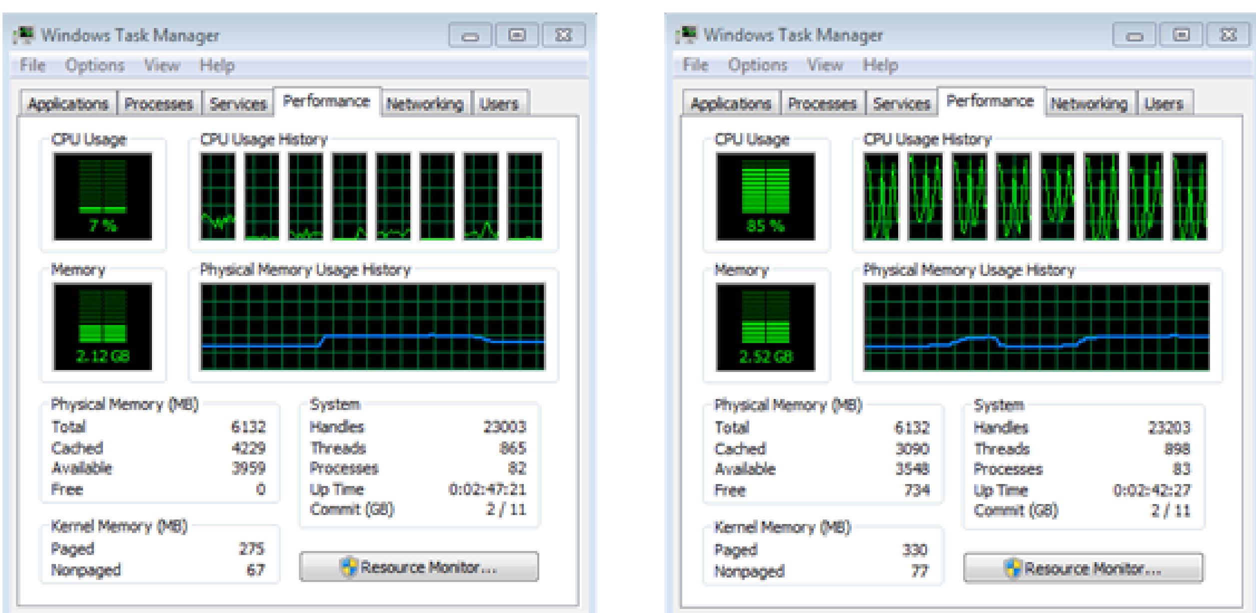


Figure: The left figure shows a traditional process using only 7% of the total processing capacity of a multi-core hyper-threaded processing chip. The right figure demonstrates the same process with OpenMP enabled, to take advantage of all processing threads

Graphical Processing (GPUs)

The GXL is the first geospatial processing system to implement GPU architecture and take advantage of graphical processors for mathematically intensive operations. The GXL processing servers use CUDA based architecture and NVIDIA GPUs in order to significantly boost performance of some of the GXL's more computationally intensive algorithms (i.e. DEM Extraction and Orthorectification). One of the primary benefits of using a GPU instead of a CPU occurs for highly parallelizable operations, where the same process can be performed on different subsets of the data.

A GPU contains hundreds of low frequency processing cores (See figure below) that are capable of performing the same process on different subsets of the data in parallel, which can significantly decrease the net processing time of certain algorithms.

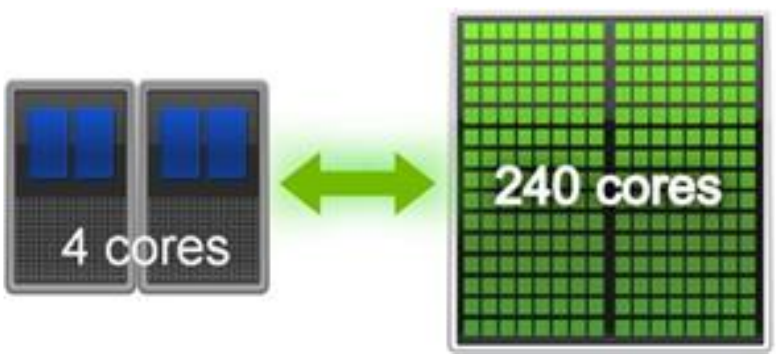


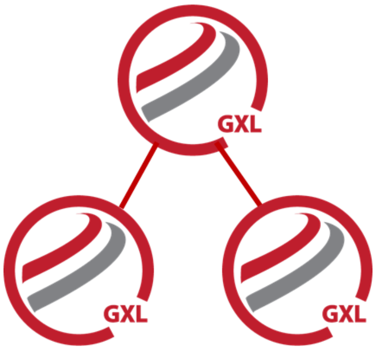
Figure: Graphical comparison of a 4 high-frequency core CPU (left) and a 240 lower frequency core GPU (right)

PCI has witnessed exceptional performance improvements by taking advantage of newly developed code, modern, multi-core processor architecture and NVidia Graphical Processing Units (GPUs).

The following GXL modules are GPU enabled:

- Orthorectification
- Automatic DEM Extraction
- Automatic Tie Point Collection
- Automatic GCP Collection
- Mosaic Generation
- Reprojection
- True Ortho
- Mosaic Generation

Distributed, Multi-Server Processing



PCI developed an autonomous distributed processing architecture that can automatically manage and distribute processing jobs between multiple processing servers. Each batch processing job submitted by a GXL operator is broken down into individual processing components, called child jobs. The child jobs are then be sent to different servers for processing.

For example, if the orthorectification workflow is launched with 100 images in the batch, then 100 child jobs will be spawned, one for each image. These child jobs are then organized into a queue on the GXL controller (JPS database). The GXL's distributed architecture allows for each processing server to fetch new child jobs from the queue as processing resources become available on each server and continue to do so until the queue is empty.

The figure below illustrates the concept of the GXL's distributed processing architecture. Each processing server is sent a number of child jobs to process. The number of child jobs sent to a particular server depends on the hardware resources of that server. As a child job completes on a specific server that processing server will then check back with the controller to see if there are any more processing jobs in the queue.

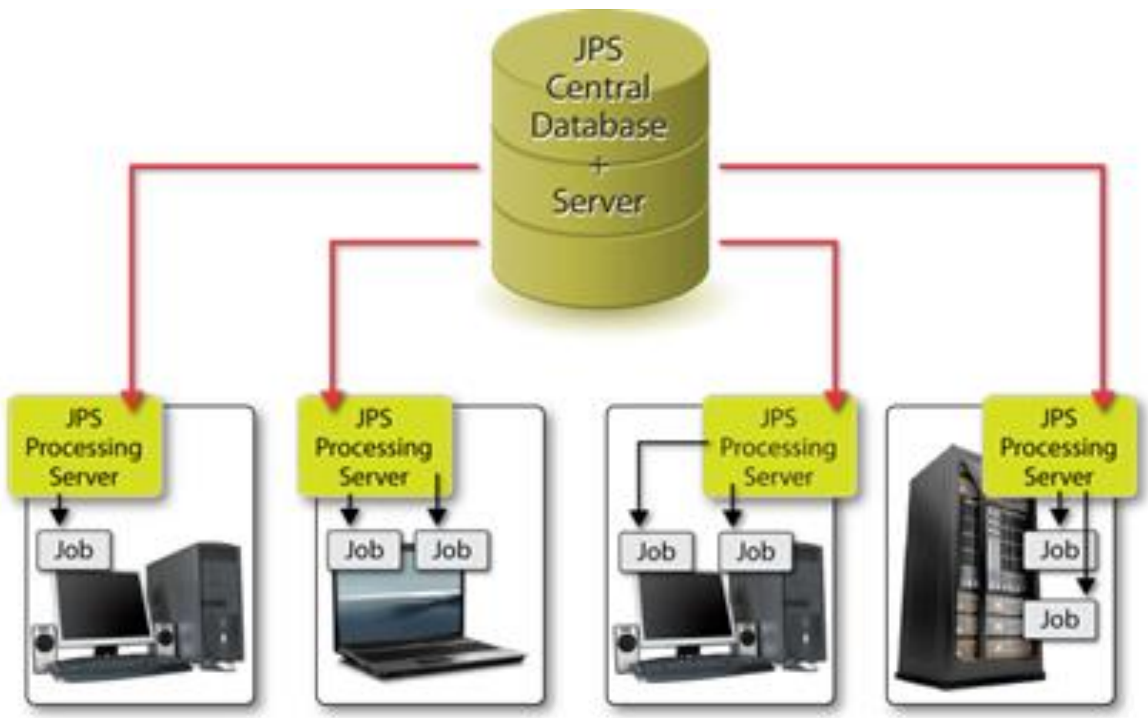


Figure: The GXL load balancing algorithm automatically and efficiently sends jobs to the various processing servers

Load Balancing

Processing jobs in the GXL are automatically and efficiently distributed to available processing servers through a proprietary load balancing algorithm. The load balancing algorithm will continue to send processing jobs to a processing server until it has reached a maximum processing load, as defined by a cost value. The cost value ensures that the GXL processing server can take a specific number of simultaneous processes that maximize overall throughput. In other words, the system is designed to maximize processing resources, but not overload them.

Automation & Scalability

Automation

In addition to the scalable, extensible nature of the Job Processing System (JPS), GXL is fully automated, supporting a distributed, cloud architecture with the following properties:

- autonomous processing on each node
- multi-core (multi-threaded) processing within nodes
- GPU processing
- distributed physical locations
- node management and control
- simple web interface for centralized job management

The result of the cloud architecture with these properties is reduced job management costs as each node is able to report its availability and select the most appropriate jobs from a master list of workflows. The JPS provides management of:

- job classes
- user permissions and priorities
- job priority and resource requirements
- flexible QA/QC breakpoints for visual inspection and manual editing

This results in greater automation and more effective project management, as well as the automation of individual tasks. The benefits of the JPS automation include:

- increased production (leading to increased revenues)
- faster QC cycles (leading to higher levels of quality assurance)
- reduction in process management (reduced operational costs)
- reduction in training costs (fewer manual operations required)
- 24/7 processing (profitability increases in proportion to output)
- effective use of hardware and technological capital

- transfer of skills from menial tasks to value creation (increased profitability)
- searching, prioritization, job sorting (efficient management)

The JPS Administrator allows users to monitors and override the default autonomous management of image processing over the distributed grid of computers/processing servers. It maintains the list of all jobs in a central database which have been submitted to the system and their current status: finished, running, etc.

Scalability

GXL features a flexible, scalable architecture that can be expanded with additional processing nodes to handle increased throughput. High-volume mosaic throughput (1000+ images per day) can also be achieved through a GXL Satellite system that can be tailored to different operational requirements.

The GXL's modular design allows for horizontal scaling to improve processing throughput. Additional processing servers can be added or decommissioned without having to take the GXL system offline. Once a new processing server has been detected by the controller, it will immediately begin sending jobs in the queue to the new server for processing.

Processing servers are a component of the entire GXL system, therefore, they can be acquired at a fraction of the cost of buying the original GXL system.

Figure: Example of how an organization can scale up processing throughput over time.

The Job Processing System

Acting as the backbone of the production system, the PCI Job Processing System (JPS) is a grid computing technology component for managing and monitoring processing workflows (jobs) over a distributed grid of computers (processing servers). The Job Processing System maintains the list of all jobs in a central database which have been submitted to the system and their current status: finished, currently running or have failed. The JPS technology includes a web-based monitoring tool that can be used to get a status of the jobs processed by the system at a particular time.

The JPS includes the following:

- web interface for ease of access and job monitoring
- email notification for job-status updates
- simple job set-up and submission with parameter-based job templates
- expandable with additional computing nodes for increased ortho/mosaic throughput
- job priority flags for dynamic rescheduling
- minimal overhead for use on any system
- online help, troubleshooting and system maintenance

Each processing node monitors the JPS, looking for a job to execute. When it finds a job, the processing node launches the job and indicates both that the job is processing and when the job is finished. The GXL system can receive different jobs at the same time and from multiple computers and/or departments.

Depending on the input data sets and the current state of the data (raw, orthorectified, etc.), it is possible to assign specific jobs to perform and in what order. If, for example, all processing nodes are currently being used, anything added to the system will be "queued" to run when resources are available. The JPS can be extended with any number of processing nodes to increase system throughput.

From an architecture perspective, the JPS consist of a JPS Server which utilizes a central database to manage the job processes. The central database is PostgreSQL which offers a low-cost, robust database technology for managing information on the status of the JPS and logging information for individual jobs.

Remote Access

The JPS-Admin can be accessed from any supported web browser, such as: Internet Explorer or Mozilla Firefox. Operators must login to the JPS Admin using a registered username and password (User Profile), before they will have access to the operator controls required to setup, submit, monitor and manage processing jobs.

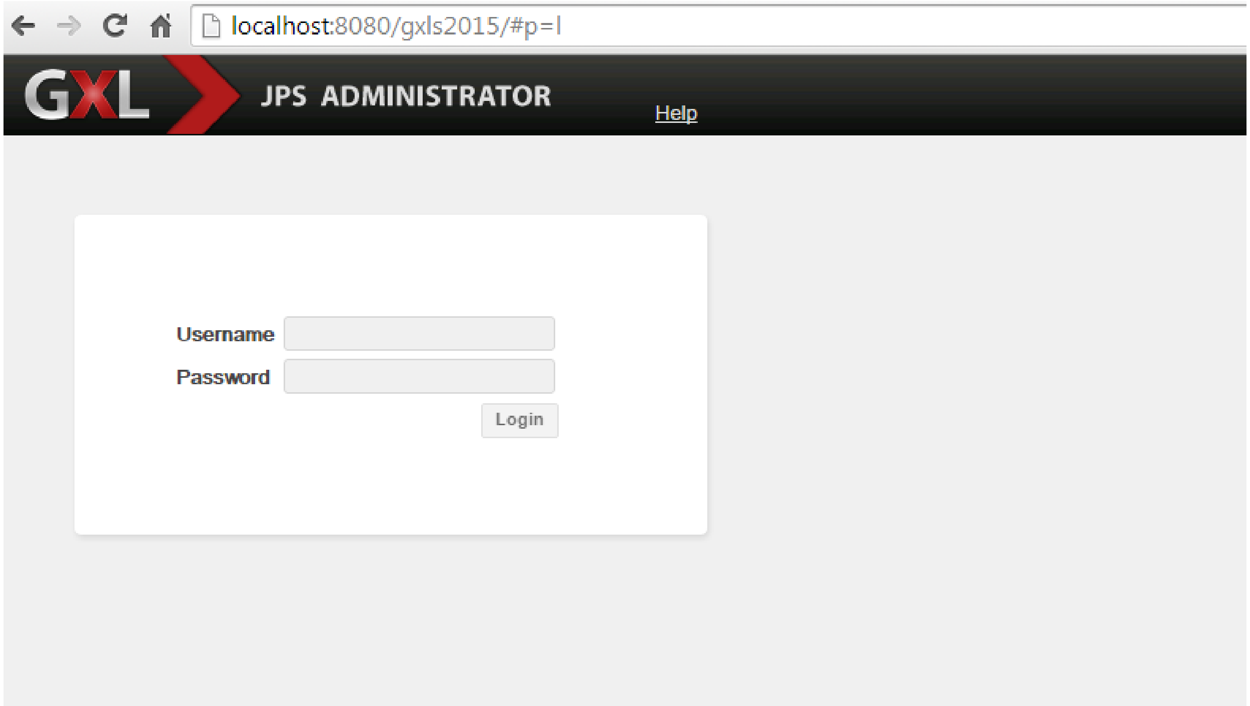


Figure: User Login page for JPS-Admin (GXL Operator Interface)

Access to the JPS-Administrator (and therefore GXL system) can be configured in a variety of ways in order to improve *ease-of-access* or *security*. The GXL is commonly deployed using one of the following three access configurations:

- WAN – The webserver is configured so that it can directly communicate with devices outside of the firewall. This allows users to access the JPS-Administrator through a supported web browser from any internet connection. This is the least secure setup, but the most accessible.
- Remote Desktop In – Direct access to the webserver from an outside connection is blocked by the network firewall. However, users can gain access to the JPS-Administrator from a computer outside of the LAN through remote desktop. The user simply uses remote desktop to access a computer inside the network and then logs into the JPS-Administrator through a web browser that has been launched from the computer on the network. This configuration offers increased security and still allows users to access the JPS administrator from an internet connection outside of the LAN.
- Closed Network – The GXL can be configured on a closed network that does not have any access to the internet. This configuration requires that operators only access the JPS-Administrator from computers attached to the local network. This configuration offers the highest level of security, but limits the accessibility of the system.

Multiple Users

Operators can access the JPS-Administrator through a web-portal that allows multiple users to be logged in under different accounts at the same time. User profile information is stored in a PostgreSQL database, which means that adding new users to the system is an administrative task. This helps to ensure that only authorized personnel can gain access to the GXL.

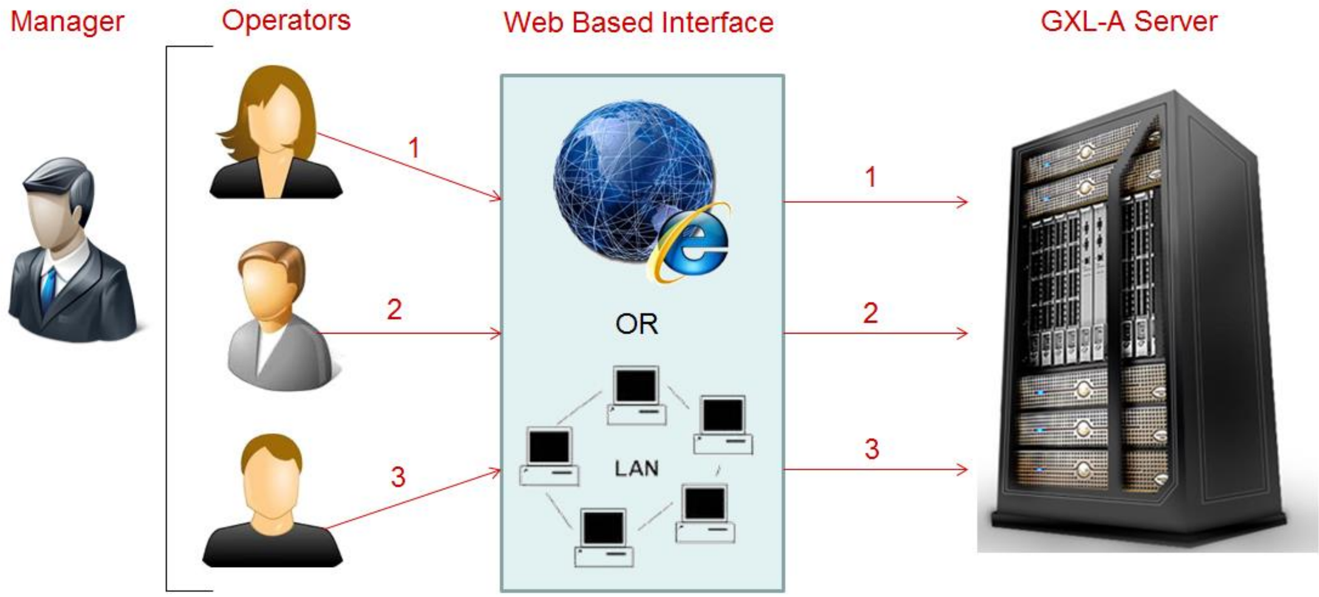


Figure: An example of how the GXL can be operationalized

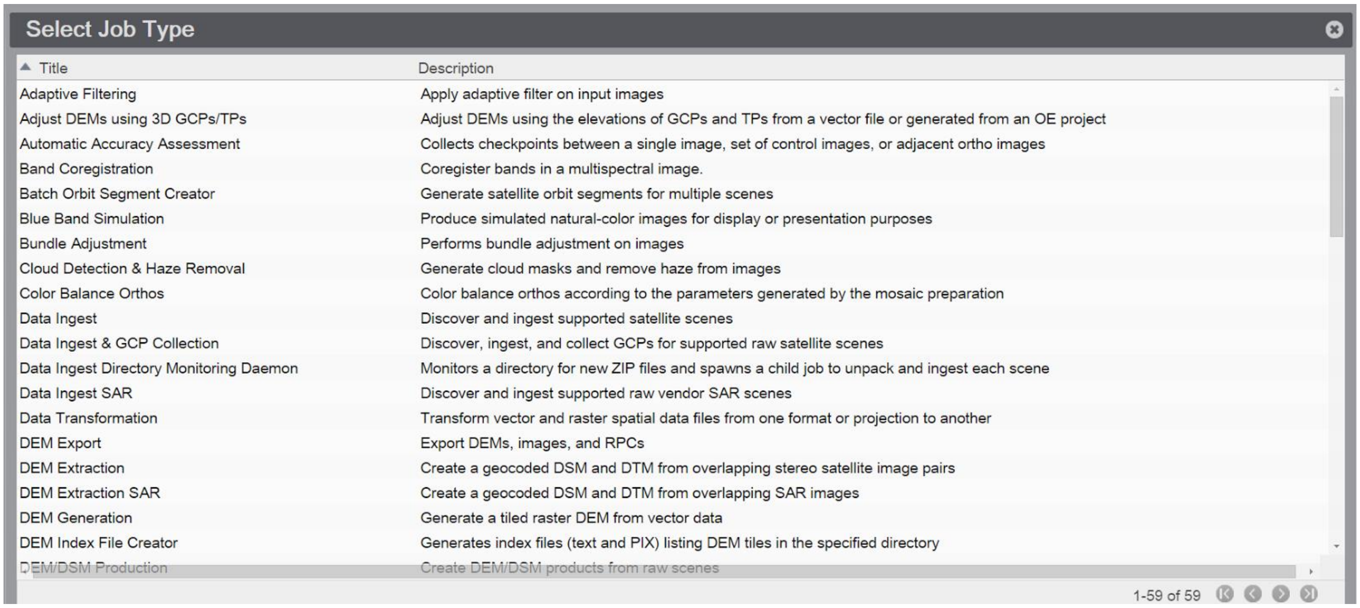
Processing Geospatial Imagery

Selecting a Processing Job

After the user has successfully logged into the JPS-Administrator, the operator can access a tabulated list of available processing jobs by clicking on the *Create Job* hyperlink, available on the main navigation bar.

Once the user has navigated to the *Create Job window*, the user will be able to choose a processing job from an alphabetically organized table. At which point, the user can single click anywhere on the row of the processing job that they wish to run. This will direct the operator to a webpage where they can then setup job parameters and submit the job for processing.

Note: A processing job can be an individual function (i.e. Automatic GCP Collection) or an end-to-end workflow (i.e. Raw Scene to Mosaic).



Select Job Type

Title	Description
Adaptive Filtering	Apply adaptive filter on input images
Adjust DEMs using 3D GCPs/TPs	Adjust DEMs using the elevations of GCPs and TPs from a vector file or generated from an OE project
Automatic Accuracy Assessment	Collects checkpoints between a single image, set of control images, or adjacent ortho images
Band Coregistration	Coregister bands in a multispectral image.
Batch Orbit Segment Creator	Generate satellite orbit segments for multiple scenes
Blue Band Simulation	Produce simulated natural-color images for display or presentation purposes
Bundle Adjustment	Performs bundle adjustment on images
Cloud Detection & Haze Removal	Generate cloud masks and remove haze from images
Color Balance Orthos	Color balance orthos according to the parameters generated by the mosaic preparation
Data Ingest	Discover and ingest supported satellite scenes
Data Ingest & GCP Collection	Discover, ingest, and collect GCPs for supported raw satellite scenes
Data Ingest Directory Monitoring Daemon	Monitors a directory for new ZIP files and spawns a child job to unpack and ingest each scene
Data Ingest SAR	Discover and ingest supported raw vendor SAR scenes
Data Transformation	Transform vector and raster spatial data files from one format or projection to another
DEM Export	Export DEMs, images, and RPCs
DEM Extraction	Create a geocoded DSM and DTM from overlapping stereo satellite image pairs
DEM Extraction SAR	Create a geocoded DSM and DTM from overlapping SAR images
DEM Generation	Generate a tiled raster DEM from vector data
DEM Index File Creator	Generates index files (text and PIX) listing DEM tiles in the specified directory
DEM/DSM Production	Create DEM/DSM products from raw scenes

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Figure: Tabulated list of processing jobs that a user can setup and submit for processing

Setup & Submission of Processing Jobs

When the user accesses the *Setup and Submit* webpage for a given processing job, they will have access to *Process Specific Parameters* and *Common Parameters*. *Process Specific Parameters* are parameters that are specific to the processing job that the user selected from the table (see above section). These parameters are different for each processing job. In contrast, the *Common Parameters* are a set of generic parameters that are available for all processing jobs.

The following figure demonstrates the layout of the *Setup and Submit Job* webpage for a given processing job. The layout for these webpages is consistent throughout all processing jobs.

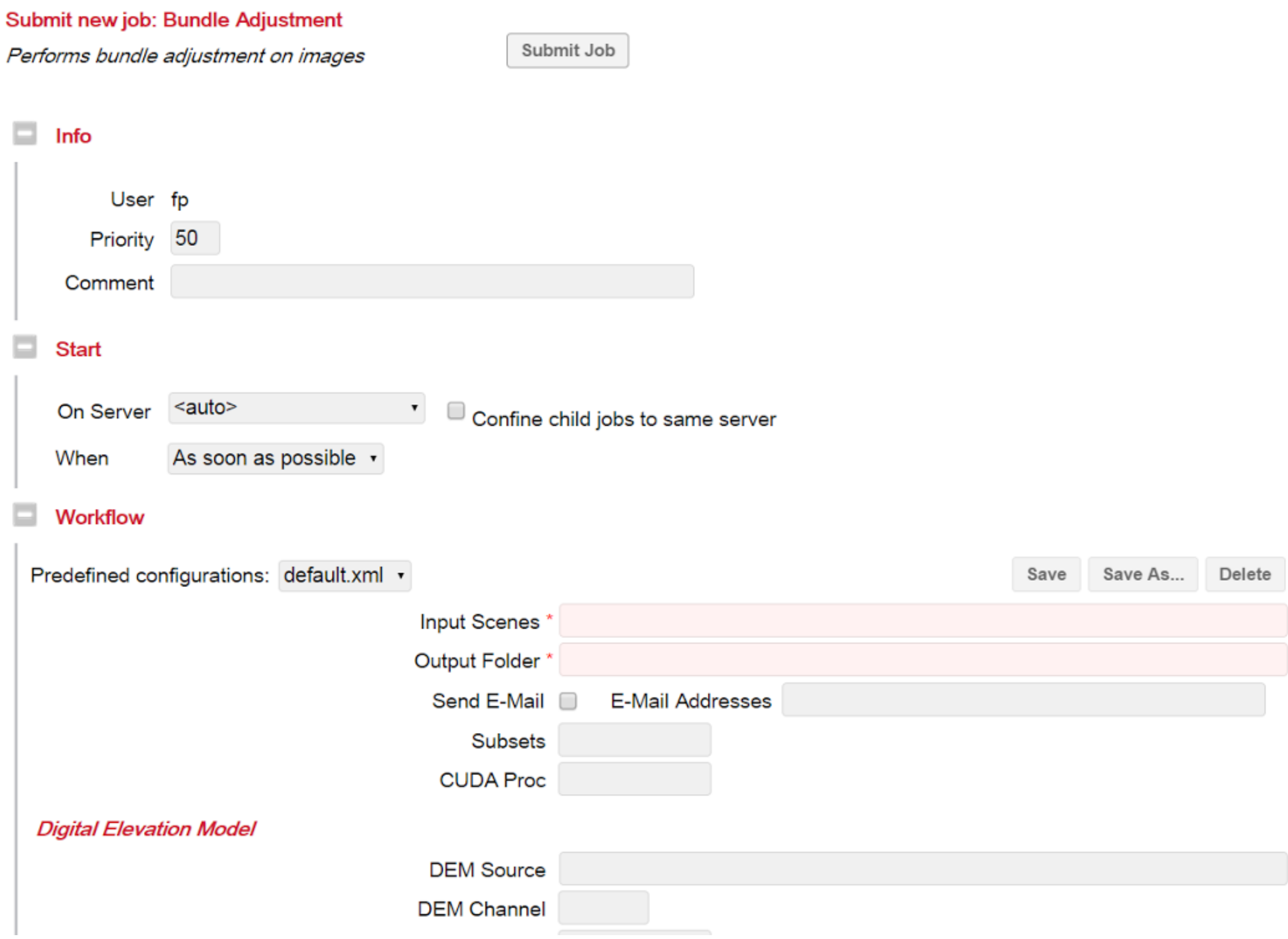


Figure: Layout of Setup and Submit Jobs webpage

Process Specific Parameters

These parameters are specific to each processing task and generally consist of input/output and algorithm configuration parameters. The following outlines four (4) primary types of process specific parameters:

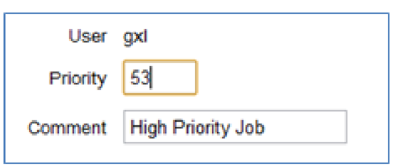
- Required Parameters – These parameters are identified by a light red input box and or a red asterisk located next to the parameter name. Generally, these parameters are used to specify input and output files (i.e. Raw Data, Reference Data, DEM), as well as file types (I.e. PIX or GeoTIFF).
- Defaulted Parameters – These are mandatory parameters that have been defaulted using the most common configurations. Users have the ability to adjust these settings for special circumstances for when the default setting is not optimal.
- Optional Parameters – If not configured, these parameters are generally ignored. Optional parameters often consist of advance algorithm options that increase the flexibility of the algorithm for more advanced users.

- Simple Batch Processing Setup – The GXL has been specifically designed for high throughput batch processing. As a result, the JPS-Administrator includes a simple and flexible input and output method for raw imagery, reference data, DEMs and outputs.
- Input raw imagery can be ingested by pointing to a single parent directory. The GXL will automatically search the parent directory and all sub-directories for valid input imagery.
- Users can point to a directory that contains multiple reference images (i.e. orthos from a previous project) for Automatic GCP Collection. The GXL will search for all valid input reference images and compare them with each raw image for overlap. GCPs will only be collected from scenes with apparent overlap.
- The user can also select multiple reference sources to be used for GCP collection (i.e. road vectors and reference imagery).
- Users can easily input multiple DEM files (i.e. tiles) by pointing to a single directory that contains all of the necessary files. Similar to the reference imagery, the GXL will only pull DEM files that have geographic overlap with the input imagery.

Common Parameters

These parameters are used to specify general processing options that are available for all processing jobs. There are six (6) common parameters that users can set, which are as follows:

- Comments – Users can write comments for each processing job. These comments make it easier to identify and find a previously submitted processing job.
- Priority Job Submission – A priority value can be provided for a processing job so as to circumvent the queue (run before other processing jobs). All active processes will be paused at their current processing state until the high priority process has completed. At this point, the paused processing job will resume from where it left off, as opposed to starting from the beginning. For example, your company's operators are submitting regular jobs for longer term projects (day-to-day operations). An important client comes with a job that needs almost immediate turnaround. In order to satisfy your client without significantly disrupting another job, the operator can submit the new job with a higher priority than the jobs that are currently processing. This new job will jump to the top of the list (above all jobs with lower priority values). It will begin processing as soon as it is 'safe' to stop a job that is currently processing.



Submission Order	Queue	Job	Priority
4th	Processing	Raw2Mosaic	53
1st	1	Ortho	50
2nd	2	Raw2Mosaic	50
3rd	3	DEM Generation	50

Figure: Demonstrates that processing jobs with a higher priority value (ordinal values) can circumvent the processing queue.

- Server Selection – When the GXL system is setup with multiple processing servers, the user can optionally select which processing server a given processing job will be initialized on. By default this parameter is set to <auto>, which will start a process on the first processing server with available processing resources.

- Saving Parameters – GXL operators have the option to save the parameter configuration of a processing job for later use. This tool is often used for creating scenario based parameters. Scenario based parameters save the operator time during setup by minimizing the number of parameters that must be setup. For example, if the user has different processing jobs that use the same set of DEMs, reference imagery, projection and GCP Collection criteria, they can save the setup of those parameters for later use. This reduces the number of parameters that need to be setup.

  There are no limits to the number of predefined configurations that can be saved for a given processing job.

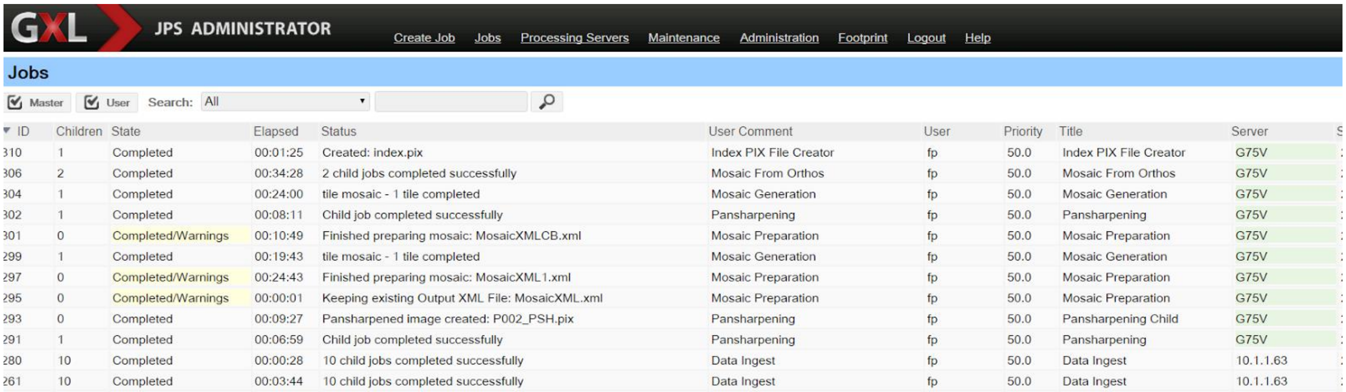
- Job Scheduling – The user can optionally specify a future date and time for when a processing job should automatically launch.

- Email Notification – The user can specify an email address that the system will automatically send email notifications to. Email notifications contain progress updates and or status changes (i.e. processing to complete).

  More information about email notification is provided in the Email Notification section (below).

Administration

The JPS-Administrator provides the ability for GXL operators to monitor and manage different levels of a given processing job. The operator can monitor active and inactive (previously run) jobs by navigating to the *Jobs page* of the JPS-Administrator. The *Jobs* page can be accessed at any time by clicking on the *'Jobs'* button located on the main navigation bar. The *Jobs page* provides an overview of the status of all processing servers and submitted processing jobs.



ID	Children	State	Elapsed	Status	User Comment	User	Priority	Title	Server
310	1	Completed	00:01:25	Created: index.pix	Index PIX File Creator	fp	50.0	Index PIX File Creator	G75V
306	2	Completed	00:34:28	2 child jobs completed successfully	Mosaic From Orthos	fp	50.0	Mosaic From Orthos	G75V
304	1	Completed	00:24:00	tile mosaic - 1 tile completed	Mosaic Generation	fp	50.0	Mosaic Generation	G75V
302	1	Completed	00:08:11	Child job completed successfully	Pansharpening	fp	50.0	Pansharpening	G75V
301	0	Completed/Warnings	00:10:49	Finished preparing mosaic: MosaicXMLCB.xml	Mosaic Preparation	fp	50.0	Mosaic Preparation	G75V
299	1	Completed	00:19:43	tile mosaic - 1 tile completed	Mosaic Generation	fp	50.0	Mosaic Generation	G75V
297	0	Completed/Warnings	00:24:43	Finished preparing mosaic: MosaicXML1.xml	Mosaic Preparation	fp	50.0	Mosaic Preparation	G75V
295	0	Completed/Warnings	00:00:01	Keeping existing Output XML File: MosaicXML.xml	Mosaic Preparation	fp	50.0	Mosaic Preparation	G75V
293	0	Completed	00:09:27	Pansharpened image created: P002_PSH.pix	Pansharpening	fp	50.0	Pansharpening Child	G75V
291	1	Completed	00:06:59	Child job completed successfully	Pansharpening	fp	50.0	Pansharpening	G75V
280	10	Completed	00:00:28	10 child jobs completed successfully	Data Ingest	fp	50.0	Data Ingest	10.1.1.63
261	10	Completed	00:03:44	10 child jobs completed successfully	Data Ingest	fp	50.0	Data Ingest	10.1.1.63

Figure: Screenshot of the 'Jobs page', which provides operators with an overview of the status (i.e. Running, completed, failed, etc.) of processing job and state of the installed processing servers.

Definition of Master (Parent) and Child Jobs

The GXL is a system that has been designed to handle many large batch processing requests in a manner that maximizes throughput potential, automation and quality. As a result, the JPS-Administrator was designed with a user friendly and flexible concept for monitoring and managing processing jobs. This concept organizes a batch process into a *Master (or Parent)* and associated *Child jobs*. A master job is essentially a wrapper for a set of batch processing jobs. The master job manages the progress of the entire batch process as a whole and can be made up of many individual processing jobs called child jobs. For example, if an operator submits a batch process that requires 1000 images to be orthorectified, the master job would be responsible for managing the batch process (project) as a whole. The master job would then spawn 1000 child jobs, each of which representing 1 of the 1000 images that are to be orthorectified. This design allows operators to monitor and manage the entire batch process as a whole or each of the individual 'child' processes that were spawned by the master job (See figure below).

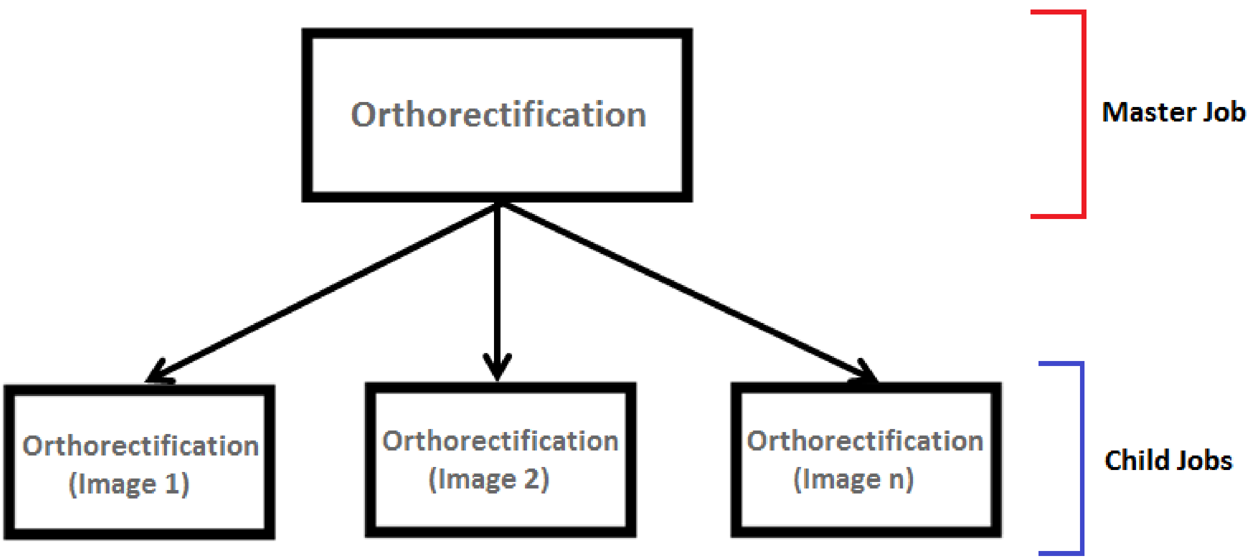


Figure: Illustration of how Master (parent) jobs and Child jobs relate

Not all processing jobs submitted through the GXL will contain child jobs. Some processing jobs are not batch processes and therefore, will not contain any child jobs. For simplicity, these processing jobs can also be referred to as master or parent jobs.

In the case of chained workflows, it is possible for a submitted processing job to have two levels of child jobs. The master job in this case would be a wrapper that manages the entire workflow. The first child job level would be the batch processing wrapper (master job in above example) and the second child job level would consist of each individual process.

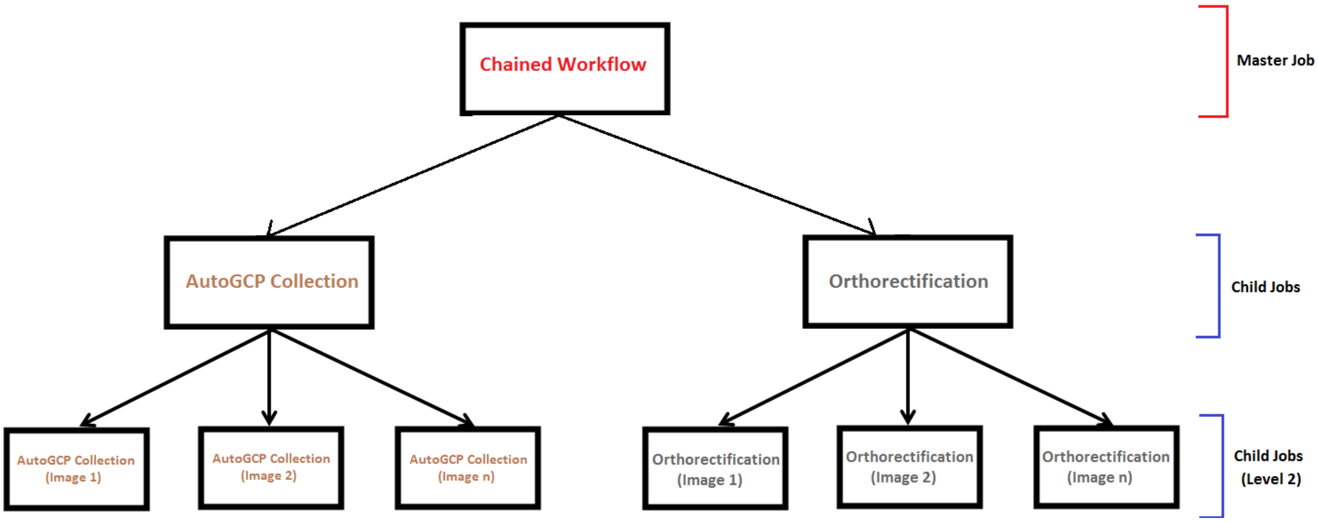


Figure: Illustrates how the Master and two Child job levels are defined and relate in a chained workflow.

Maintenance

The *Maintenance* page is used for maintaining the integrity of the JPS Database. Such activities include removing jobs and processing servers from the JPS system. This allows the user to delete multiple non-running jobs from the database by setting up conditions.

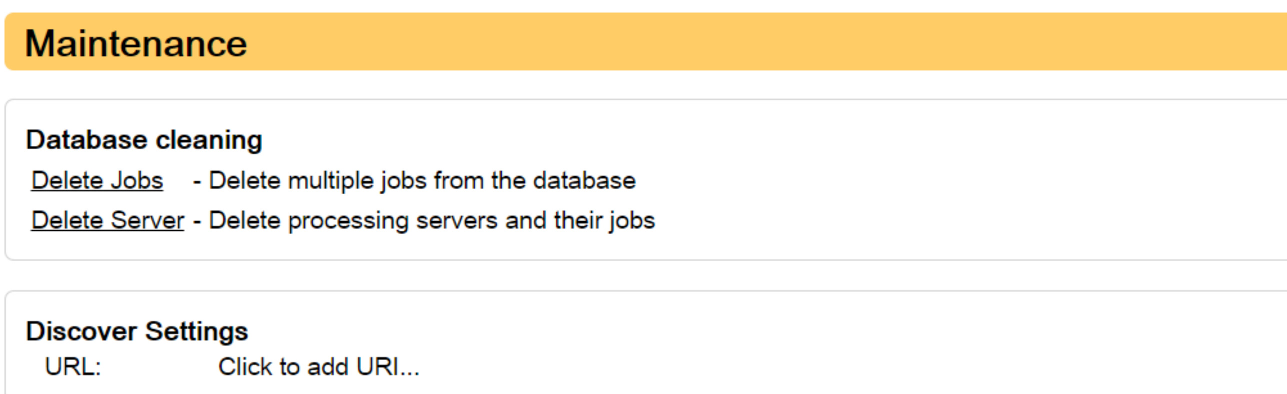


Figure: Maintenance Page

User Administration

System user accounts can be added and removed in the *Administration* tab. Similarly, account information can be edited here, such as email, password, description, and user first and last name.

Users

Add new user...

Username	First Name	Last Name	Description
fp			
gxladmin	GXL	GXL	Admin user to run GXL jobs

Figure: Administration Page

Monitoring Master Jobs

To reiterate, a master job is the highest level of a processing request, which acts as a container for all subsequent child jobs, if they exist. This may be in the form of an end-to-end workflow that is responsible for orthorectifying and mosaicking 1000 satellite images together or the preparation of a single mosaic file, which does not contain any child jobs.

When a user logs into the JPS-Administrator, they are automatically redirected to the 'Jobs page', which can also be accessed by clicking on the 'Jobs' link on the main navigation bar. The Homepage is where operators can monitor active and inactive processes that have been submitted to the GXL for processing. On the homepage, previously submitted processing jobs are organized in a sortable table that provides information about a processing job's state, status, elapsed time and more. Some of the jobs listed in the Jobs table contain child jobs (batch processes) and others do not (standalone processes). An operator can quickly determine whether a record in the Jobs table is a child job by looking at the status information for that specific record.

Jobs

Master | User | Search: All

ID	Children	State	Elapsed	Status	User Comment	User	Priority	Title	Server
310	1	Completed	00:01:25	Created: index.pix	Index PIX File Creator	fp	50.0	Index PIX File Creator	G75V
306	2	Completed	00:34:28	2 child jobs completed successfully	Mosaic From Orthos	fp	50.0	Mosaic From Orthos	G75V
304	1	Completed	00:24:00	tile mosaic - 1 tile completed	Mosaic Generation	fp	50.0	Mosaic Generation	G75V
302	1	Completed	00:08:11	Child job completed successfully	Pansharpening	fp	50.0	Pansharpening	G75V
301	0	Completed/Warnings	00:10:49	Finished preparing mosaic: MosaicXMLCB.xml	Mosaic Preparation	fp	50.0	Mosaic Preparation	G75V

Figure: Illustrates how an operator can quickly determine jobs with child process and those without.

As previously mentioned, the Jobs table provides information about a master job's state, status, elapsed time and more. The State of a master job provides a simple header that informs the operator that a process is: Running, failed, contains warnings, completed, and cancelled by the user or more. The Status column also provides details about the current State. For example, the state may inform an operator that a process failed, whereas the Status informs the operator that the DEM parameter was not specified, causing the failure.

Managing Master Jobs

Overview

The operator can access more details and management controls for a master job by clicking on the job record in the *Jobs* page. This link will direct the operator to a webpage that provides additional details of the master job, a log specific to the master job for advanced troubleshooting and management controls that may only affect the master job or may affect the master job and all its child jobs. Similarly, if the operator places the cursor over a specific record field (State, Elapsed, and Status), a window will pop up and show information about the specific job.

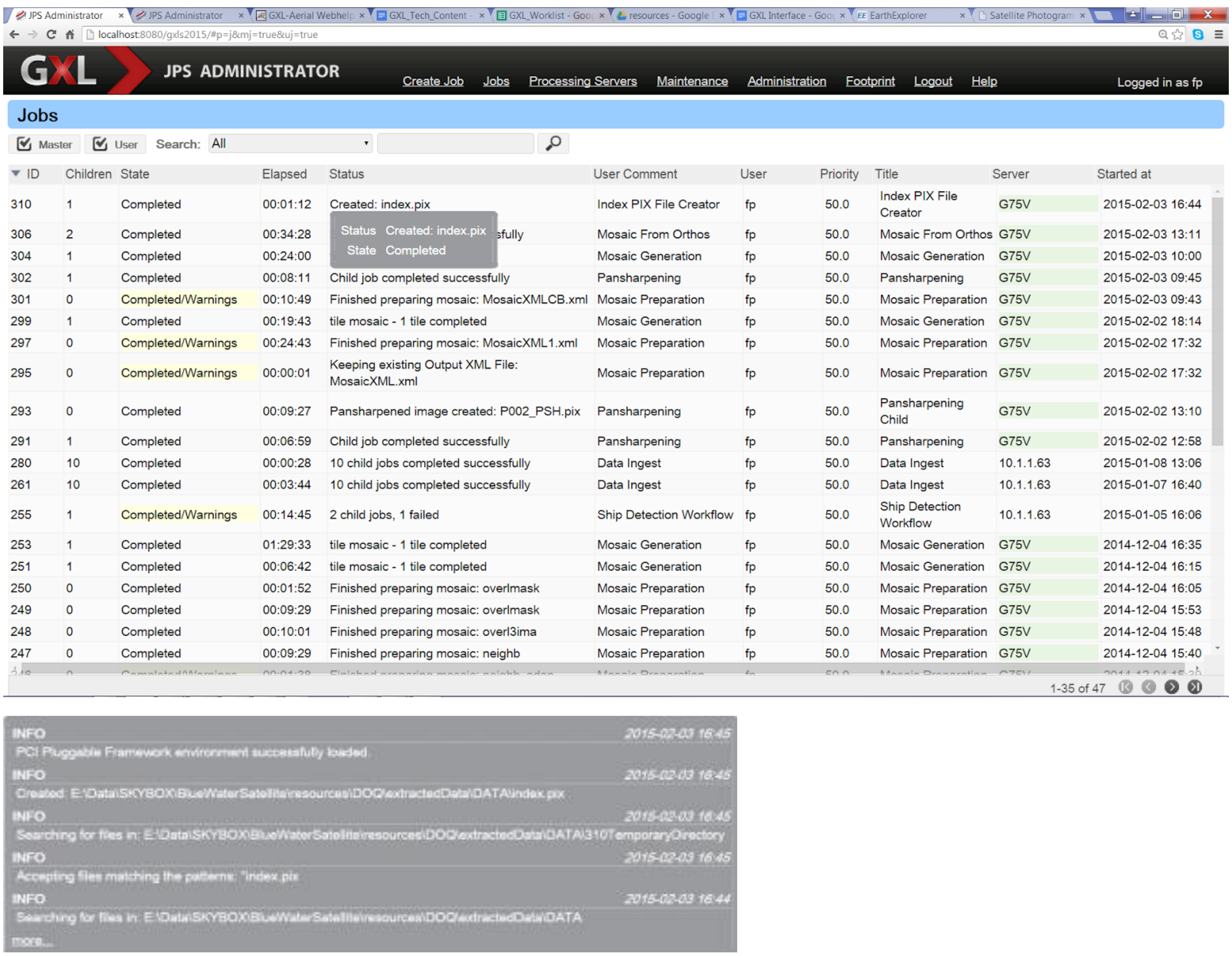


Figure: Illustrates how a user can access details and management controls for a master job

Master Job –Job Details Page

The Job Details page provides operators access to information about the master processing job, as well as management controls for the given master job. The Job Details page consists of the following sections and controls (See figure below):

- Basic Details– Provides additional details about the processing job, such as: Elapsed time, status, state, user who submitted the job, the server that it was processed on and etc.
- Cancel– The cancel button will terminate the master job and all subsequent child jobs from processing when it is safe to do so.
- Link New Job – This button opens the “Jobs” page and adds a new selected job to the queue after the current process is completed successfully.
- Kill - The kill button will immediately kill the process of the master job and all child jobs, regardless of whether it is `safe` to do so or not. If a process is killed, the operator may be required to perform additional maintenance.
- View Job Parameters – This button will redirect the operator to the setup and submission page for that processing job and copy the parameters of the batch process that were set when the job was submitted. This allows operators to make quick changes without having to configure all of the parameters.

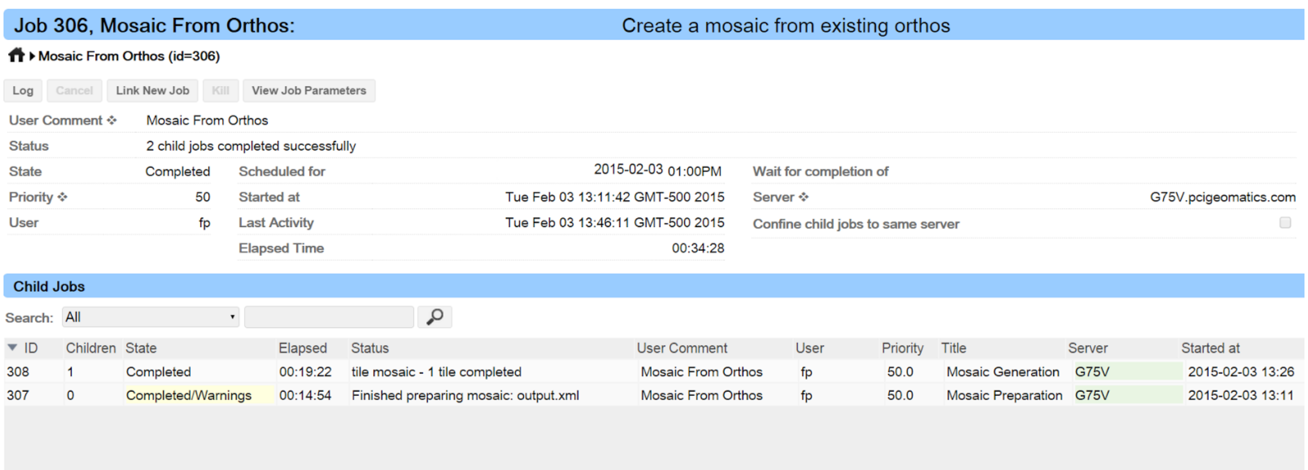


Figure: Annotated diagram of Job Details page for a master job

Master Job – Log

After the user has accessed the Job Details page, they can view a detailed log by clicking on the Log button. This log can be used for advanced monitoring and troubleshooting.

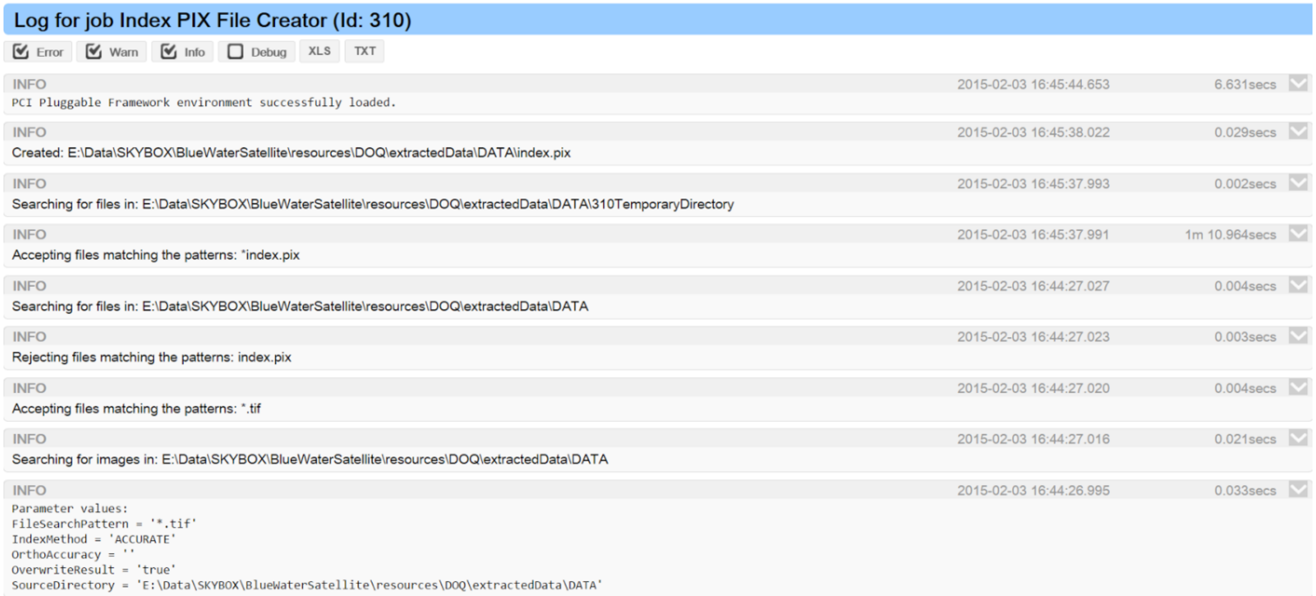


Figure: Illustrates how the log of a master job can be accessed and part of the information provided in the log

Monitoring Child Jobs

GXL Operators have the ability to monitor and manage individual child jobs that are spawned by a master job. After clicking on a master job, the user will be redirected to a page that organizes the child jobs, for the given master job, into a table. The operator can access any child job by clicking on any of the records in the Child Jobs (see figure below).

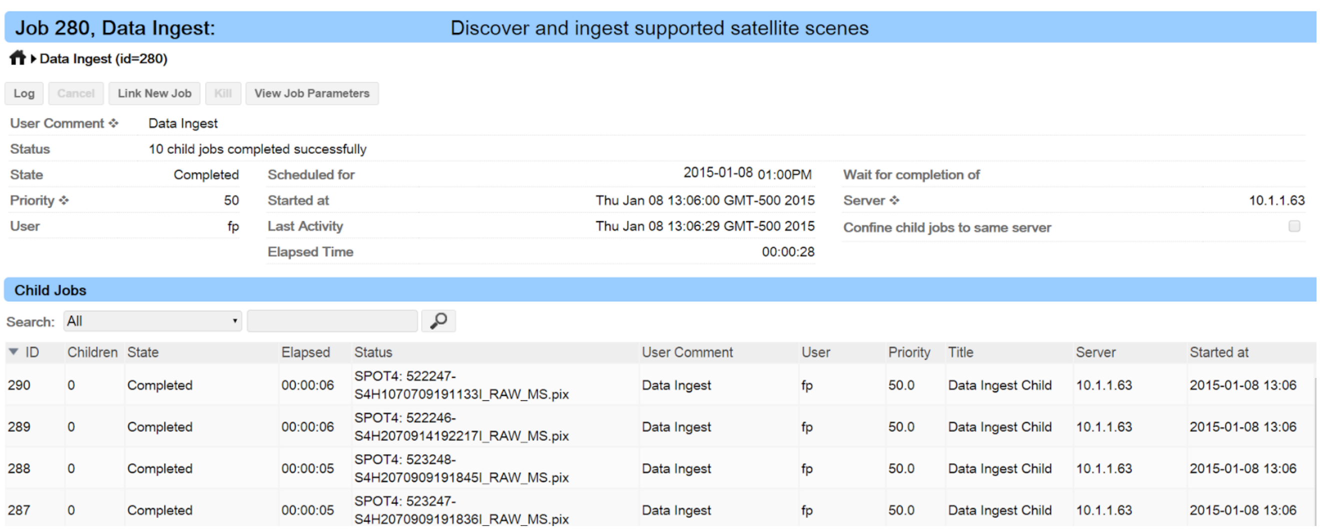


Figure: Illustrates how the child job table can be accessed and how it is organized

Managing Child Jobs

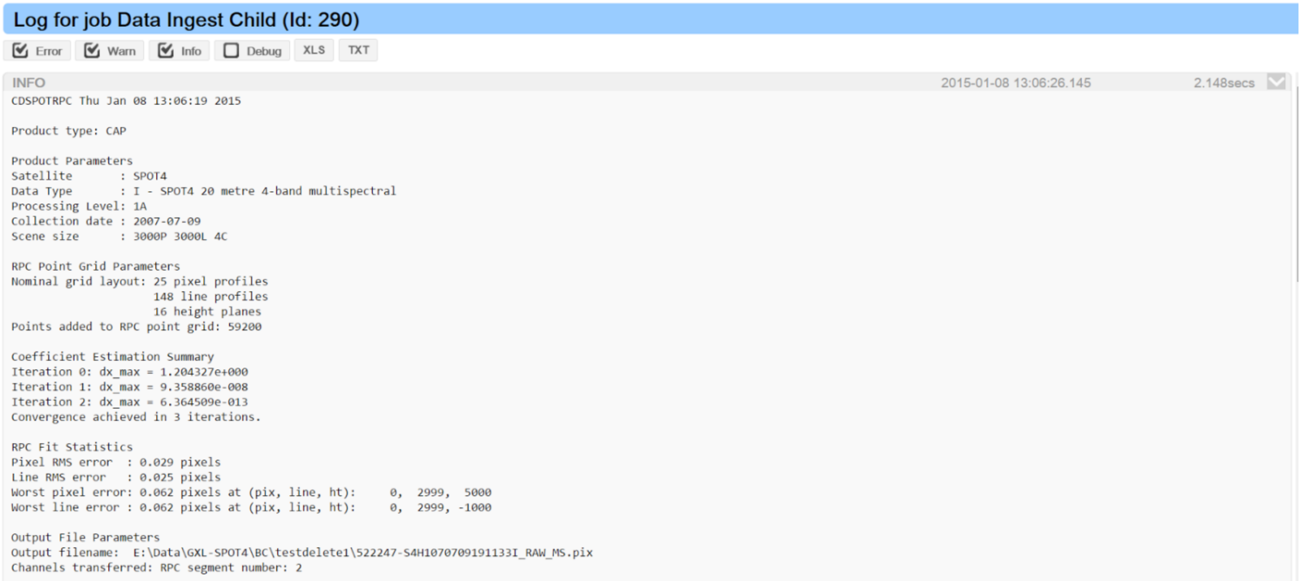
Child Job – Job Details Page

The Job Details page for child jobs is identical in function and design. The Job Details page for child jobs consists of the following sections and controls (See figure in the Master Job – Job Details Page section previously described):

- Basic Details– Provides additional details about the processing job, such as: Elapsed time, status, state, user who submitted the job, the server that it was processed on and etc.
- Cancel– The cancel button will terminate the master job and all subsequent child jobs from processing when it is safe to do so.
- Link New Job – This button opens the “Jobs” page and adds a new selected job to the queue after the current process is completed successfully.
- Kill - The kill button will immediately kill the process of the master job and all child jobs, regardless of whether it is `safe` to do so or not. If a process is killed, the operator may be required to perform additional maintenance.
- View Job Parameters – This button will redirect the operator to the setup and submission page for that processing job and copy the parameters for that specific child job based on the master job that was originally submitted. This allows operators to make quick changes without having to configure all of the parameters.
- This can be highly advantageous when running very large batch processing jobs, particularly, when some of the child jobs fail during processing. For example, a master orthorectification job is submitted, which contains 3000 images and therefore 3000 child jobs. After processing, the user is informed that 7 of the 3000 child jobs failed (perhaps because the DEM did not overlap these images). The JPS Administrator makes it possible for the user to quickly identify the child jobs that failed, as well as provides functionality to handle them effectively. Without the ability to manage child jobs, the user would have to either create a new processing job with only the images that failed or rerun the entire batch process, both options include unnecessary setup or processing time.

Child Job – Log

After the user has accessed the Job Details page for the given child job, they can view a detailed log by clicking on the Log button. The log is specific to the child job selected and will provide specific details about processes that occurred for this child job. Each child job will have a unique log. This log can be used for advanced monitoring and troubleshooting.




```
CDSPOTRPC Thu Jan 08 13:06:19 2015

Product type: CAP

Product Parameters
Satellite       : SPOT4
Data Type       : I - SPOT4 20 metre 4-band multispectral
Processing Level: 1A
Collection date : 2007-07-09
Scene size      : 3000P 3000L 4C

RPC Point Grid Parameters
Nominal grid layout: 25 pixel profiles
                     148 line profiles
                     16 height planes
Points added to RPC point grid: 59200

Coefficient Estimation Summary
Iteration 0: dx_max = 1.204327e+000
Iteration 1: dx_max = 9.358860e-008
Iteration 2: dx_max = 6.364509e-013
Convergence achieved in 3 iterations.

RPC Fit Statistics
Pixel RMS error  : 0.029 pixels
Line RMS error   : 0.025 pixels
Worst pixel error: 0.062 pixels at (pix, line, ht):     0,  2999,  5000
Worst line error : 0.062 pixels at (pix, line, ht):     0,  2999, -1000

Output File Parameters
Output filename:  E:\Data\GXL-SPOT4\BC\testdelete1\522247-S4H1070709191133I_RAW_MS.pix
Channels transferred: RPC segment number: 2
```

Figure: Illustrates how the log of a child job can be accessed and part of the information provided in the log

Email Notification

The GXL supports automatic email notification, which notifies operators of status changes or progress updates by automatically sending them an email message. This functionality allows operators to take a more reactive approach to monitoring and managing processing jobs. Prior to automatic email notification, operators would be required to either go into the office or log into the system remotely to get updates of processing progress or errors. This is a disruptive task and can prevent an operator from completely immersing themselves in another task (i.e. Quality Assurance). Automatic email notification eliminates this requirement, because it will automatically notify the operator when a processing task has reached a benchmark, completed or if something went wrong. This functionality not only improves the operators efficiency, but also provides a less intrusive method for the operator to monitor and manage jobs outside of work hours or when off-campus.

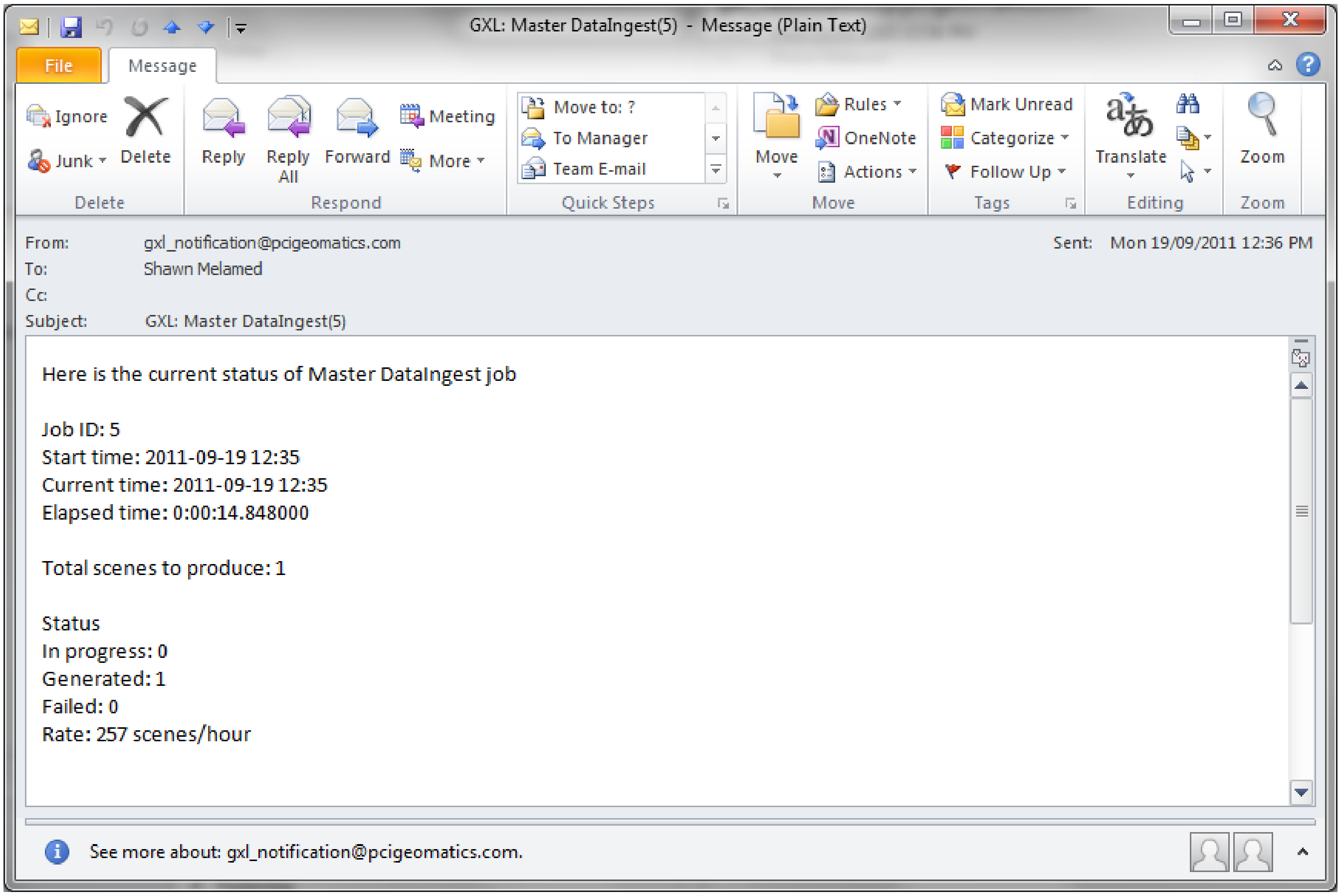


Figure: Example e-mail notification

File Export

The File Export process scans the input directory for all valid spatial file formats (.PIX, .TIFF, .SHP, etc.) and creates a copy of each file found in the output file format. This process can export vectors, rasters, bitmaps, Look up tables (LUTs) and pseudo color tables (PCTs)

The File Export process supports most major vector and raster formats for export.

Mosaicking

Overview of Mosaicking Workflow

The GXL's mosaicking operation consists of two (2) automated steps and one (1) optional interactive quality assurance step. The first automated step, named Mosaic Preparation, is responsible for normalizing the images (i.e. hotspot removal), calculating color balancing and generating the seamlines (cutlines). The Mosaic Preparation process creates a very lightweight mosaic preview that can optionally be viewed and edited with the GXL's interactive *Mosaic Tool* or fed directly into the Mosaic Generation module. The Mosaic Generation process automatically generates the full resolution mosaic or mosaic tiles, applying the color balancing adjustments and seamlines computed in the Mosaic Preparation module and optionally edited with the Mosaic Tool.

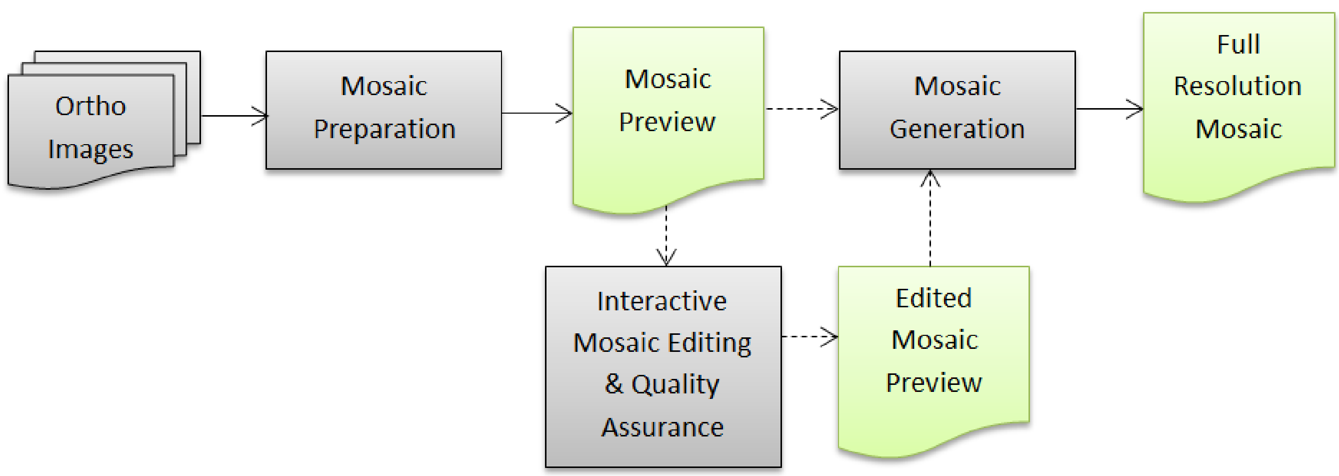


Figure: Flowchart illustrating the mosaicking workflow

Mosaic preparation

The Mosaic Preparation processing module is responsible for automatically normalizing the images, calculating color balancing and generating the seamlines (cutlines). The output is a very lightweight mosaic preview that can be viewed and edited using the GXL's Mosaic Tool. The Mosaic Preview does not generate an actual mosaic image, but rather it stores all of the necessary information in XML files (i.e. color balancing coefficients, image sorting, links to ortho-images, etc.). The Mosaic Tool and Mosaic Generation module can interpret this information in order to render the preview mosaic on-the-fly or generate the full resolution final mosaic, respectively.

Image Normalization

Some images may contain patterns in visual brightness that can affect the seamless integration of the images into a mosaic. The Normalization methods are used to even out the bright and dark effects to achieve a more pleasing mosaic. Three Image normalization methods exist: Hot Spot, Adaptive and Order.

Color balancing

Color Balancing produces a uniform mosaic by matching the histogram for each image applied to the mosaic so that, as a group, the input images have a similar histogram range and distribution. Automatic histogram modification can be done either by changing every value in the histogram through the use of a look-up table (LUT matching), or by applying a gain and bias to the original histogram. Six different color balancing algorithms and methods exist in the GXL: Bundle, Overlap, Histogram, Neighborhood, Reference and LUT.

Figure: Color balancing example

Seamlines (Cutlines)

Seamlines (cutlines) are used to determine where an image should be "cut" and added to the mosaic so that there are no visible differences between features at the seam of two or more images. The cutline is generated in the overlap area of two adjacent images. The cutline algorithms have been designed in a manner that they automatically avoid edge features and in most cases, buildings, cars or other objects that would prevent the generation of a seamless mosaic (See figure below).

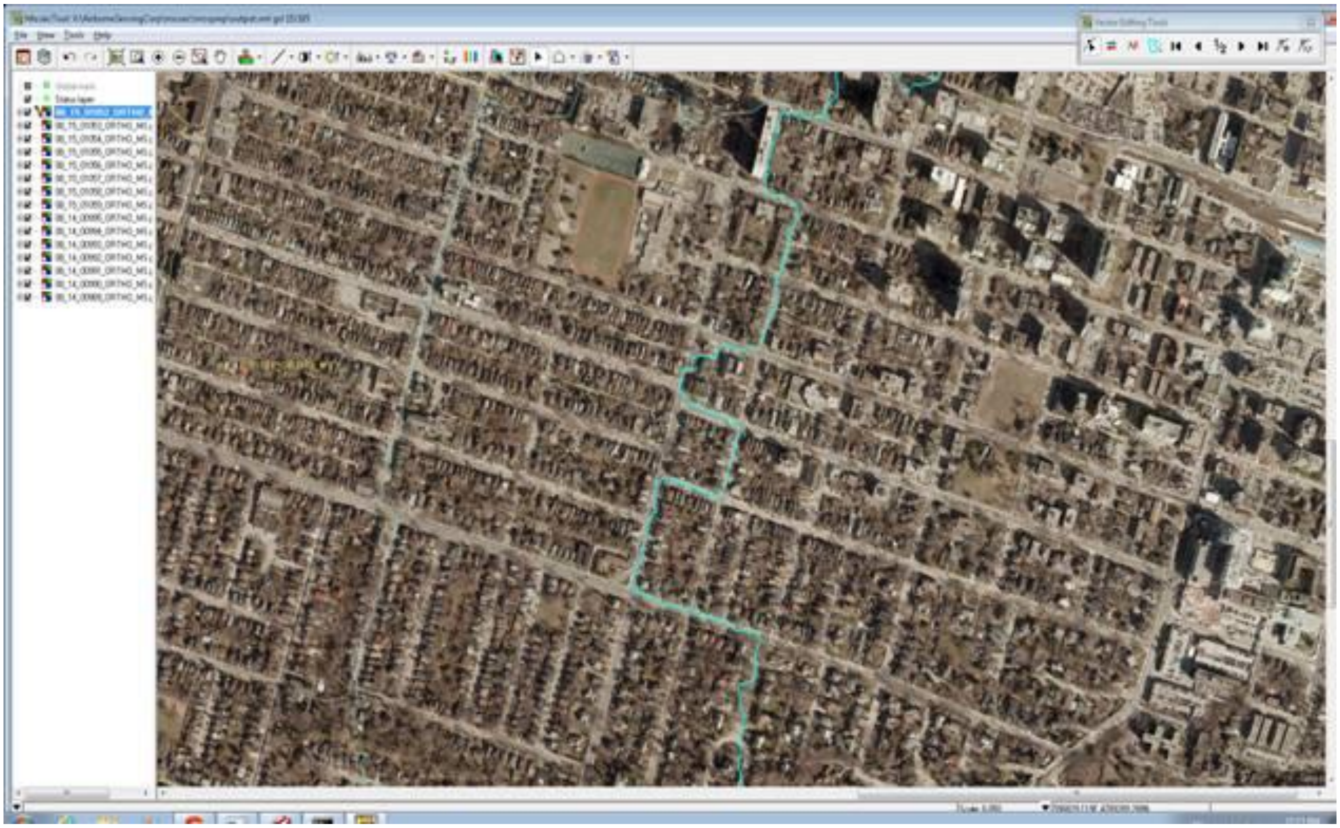


Figure: Example of the quality of the automatic cutlines (seamlines) that the GXL can create. Intelligence built in to avoid surface features

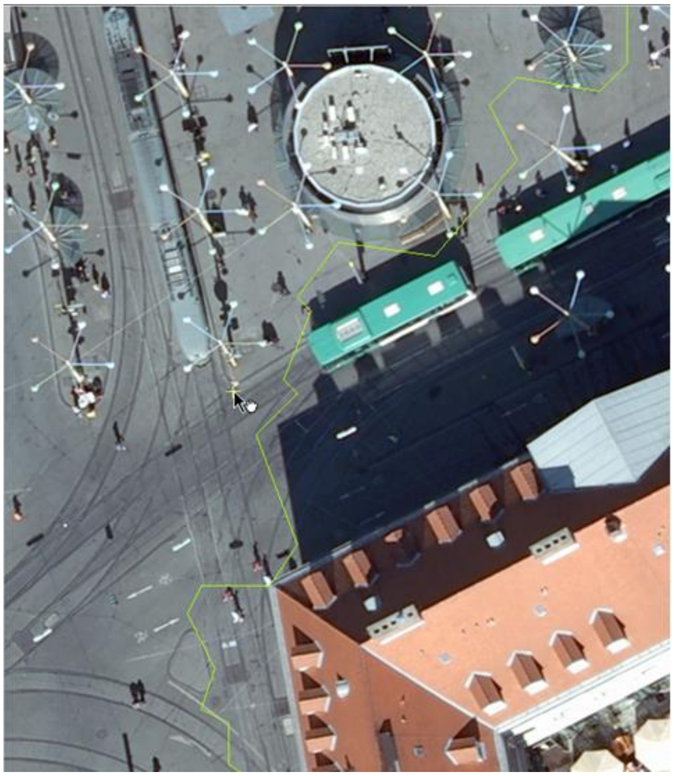


Figure: Example of the quality of the automatic cutlines (seamlines) that the GXL can create. Intelligence built in to avoid surface features

Mosaic Generation

The output XML file from the Mosaic Preparation process, optionally edited with the Mosaic Tool, is an input into the Mosaic Generation module. The XML file provides the Mosaic Generation process with all of the information it needs to generate the final mosaic (i.e. path to input ortho images, sorting order, color balancing coefficients for each image, cutlines and etc.). The Mosaic Generation process has the following options for defining how the final mosaic is generated: Tiling options, blending width, “cookie cutting” and file format.

Mosaic Tiling

Mosaic tiling can be defined by pixel dimensions or by a vector shapefile.

Defining mosaic tiles by dimensions, requires that the operator specify the number of pixels in the X and Y orientations that should be used to define the size of each tile. The GXL system then automatically cuts the tiles to these dimensions, using the top-left pixels as a starting point.

A vector shape file can be provided to define the tile dimensions of each individual tile. This option does not require that the tiling dimensions be uniformly defined. Furthermore, attribute records for each shape (from a given field) can be used to automatically provide names for each tile (i.e. Tile ID).

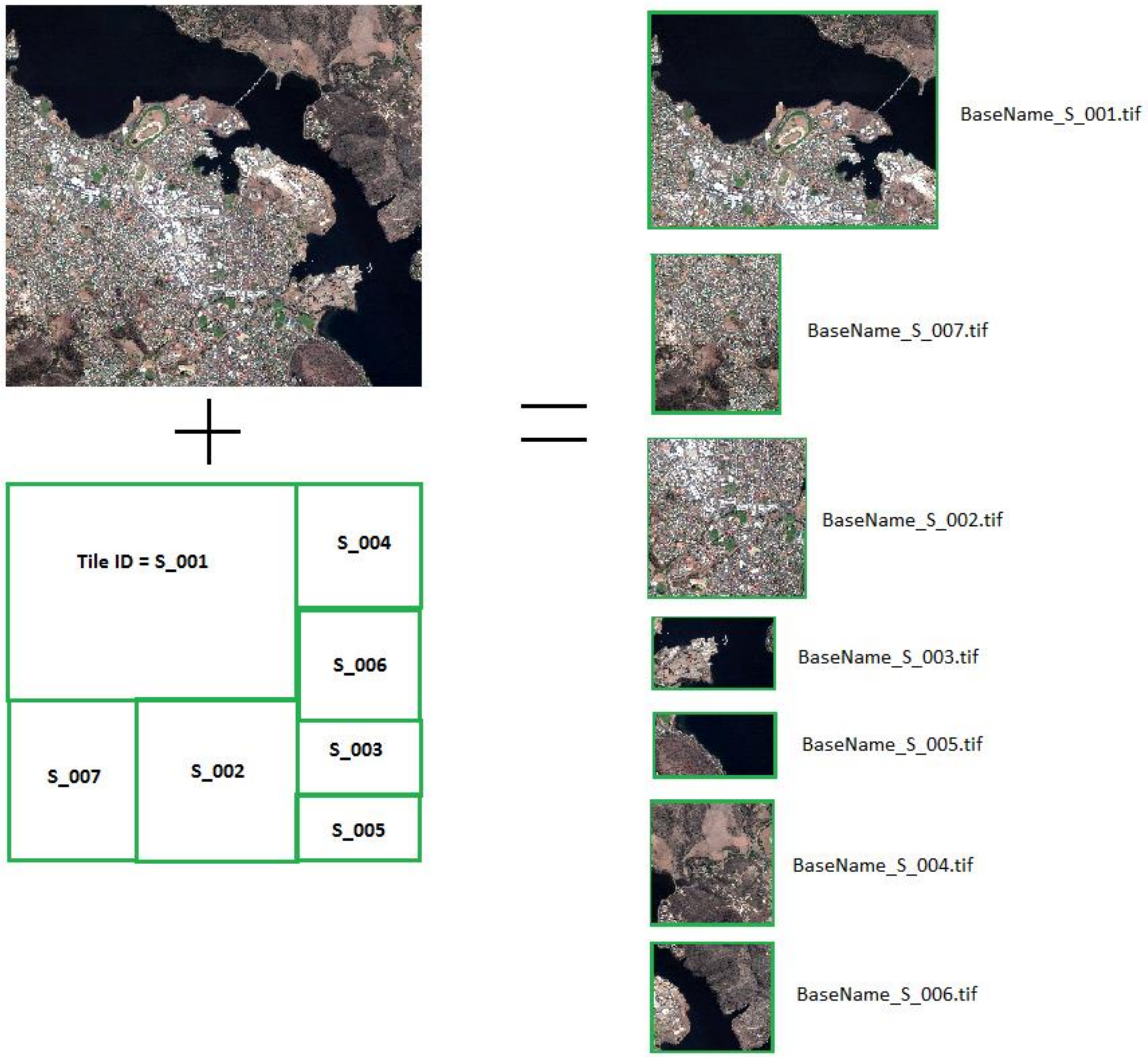


Figure: Example of automatic tiling and naming from a vector polygon layer

Cookie Cutting

A polygon vector can be provided to define the outline of the final mosaic. The GXL accepts complex irregular polygons as inputs and will cut the mosaic or mosaic tiles to the exact outline of the polygon. This is often used for country-wide mosaics where the mosaic is cut along the national borders or based on other political boundaries.

Figure: 'Cookie Cutter' approach to clip a country-wide mosaic of North Korea based on a vector polygon defining North Korea's national borders

Automatic Accuracy Assessment

The Automatic Accuracy Assessment workflow uses image-matching techniques to automatically collect check points (CP) between the input ortho images and one or more control images. The check points are used to assess the positional accuracy of the ortho images as they compare to one or more control images. The module has two assessment modes, which can be performed independently or in combination:

- Absolute: Check points are collected between valid overlapping regions of the input ortho scenes and one or more control images. With this option selected, an output statistical summary report is created, and a set of geographical output files is also created to simplify evaluation of the absolute positional accuracy.
- Relative: The specified input folder is scanned for all valid images that overlap each other. Check points are collected automatically on all overlapping regions of each input file. With this option selected, an output statistical summary report is created and a set of geographical output files is also created to simplify evaluation of the relative positional accuracy.
- All: Combines the Absolute and Relative modes and merges the output.

Statistical accuracy measures include: Residual error of individual images, RMSE of project, CEP90 of project.

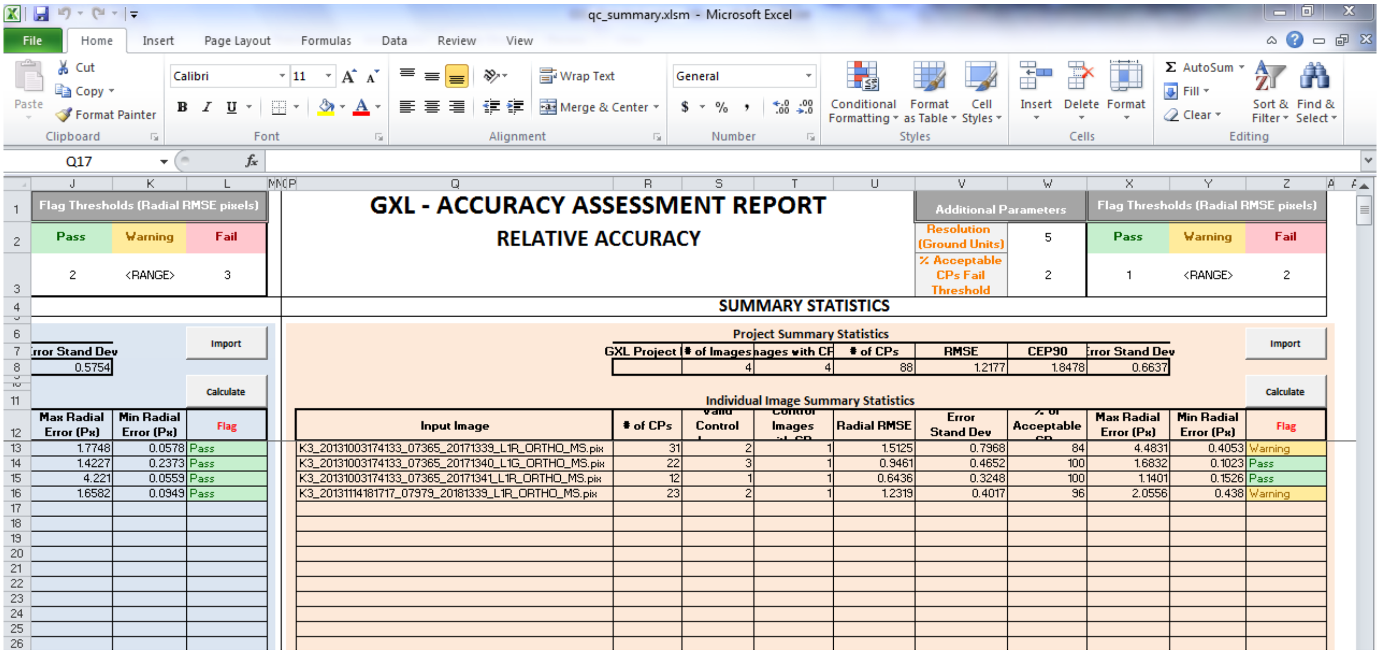


Figure: Example output of Automatic Accuracy Assessment. A statistical report and graphical output are generated to help operators locate potential errors and make informed decisions about correcting them.

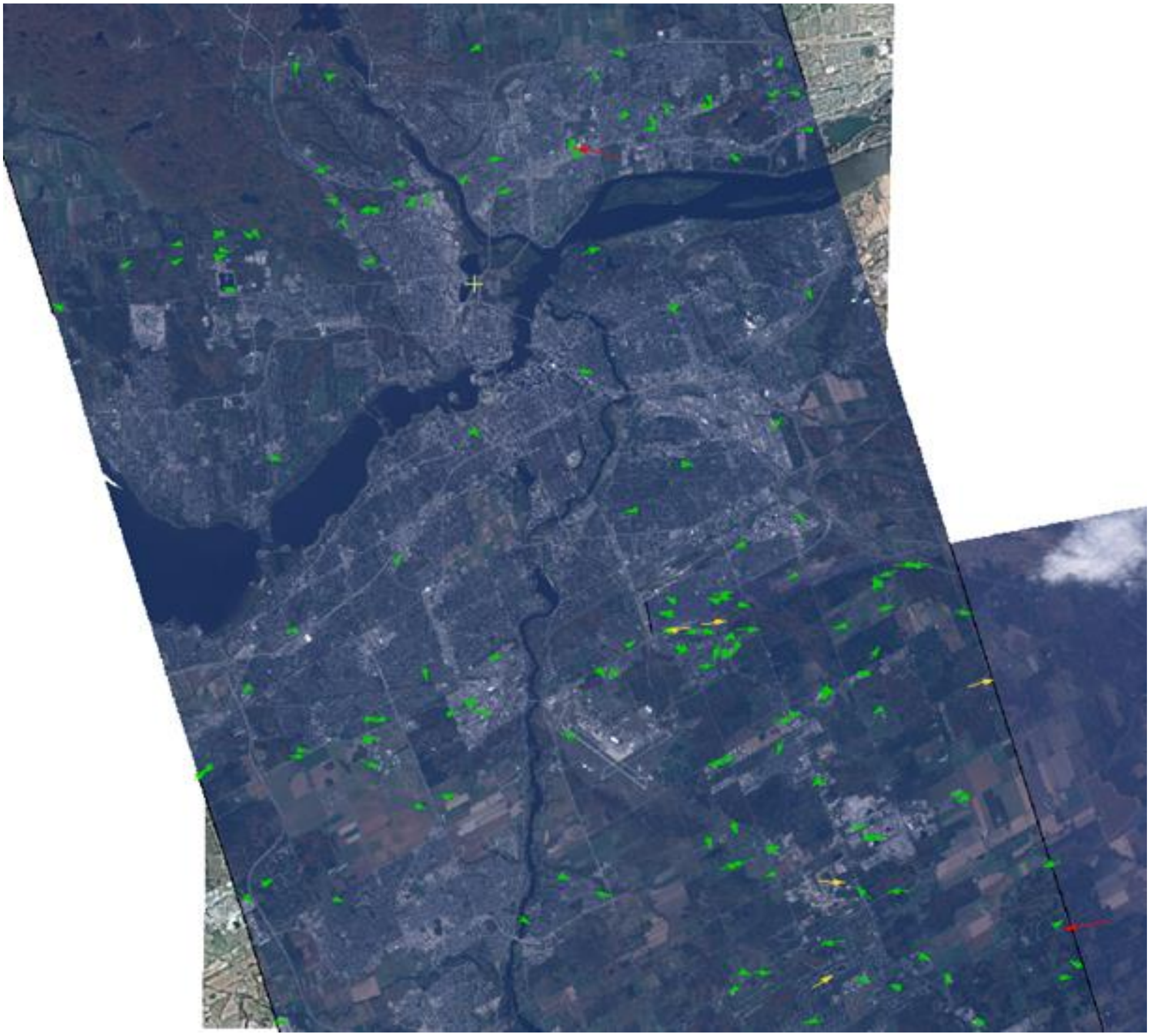


Figure: Example output of Automatic Accuracy Assessment. A statistical report and graphical output are generated to help operators locate potential errors and make informed decisions about correcting them.

DEM Generation

Highly accurate and detailed Digital Elevation Models (DEMs) can be constructed from a variety of vector layers, such as: LIDAR points, contours, break lines, TINs, and building footprints. The DEM Generation workflow provides an easy-to-use method for generating the most accurate DEM from multiple input vector layers. The algorithm automatically determines priority of each layer to ensure the most accurate and relevant vector layer is used for determining the elevation value of each pixel in the output raster DEM.

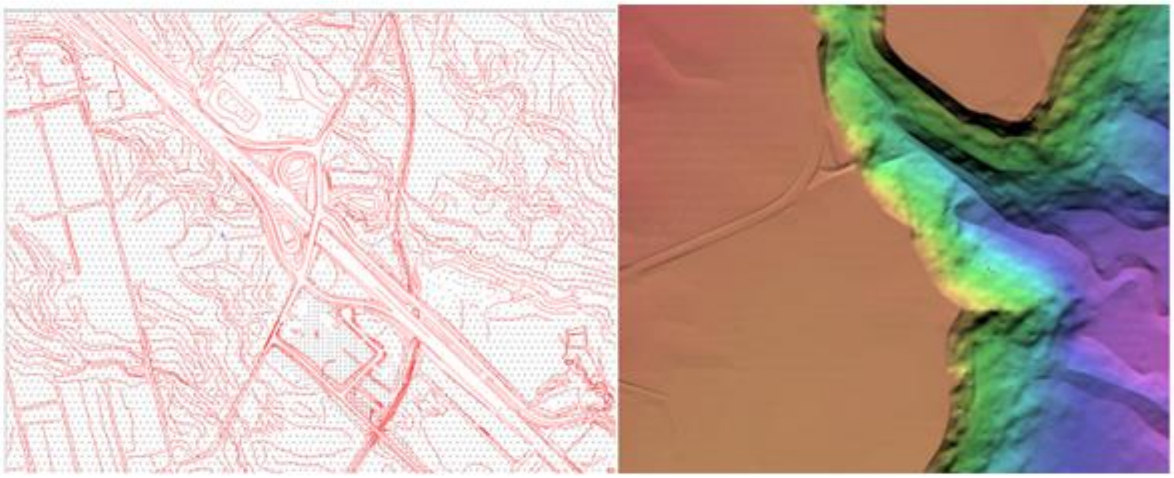


Figure: Input elevation vectors (contours, points, breaklines) on left and output raster DEM generated from vectors on right

DEM Export

The DEM Export process generates a DEM and imagery files that can be viewed and edited in a 3-D editing program such as DAT-EM. The algorithm exports to LAS and GeoTIFF formats, and generates an RPC text file for the math model associated with the images.

DEM Index File Creator

The DEM Index File Creator process scans the source directory for tiled DEM files and generates a PCIDSK (index.pix) file and a text file (index.txt). The index.pix files creates footprints for the DEM files in an input directory so that the algorithm can quickly find which DEM intersects an input image for GCP collection, Tie Point collection and orthorectification. The index.txt file provides the path to all input images and useful information about the DEMs, such as vertical accuracy.

This process helps speed up GXL processes where DEM tiles are provided as inputs.

This algorithm offers the flexibility between choosing different Indexing Methods. The two options available for indexing are **Fast** and **Accurate.** With the Fast option selected, the four corners of the DEM are detected, including areas where there is no data. This option performs indexing the fastest. With the Accurate option selected, the system attempts to find the inner four corners where data exists, and excludes most of the no-data area.

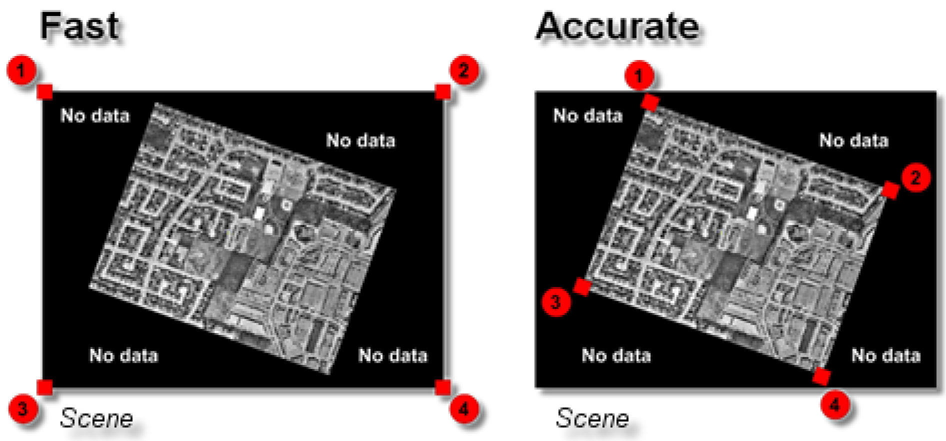


Figure: Example of Fast vs. accurate indexing method for DEMs

DEM Tri-stereo Merge

The DEM Tri-stereo Merge process is used to merge multiple sets of digital surface models (DSM) and digital terrain models (DTM) created from different combinations of views for tri-stereo images.

The input DSM/DEM must have been created from different combinations of views for tri-stereo images. Such results are normally created with the DEM Extraction module.

DEM Extraction

The GXL's DEM Extraction workflow generates a Digital Elevation Model (DEM) from a single set of stereo images or multiple sets of stereo images. This workflow supports optical satellite imagery containing a *rigorous* or *rational function* model and airphotos with a *digital airphoto* model.

The DEM Extraction workflow automatically scans an input directory for all valid stereo pairs, computes the epipolarized images and extracts the Digital Surface Model (DSM) for each stereo pair. Elevation values in a DSM are determined by matching points in a left and right epipolar input image using image correlation. The image disparity for the point pair is computed and this value, combined with the geometric model for each image, is used to compute the scene elevation for the corresponding scene point.

After all DSMs in the batch are extracted, the GXL automatically mosaics them together into a single seamless DSM.

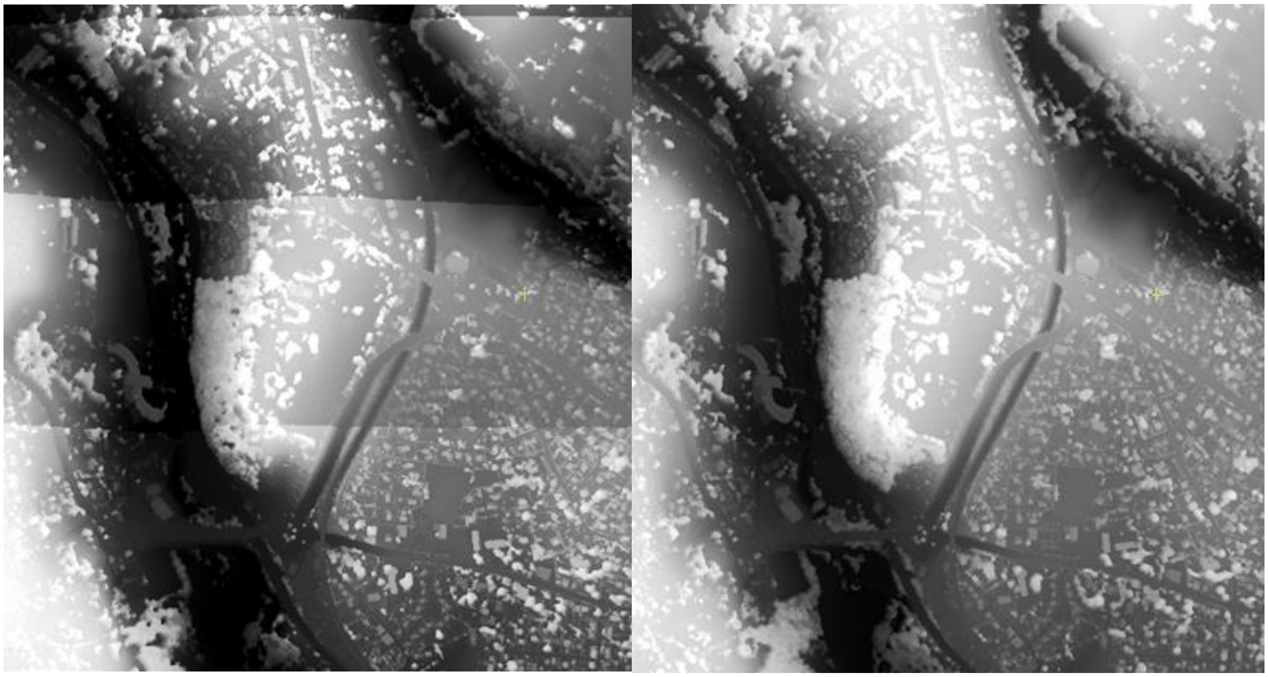


Figure: DSM extracted from multiple aerial images (left). Mosaicked DSM (right)

Optionally, the DSM can be automatically filtered to a bare earth Digital Terrain Model (DTM).

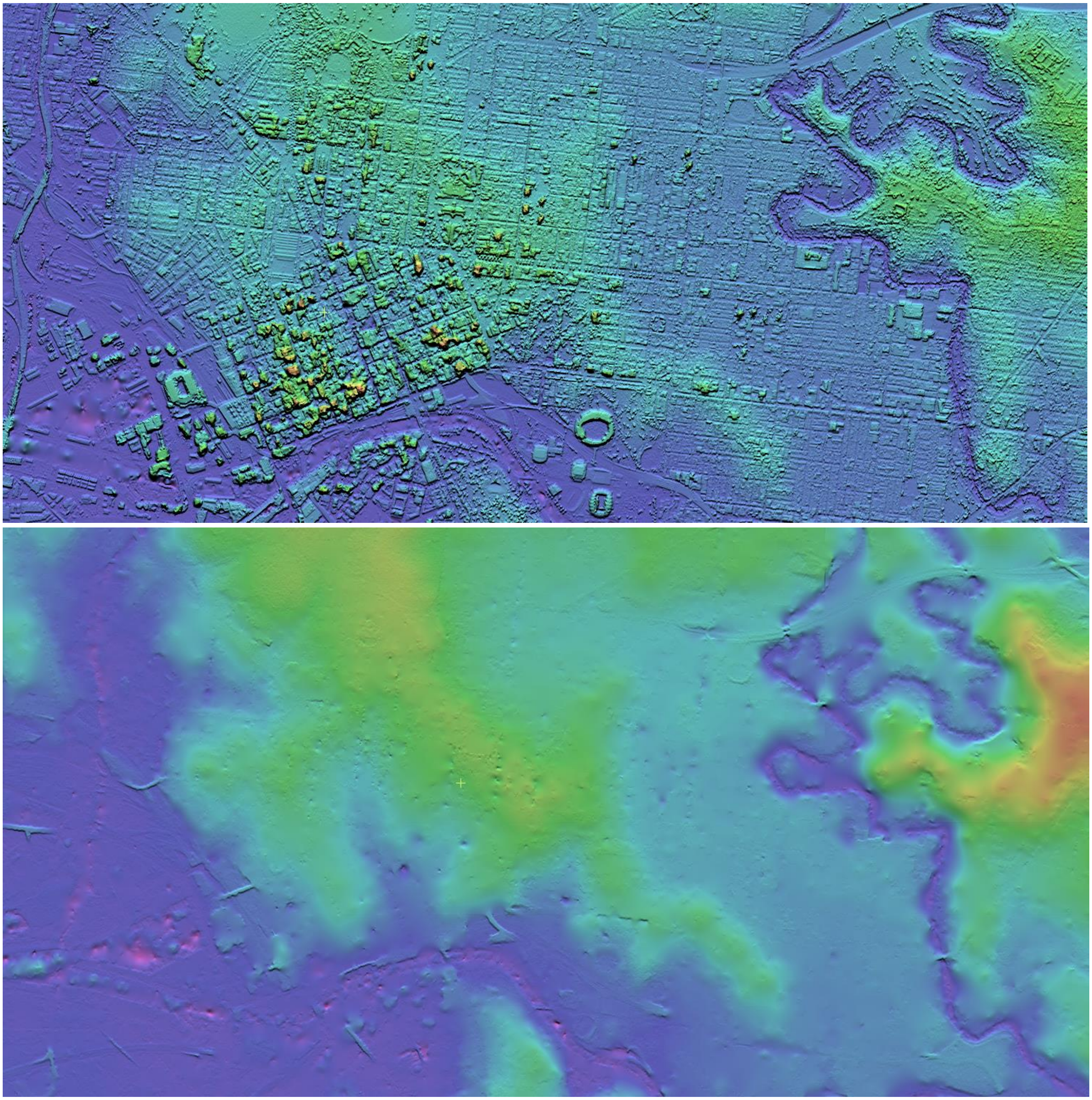


Figure: DSM (top) and DTM (bottom) extracted from Pleiades satellite imagery

Image Desaturation (Exposure Correction)

The Image Desaturation processing scans an input mosaic for over-exposed areas and automatically decreases the brightness of these areas without affecting the pixels around it. The algorithm looks for large areas of over-exposed pixels (aka bleached pixels), analyzes the surrounding area to determine how much to reduce each pixel value by and then applies the correction. Only overly bright pixels, classified as over-exposed are adjusted.

After the correction is applied, the area will be less bright with better contrast, resulting in greater visible detail in the area, while not adversely affecting the surrounding pixels.

Figure: Over-exposed airport before and after correction applied

Color Balancing Orthos

The Color Balancing Orthos process performs color balancing on a set of input ortho-images, but does not mosaic them together into the same output image file. The output is a set of ortho images with color balancing applied so that features in the overlapping region of the ortho-images have similar colors.

This module is run after the Mosaic Preparation module, in place of the Mosaic Generation module.

Image Scaling

Remote sensing data is structured in 8-bit, 16-bit, and 32-bit formats. In many instances, it is necessary to scale data from a higher to a lower bit depth. Usually for lowering the disk size of large mosaics.

The Image Scaling process rescales multiple images by mapping the gray levels of an input image to the gray levels of an output image. Furthermore, it is possible to stretch or shift the dynamic range of an input image for visual enhancement.

Index PIX File Creator

The Index PIX File Creator process scans the source directory for all valid GDB raster files and generates a PCIDSK (index.pix) file. The index.pix file contains footprints for the files in an input directory so that future algorithms can optimally calculate intersections, especially when using reference data for GCP collection, Tie Point collection and orthorectification.

This process helps speed up GXL processes where reference files are provided as inputs.

Pansharpening

The Pansharpening module automatically generates pansharpened image products from a coincidently captured satellite or aerial imagery. In some cases, it is required that the images are orthorectified and co-registered before being processed.

The process consists of creating a single image product for each multispectral-panchromatic image pair, by fusing together the high-spectral resolution multispectral image with the high-spatial resolution panchromatic image.

Figure: Comparison of raw resolution multispectral image (left) and pansharpened image (right)

The Pansharpening module supports processing using GPUs and multi-core processors.

Mosaic from Orthos

The Mosaic from Ortho workflow combines multiple GXL processes to generate a final, full resolution mosaic. This workflow first calls the Mosaic Preparation algorithm to calculate color balancing coefficients and generate cutlines, followed by the Mosaic Generation process, which creates the full resolution mosaic. All of the parameters for both processes are setup at the beginning and the algorithms are called in sequence. This workflow requires that orthorectified images are provided as an input.

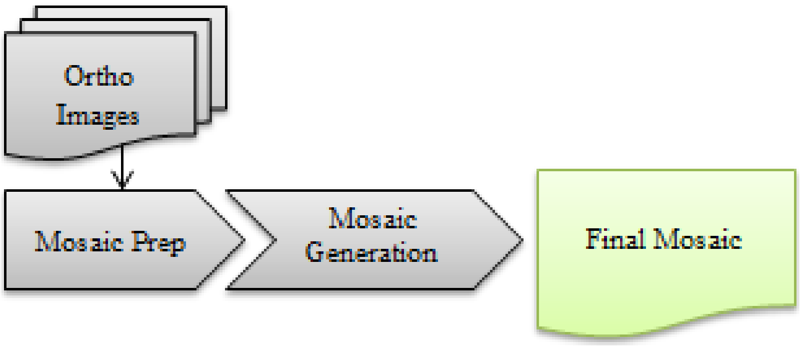


Figure: Flowchart that illustrates the Mosaic from Ortho workflow

Mosaic Updating

Overview of Workflow

The Mosaic Update workflow provides users with a means to update existing mosaics with new imagery. This is ideal for filling holes (no data) in existing mosaics or updating areas of the mosaic with improved scenes (i.e. replacing images with clouds, haze or seasonal differences).

The user is required to provide the location of the existing mosaic (or directory with the mosaic tiles) and the location of the new ortho-images that are to be added to the existing mosaic. The remaining parameters and process flow is the identical to that of the workflow used to generate the original mosaic.

Mosaic Update Preparation

The Mosaic Update Preparation process will calculate the color balancing statistics, generate seamlines (cutlines) and determine the sorting order of the new image or images being added to the existing mosaic. The new images being added to the mosaic will be adjusted so that they blend well with the existing mosaic.

Mosaic Update Generation

The Mosaic Update Generation process is responsible for updating the full resolution mosaic with the new imagery and applying the color balancing and seamlines (cutlines) calculated in the Mosaic Update Preparation algorithm.

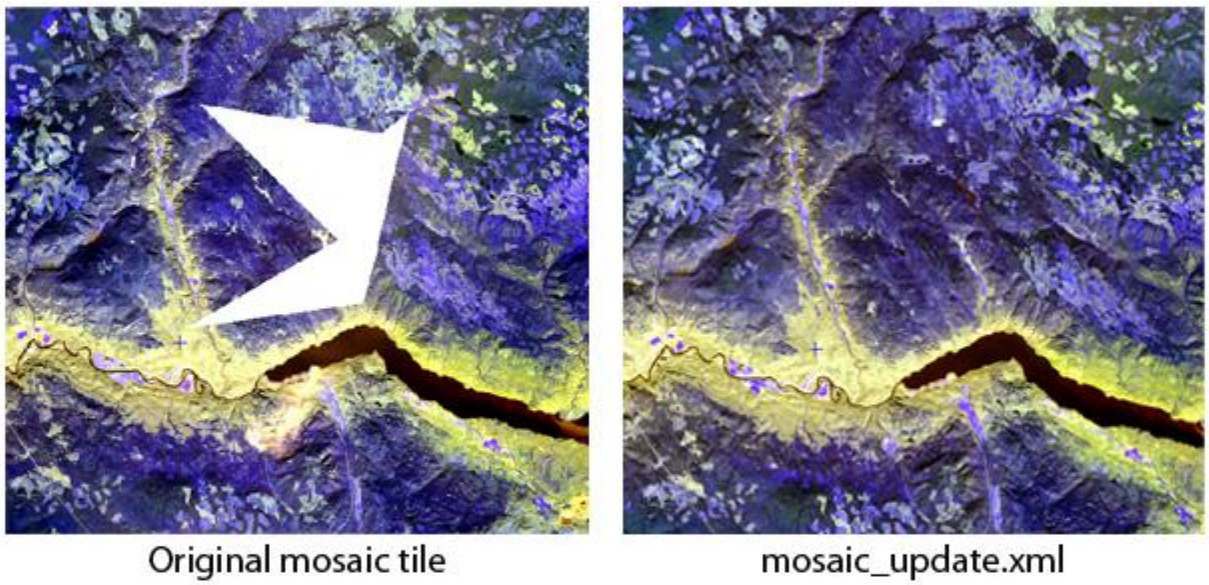


Figure: Original Mosaic with no-data hole on the left, updated mosaic on the right

Data Transformation

The Data Transformation workflow provides the capability to reproject, resample and or export a batch of raster or vector data. The workflow will crawl the input directory for all valid input rasters and vectors that match the search mask (e.g. *.tif) and then perform any combination of the following:

- Export the input data to a different file format
- Reproject from one projection to another projection
- Resample to a new resolution (rasters only)

Image Enhancement

This workflow will apply a permanent enhancement to an image or batch of images. One of six (6) optional histogram stretches can be applied to a batch of images to improve contrast, brightness and create a more aesthetically pleasing image. The enhanced values are then permanently written to the image pixels in the output image files. The six (6) enhancement options are: Histogram Equalization, Histogram Normalization, Histogram Infrequency Brightening, Adaptive Enhancement, Reference Image and Existing Look-up Table (LUT).

Image Tiling

This process will divide an image into equal tiles, defined by the number of tiles set by the user. The user can optionally specify an overlap amount in pixels, which will be applied to all tiles. Only tiles along the left and bottom edges may differ in size, depending on whether or not the image can be divided equally or not.

Mosaic Clip AOI

This workflow clips a mosaic, mosaic tiles or ortho-images to an exact area of interest (AOI), defined by the boundary of a vector polygon. The workflow accepts complex irregular polygons as inputs and will cut the image to the exact outline of the polygon. This is often used for country-wide mosaics where the mosaic is cut along the national borders or based on other political boundaries.

Figure: 'Cookie Cutter' approach to clip a country-wide mosaic of North Korea based on a vector polygon defining North Korea's national borders

Merge Multiple Sets of DSM/DTMs

This process takes a set of tiled DEMs, which may be perfectly abutting or have overlap and merges them together into a single DEM file. The GXL operator points to a folder that contains all of the DEM tiles that are to be merged together. The operator can optionally use a wildcard to filter the input files in a given directory.

GCP Reference Image Preparation

The GCP Reference Image Preparation workflow is most commonly used when multiple reference images are provided (i.e. mosaic tiles, ortho-images, etc.). This workflow scans a folder for all valid reference images (based on a wildcard filter) and proceeds to perform the following tasks:

1. Generates overviews for each reference image, which will improve processing times when running the GCP collection module
2. Creates an index file, which the GXL can use during the GCP collection process in order to quickly find which reference images overlap a given input image
3. Horizontal accuracy is set, which defines how much freedom the GXL has to refine the position of the GCPs in order to construct the best statistical model
4. Optionally, search for candidate GCPs for stereo GCP collection

Image Co-registration

This workflow is used to automatically co-register a stack of imagery. This is most commonly used to provide sub-pixel alignment between images captured over the same area, but at different dates or times (temporal stack). This process is required before temporal change detection can be performed accurately.

The process uses a reference image to collect GCPs on the first image in the stack, orthorectifies that image and then uses it as a reference to collect GCPs for the remaining images in the stack. This workflow supports rational function model, rigorous model and file georeferencing.

DEM/DSM Production

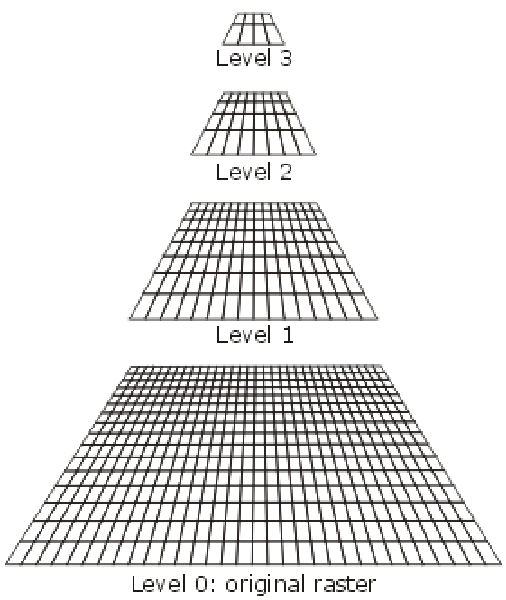
The DEM/DSM Production workflow searches for valid images that will be used to generate stereo pairs. Qualified stereo pairs are then processed in a series of child jobs, one for each pair of stereo images. Each job first reprojects the stereo pair so that both images have a common orientation. The reprojected stereo images become a pair of epipolar images. The job then extracts a DTM from the epipolar pair and generates an epipolar DEM. Using epipolar images increases the speed of the correlation process and reduces the possibility of incorrect matches. Finally, all generated epipolar DEMs are then processed by a single DEM Geocoded Creation job, which reprojects all epipolar DEMs and merges them into a single geocoded DEM.

Pyramid

The Pyramid module creates image pyramid layers (raster overviews) for one or more raster images.

Pyramid layers are rasters derived from the original raster, but reduced in size and resolution to improve performance when you zoom out of the raster. Smaller and lower-resolution rasters display faster and require less storage space; however, in the process, detail is reduced. The number of levels that can be created depends on the original size of the raster.

The following image shows an example of pyramid levels.



GXL users should create pyramids for all reference data required for GCP collection, including reference images and digital elevation models (DEM). Pyramids increase the performance of GCP collection and other operations in GXL.

Airphoto Ingest

Airphoto Ingest is the process of importing all aerial imagery from an input folder into the GXL's working format (.pix), then using the information in the Exterior Orientation (EO) file and camera calibration parameters (i.e. focal length, etc.) to calculate the initial georeferencing for each image. This step is required for subsequent aerial image processes, such as DEM Extraction and orthorectification.

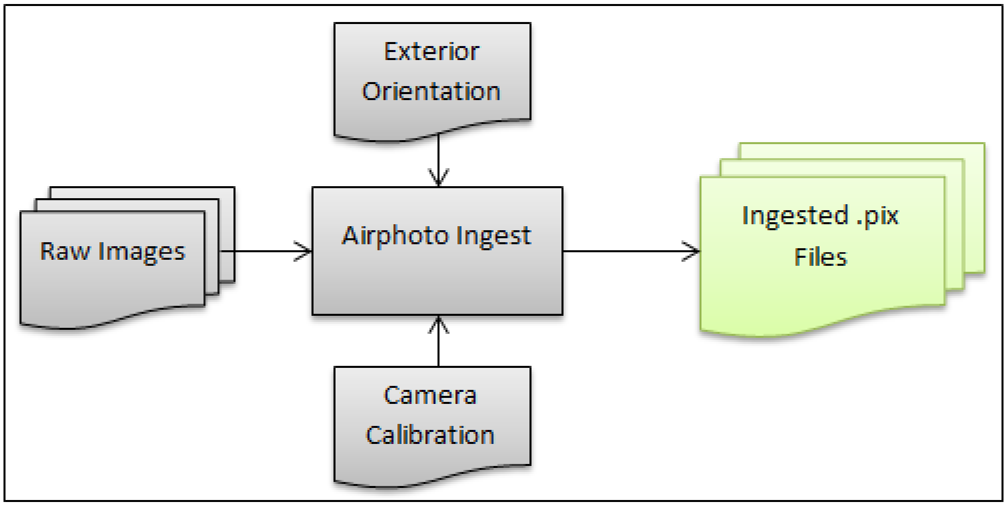


Figure: Airphoto Ingest workflow

The GXL Airphoto Ingest process creates link pix files by default. The link pix files contain the required file format and store the math model and georeferencing segment necessary for additional photogrammetric processing. The link files are unique, because they do not contain any imagery in them, but rather link back to the raw images. This allows them to be generated in a fraction of the time it takes to generate a regular pix file.

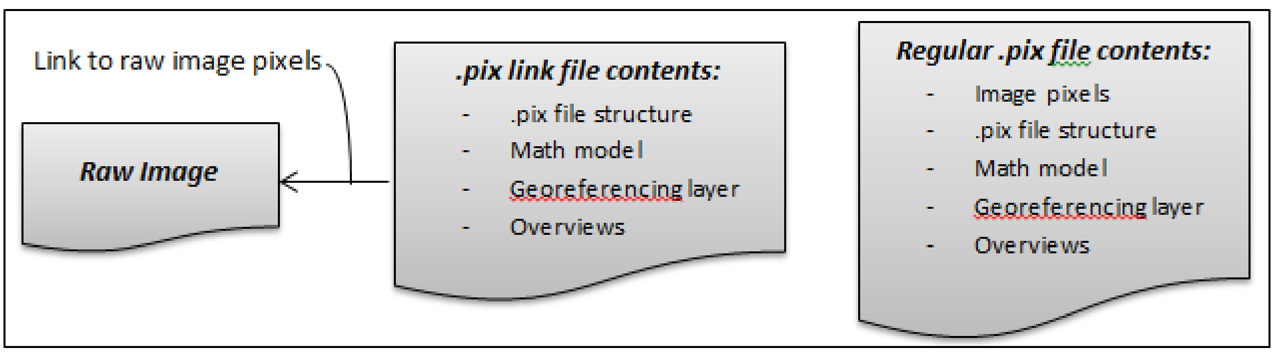


Figure: Comparison of .pix link file to a regular file

Airphoto Ingest for AT

The Airphoto Ingest for AT workflow prepares the input data for optimal processing performance and simple interaction with the Quality Assurance (QA) tools, such as OrthoEngine (OE).

This workflow produces a single OE Project (PRJ) and potentially outputs PIX files. The OE PRJ file contains the imported Exterior Orientation and the camera calibration information, and the output PIX files are created if the input files do not have pyramids.

Some of the advantages of the output files are that they can be used as input into the GCP Collection and Bundle Adjustment workflows to improve the accuracy of the geometric model.

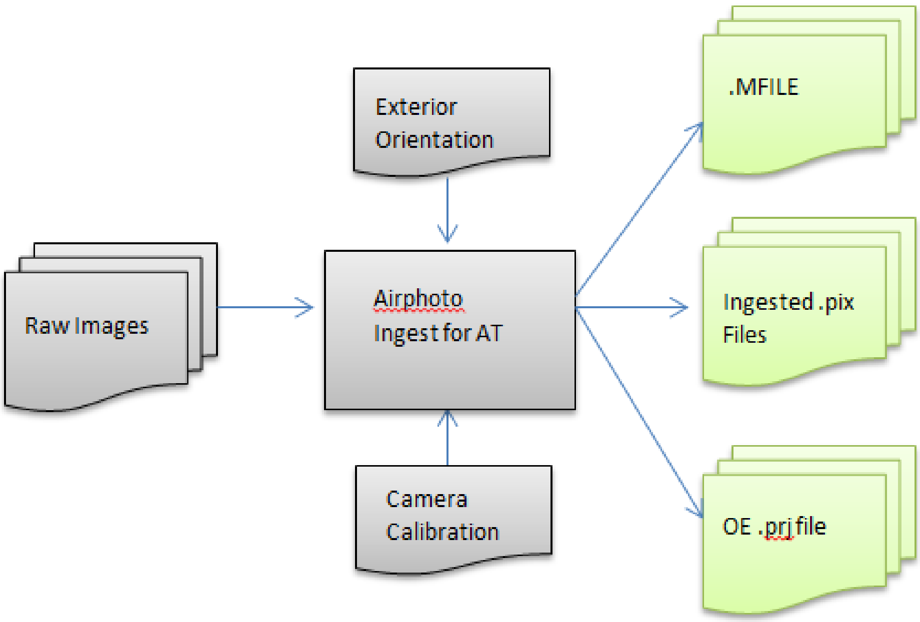


Figure: Flowchart that demonstrates the Airphoto Ingest for AT workflow

Airphoto Ingest for ADS

The ADS Ingest process generates an ADS math model for Leica ADS40/80/100 level 1 data into the PCIDSK format. With respect to each data product, the process is capable of importing the multispectral, panchromatic, and pansharpened (raw) images.

The Airphoto Ingest for ADS process allows for a variety of actions to take place, such as the ingesting of the nominal math model provided with the Level 1 sensor data (orbital model, RPC model, etc.), and also setting default metadata to the ingested PCIDSK file.

Furthermore, this process also automatically generates an OrthoEngine project file for each scene that was successfully ingested. To facilitate QA processes, it also generates a single OrthoEngine project file that includes all processed scenes. The merged file, OEProject.prj, is located in the specified output directory.

Airphoto Ingest and Orthorectification

The Airphoto Ingest and Orthorectification workflow first imports aerial imagery from a frame-based airborne sensor into the GXL system, creating a geometric math model from the Exterior Orientation (EO), camera calibration parameters (i.e. focal length, etc.), and calculates the initial georeferencing. Secondly, the orthorectification process is performed to correct distortions in the input image using a math model and digital elevation model.

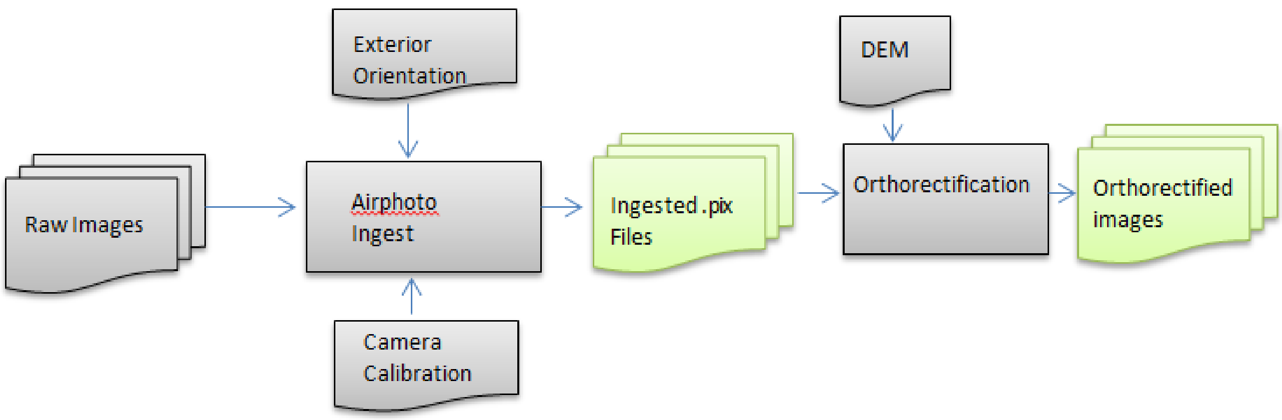


Figure: Flowchart of Aerial Ingest and Orthorectification workflow

Aerial GCP Collection & Refinement

GCPs are required as inputs into the GXL's Aerial Triangulation (AT) solution, specifically, the Bundle Adjustment process. GCPs register a location on the image to a coordinate on the ground, which is a requirement for photogrammetric processes, such as, DEM extraction and orthorectification. Automatic GCP collection is accomplished by using an image correlator to automatically find and place points on common features in the input (uncorrected) image and the accurate control source, a second algorithm is then launched to refine and remove bad GCPs based on statistical accuracy measurements (RMSE, residuals, etc.)

Automatic Ground Control Point (GCP) collection is a relatively new concept for digital aerial image projects. Until recently, these projects have required that GCPs be collected on the ground using precision survey (GPS) on easily discernable features. Operators were then required to manually add the GCP points to the Aerial Triangulation project. Due to the high resolution of aerial images, finding reference imagery for automatic GCP collection via image correlation was not possible. However, this is quickly changing as many regions have been previously surveyed via aerial vehicles. These areas often require updating every few months or years. As such, it is becoming possible for processing groups to obtain accurate reference imagery with an adequate resolution for automatic GCP collection. Automatic GCP collection can save time and improve results by allowing more GCP points to be added to a project than is possible through manual methods.

Aerial Orthorectification

Orthorectification is an essential process to any photogrammetric project because, once performed, features in the image can be related to their actual locations on Earth. The orthorectification Airphoto workflow in GXL scans the source folder for multispectral and panchromatic image files and creates an orthorectification job for each image pair. The process automatically orthorectifies and corrects airphoto scenes that contain a valid math-model segment.

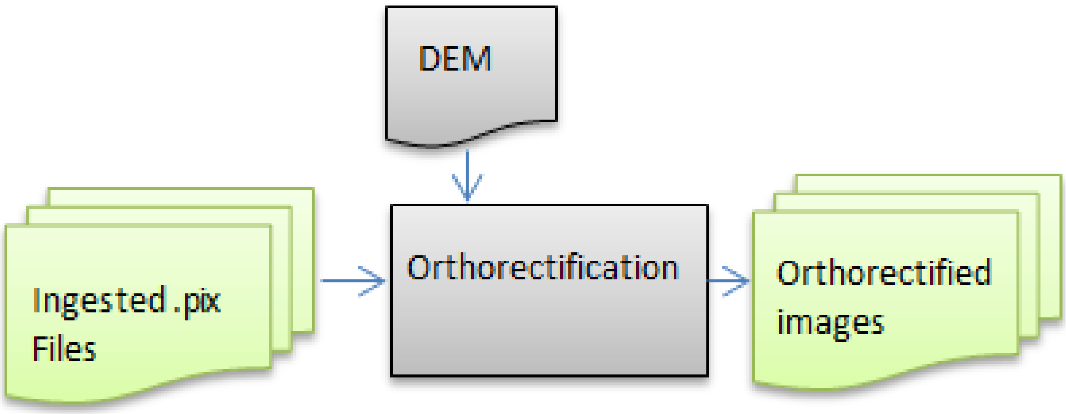


Figure: Flowchart that demonstrates the airphoto orthorectification workflow

True Ortho

The true orthorectification process corrects output orthorectified images for geometric distortions due to sensor tilt, ground surface relief, and above ground objects, such as buildings and bridges. Vector building models are required as an input to produce smooth rooflines and to assist in the production of a fully top-down mosaic without building lean.

The true ortho process compensates for occluded areas in each ortho image from adjacent overlapping images. Objects are shown in their actual planimetric locations on Earth and provide a means for taking accurate measurements.

Figure: Comparison of standard ortho with building lean (left) and true-ortho with reconstructed nadir view of all buildings (right)

Airphoto Bundle Adjustment

The Airphoto Bundle Adjustment workflow consists of simultaneously refining the geometric model of the images in the project in order to improve the geometry of the entire project. The process involves collecting matching points in two or more images, known as Tie Points, which assist in aligning overlapping images. It is important to ensure that accurate GCP collection has been performed prior to this process as it helps with the image correlation during tie point collection.

The GCPs and tie points are used in the computation of the block bundle adjustment and are critical for improving the overall model accuracy of aerial images, which is a prerequisite for DEM Extraction and Orthorectification.

Mosaic from Raw Airphoto

The Mosaic from Raw Airphoto workflow combines multiple GXL processes to complete an end-to-end airphoto workflow. This workflow first calls the Airphoto Ingest algorithm, followed by the Orthorectification Airphoto process and it finishes by running the Mosaic Preparation and Mosaic Generation processes. All of the parameters are setup at the beginning of the process and the different algorithms are called in sequence, creating an output final mosaic. This workflow requires that Level 3 airphoto images are provided with an accurate exterior orientation (EO) file, camera calibration model and DEM.

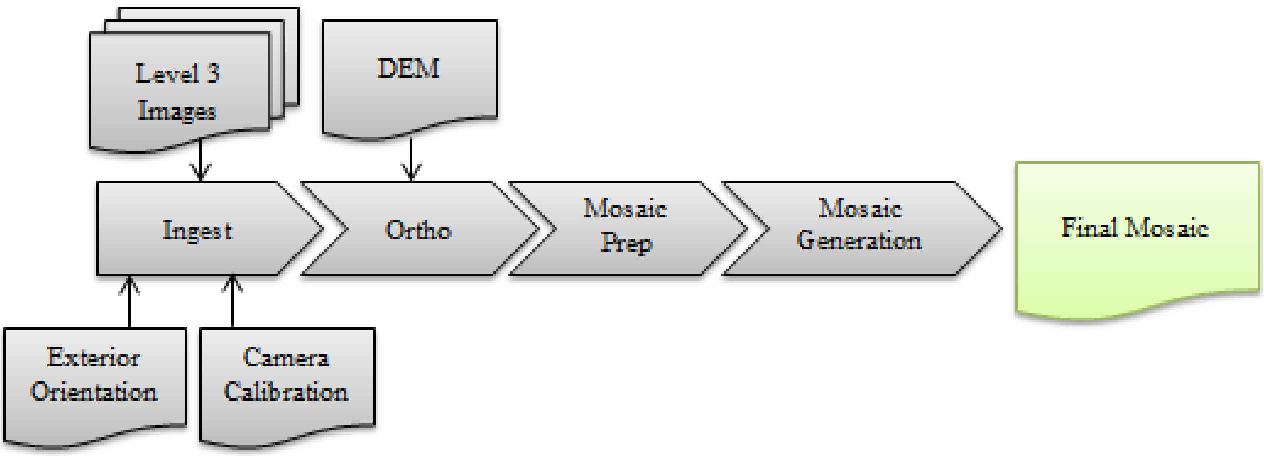


Figure: Flowchart for the Mosaic from Raw Airphoto GXL workflow

Mosaic from Raw Imagery

The Mosaic from Raw Scenes workflow imports satellite imagery into the GXL system for running a series of jobs and produces an output mosaic.

The process involves data ingestion, where the imagery is imported into the GXL system, followed by the automatically Ground Control Collection (GCP) algorithm. It is then optional to run the bundle adjustment, which is utilized to collect tie points and automatically perform a block bundle adjustment on all the images in the project. The pansharpening process is also optional and depending on the sensor, can be run before or after orthorectification. The pansharpening process produces a single high-resolution color image from fusing the panchromatic and multispectral image pairs. The Orthorectification process corrects the image distortion using the GCPs, Tie Points and DEM, ensuring that pixels in the image or assigned the correct geographic coordinates. Finally, the mosaicking workflow is launched, which consists of running the Mosaic Preparation process to perform color balancing and cutline generation, followed by the Mosaic Generation process, which generates the final resolution mosaic.

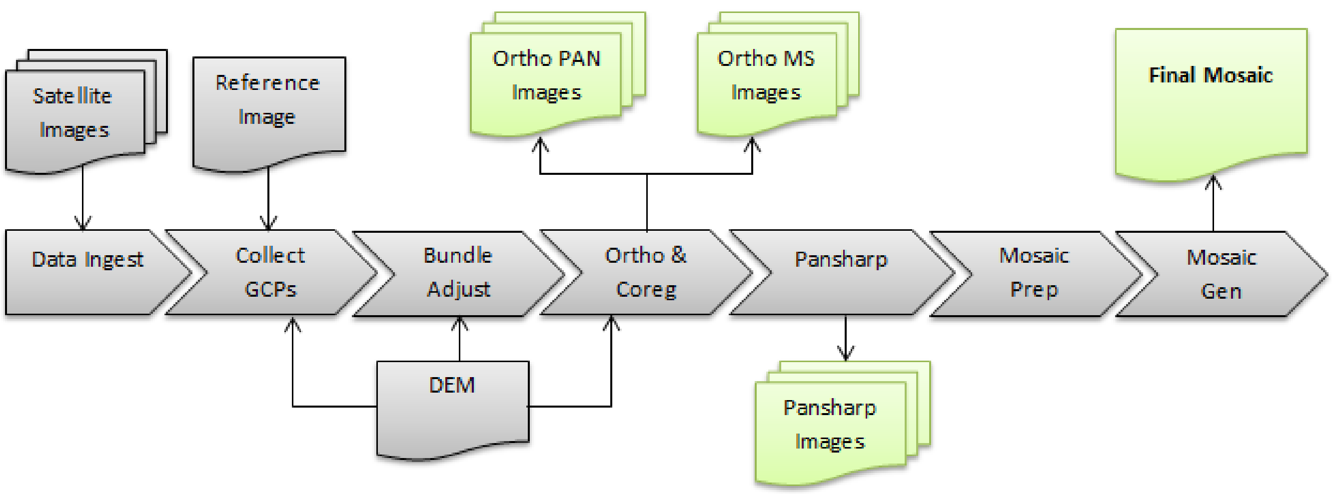


Figure: Flowchart for the Mosaic from Raw Imagery GXL workflow

Data Ingest

The Data Ingest process scans the source folder (directory) for raw images and spawns a data-ingest job for each scene found. This process consists of ingesting the nominal math model provided with the raw data (orbital model, RPC model, etc.) and setting default metadata to the ingested PCIDSK file.

Data Ingest and GCP Collection

The Data Ingest and GCP Collection workflow automatically imports raw satellite imagery into the PCIDSK format and collects Ground control points (GCPs) from a variety of optional sources.

Blue-Band Simulation

SPOTBLUE generates a simulated blue band from an input SPOT multispectral image and outputs either a natural color image (RGB) or a single synthesized blue band. The input image must contain a SPOT image in a GDB-supported format. Multispectral scenes from SPOT satellites 1 to 5 are supported. Both raw and orthorectified images can be processed. The output file will contain the red and green bands transferred from the input image to channels 1 and 2, and the simulated blue band in channel 3.

Figure: Natural color image (RGB) outputted from SPOTBLUE

Satellite GCP Collection & Refinement

GCP Collection

Automatic Ground Control Point (GCP) collection is a key component for correcting imagery in an automated batch workflow. GCPs are required as inputs into the orthorectification module for satellite imagery. Automatic GCP collection is accomplished by using an image correlator to automatically find and place points on common features in the input (uncorrected) image and the accurate control source. The control source is most commonly a single accurate image (ortho-mosaic), but can also be multiple ortho images, road vector layers, lake polygons or a chip database.

Automatic GCP Refinement

The GCPs that are automatically collected are then subjected to automatic blunder detection and removal. By default, the GXL system will iteratively remove the worst GCPs, based on residual errors, until the root-mean-square-error (RMSE) falls below an acceptable threshold (i.e. 0.5 pixel). Other methods also exist for performing automatic GCP blunder detection and removal, which gives the operator a lot of flexibility when determining the best method to automatically detect/remove GCP blunders.

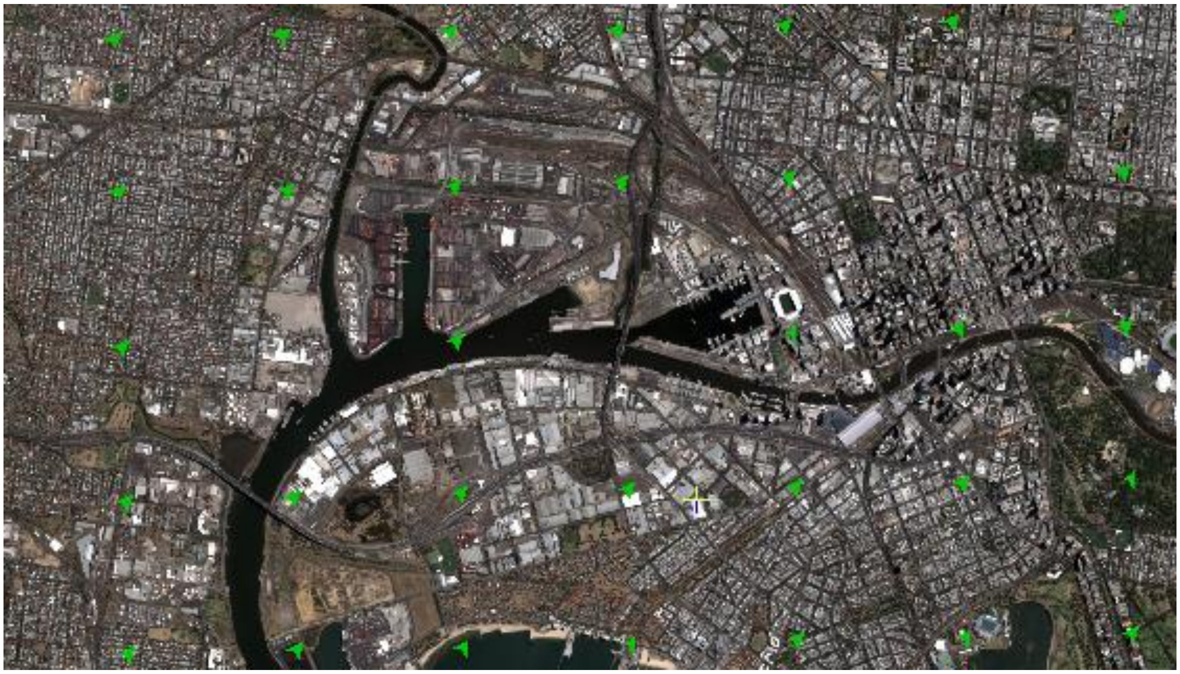


Figure: Example of sub-pixel GCPs collected in an even grid layout throughout the input Pleiades image

GCP Collection and Refinement of MS and PAN Pairs

For Satellite datasets that come with Multispectral and panchromatic pairs, the GCPs are only collected on the panchromatic images. The Satellite Orthorectification process will collect GCPs on the multispectral image in order to co-register the pair. This method removes redundant processing and improves the registration of the multispectral and panchromatic pairs for pansharpening.

Satellite Bundle Adjustment

The Bundle adjustment workflow consists of simultaneously refining the geometric model of the images in the project in order to improve the geometry of the entire project.

The process involves collecting matching points in two or more images, known as Tie Points, which assist in identifying how the images in the project relate to each other.

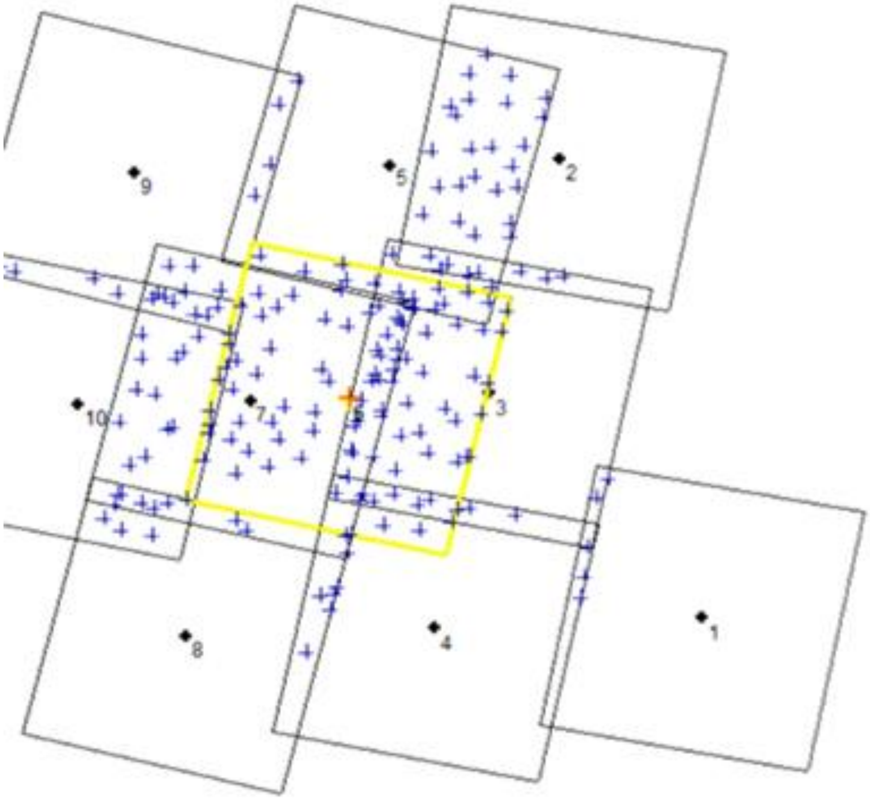


Figure: example of position of tie points on image frames. Tie points are collected in the overlap region of two or more input images

It is important to ensure that accurate GCP collection has been performed as this process helps with the image correlation. GCPs' image pixel and line locations in the raw image are identified and corresponded to features in a georeferenced image.

The GCPs and tie points are used in the computation of the block bundle adjustment and are critical for improving the overall model accuracy.

Satellite Orthorectification

Orthorectification is an essential process to any photogrammetric project because, once performed, features in the image can be related to their actual locations on Earth. The Orthorectification process in the GXL scans the source folder for multispectral and panchromatic image files and creates an orthorectification job for each image pair. The process automatically orthorectifies and corrects image scenes that contain a valid math-model segment. When a multispectral and panchromatic pair are found, the GXL first orthorectifies the panchromatic image and then uses it as a reference to collect GCPs for the multispectral image. This process ensures a sub pixel alignment between the panchromatic and multispectral pairs.

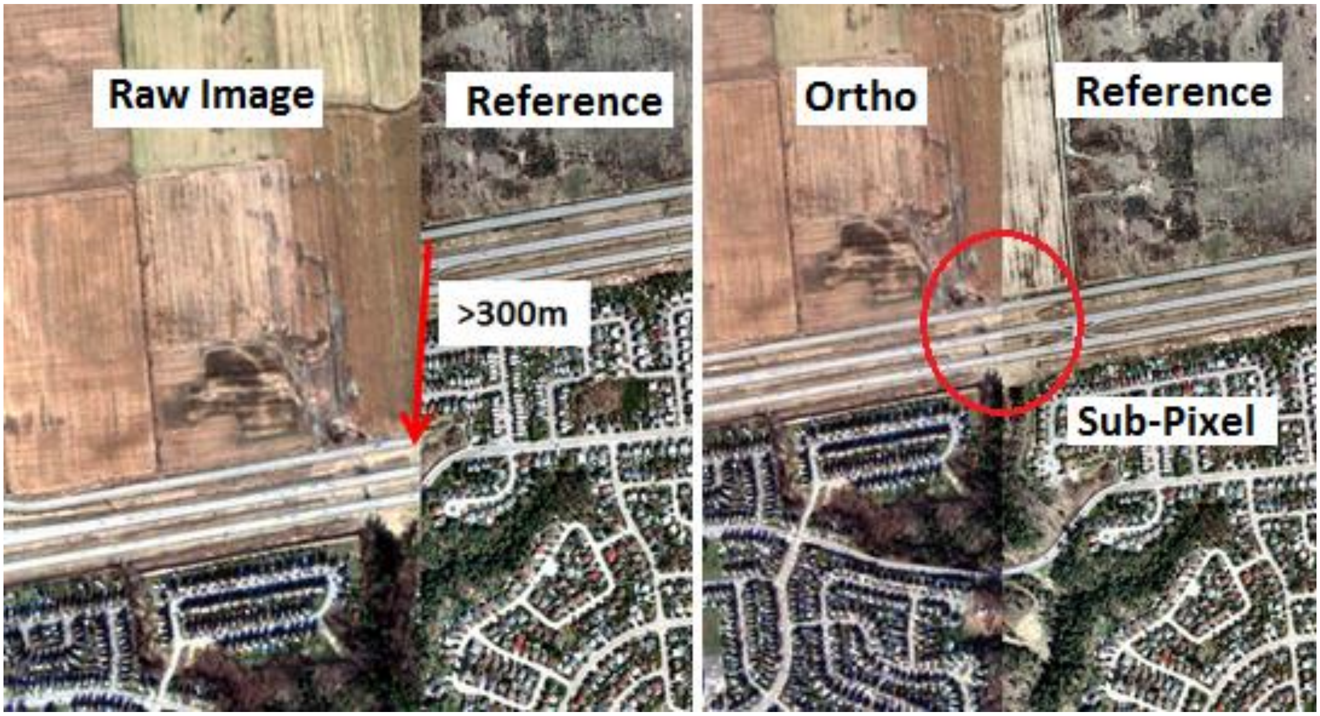


Figure: Comparison of the positional accuracy of a Kompsat-3 image before orthorectification (left) and after orthorectification (right)

Cloud Masking

Automatically detects and masks clouds using a vector polygon. Cloud masking is accomplished using a hybrid approach that combines a cloud seeding technique with spectral and texture measures to ensure that all obstructive clouds are masked in their entirety (no cloud rings), while also minimizing false positives (masking of non-cloud features).

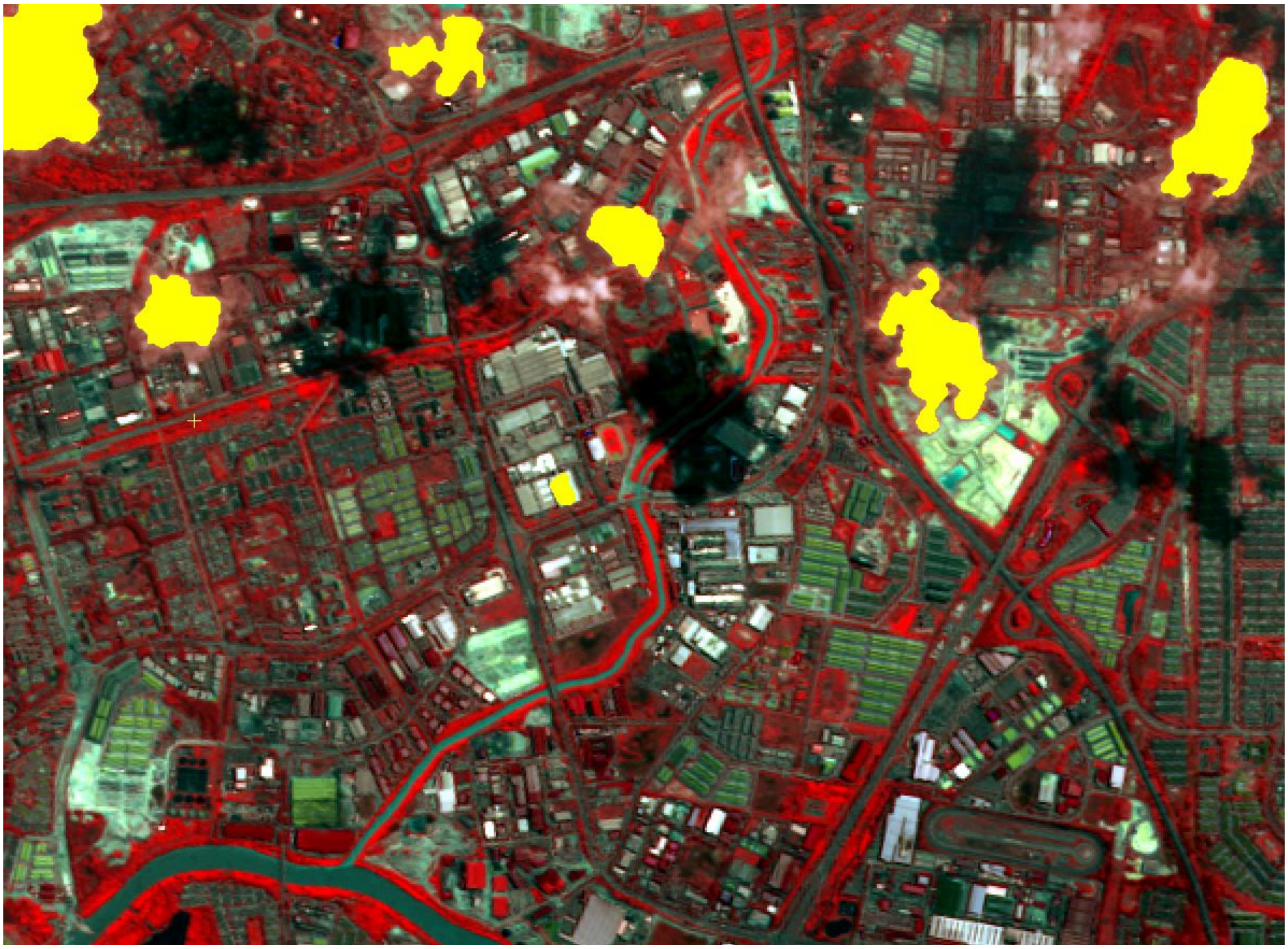


Figure: Example of Automatic Cloud Detection

Haze Removal

Automatically detect and remove (minimize) the effect of haze on a multispectral image. This module calculates the influence of haze on a given pixel using an enhanced haze optimized transform (HOT) image. The additive effects of haze is then removed based on a calculated delta value, which subtracts the backscatter of haze in a given band.

Depending on the type of haze it scatters visible in either a Mie or Non-selective manner. As such, each band is treated independently of one another.

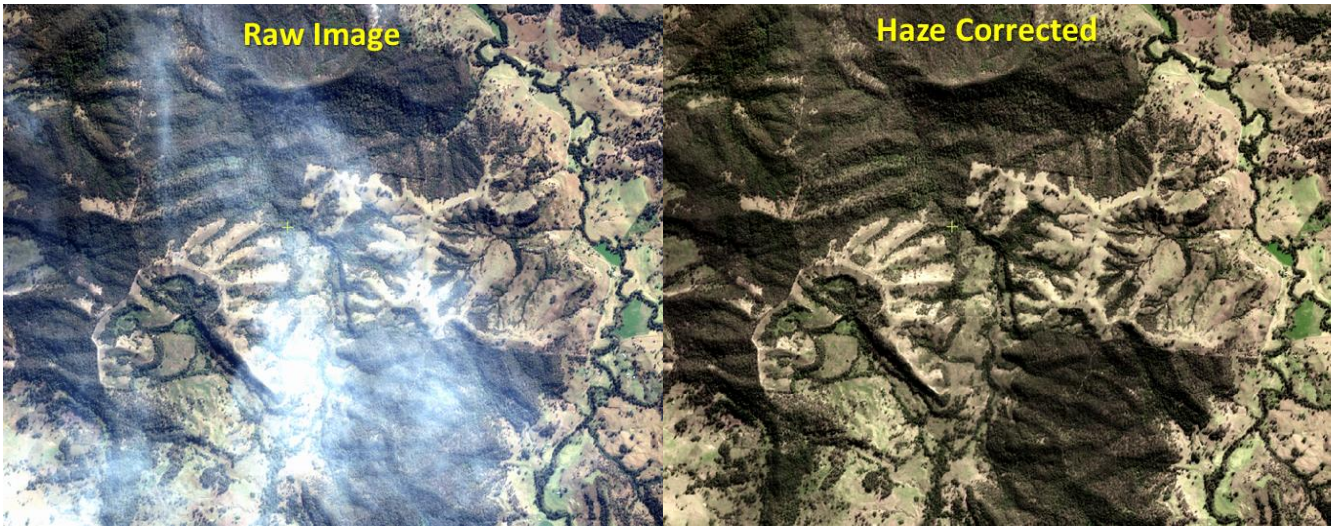


Figure: Example of before and after Haze Removal

Water Colorization

The Water Colorization process is utilized to assign a uniform color to all the water bodies in an image or mosaic tile. The algorithm uses polygons that define water bodies stored in a specified mask vector file and a pixel value parameter that defines the color assigned to the pixels beneath the water body mask polygons. For each image found in the specified input directory, the Water Colorization process creates a new image in which all of the water pixels are of the same color.

GXL SAR Package

The PCI GeoImaging Accelerator SAR package is a powerful and specialized add-on that brings efficiency, distributed processing techniques and automated workflows to the GXL for the production of high-quality, accurate, SAR image correction and analysis.

The GXL SAR Modules are typically chained together to create general workflows for the following:

- Ingesting SAR imagery into the GXL for processing
- Orthorectifying the SAR imagery
- Applying polarimetric parameters for further analysis
- Visualize SAR data layers
- Monitoring changes over time with SAR change detection

Outside the typical workflows, there are variations in how the modules can be used. Not all data must be processed through all the modules, and the order in which the data is processed may vary. Note, however, that all input imagery should be imported by the SAR Data Ingest module before data can be processed further.

Package Prerequisites

GXL SAR capabilities require an installation of the GXL Satellite system, and are included in an add-on GXL SAR package

Supported Formats

Supported Sensors

GXL-S supports the following sensors*:

- RADARSAT-2
- Cosmo-SkyMed
- KOMPSAT-5
- TerraSAR-X

*For complex-valued imagery, GXL converts the input dataset into PCIDSK Complex Imagery format, required for processing by SAR modules.
For a complete list of look/level/mode combinations, please contact PCI Geomatics

Supported Polarimetric Metadata

In addition to image and segment data, the polarimetric algorithm extracts metadata related to POLSAR processing and writes them to the output file. There are two levels of metadata: File-level and channel-level.

The file-level POLSAR metadata contains information that relates to the data set as a whole.

The file-level POLSAR metadata includes the following:

- **SensorModelName:** Description of the sensor; for example RADARSAT-2
- **SensorType:** Always SAR
- **Product_Type:** Imported data product; for example, SLC for RADARSAT-2 or ASA_APM_1P for ASAR
- **Matrix_Type:** Matrix stored on file; for example, s4c or c2r
- **Acquisition_Type:** Optional detailed information related to the image; for example, Standard Quad Polarization for RADARSAT-2 or Alternating Polarization for ASAR
- **SAR_Calibration:** Physical quantity represented by pixel values; for example, $\sigma°$
- **MicrowaveBand:** SAR band of the image; for example C or X
- **Polarizations:** List of polarizations of the data in the image, for example, HH, HV. Each polarization is represented by two characters. The first character specifies the transmit polarization, the second specifies the receive polarization
- **NumLooks:** Nominal number of SAR looks for each pixel
- **NumRangeLooks:** Number of SAR looks, in range direction, for slant-range images
- **NumAzimuthLooks:** Number of SAR looks, in azimuth direction, for slant-range images

The channel-level metadata for polarimetric data identifies the matrix element stored in the channel:

- **Matrix_Element:** Describes the element's row and column position within the matrix

For example, for a data set stored as an s4c matrix, the first channel is identified as _1_1 and the second channel is identified as _1_2.

GXL SAR Jobs

Data Ingest SAR module

The Data Ingest SAR module allows you to automatically import raw satellite sensor data into the PCIDSK format. This is a mandatory step in the GXL workflows, and allows several actions to take place, including:

- Ingesting the nominal math model provided with the raw SAR data
- Setting default metadata to the ingested PCIDSK file

For complex imagery, this module converts the input data set into PCIDSK Complex Imagery format, required for processing by other SAR modules.

The Data Ingest SAR module begins to search the scene directory to identify all raw scenes to be imported to PCIDSK format. For each raw scene it encounters, the module creates a child job and submits the child job.

Orthorectification SAR module

Orthorectification is an essential process in any photogrammetric project because, once performed, it allows you to relate features to their actual locations on Earth, and provides a means of taking accurate spatial measurements.

Orthorectification is the process of using a rigorous math model and a digital elevation model (DEM) to correct distortions in raw images. The quality of the orthorectified image is directly related to the quality of the rigorous math model and the digital elevation model. A poorly computed math model, an inaccurate DEM, or an incorrect relationship between the two will cause errors in the orthorectified images. The Orthorectification SAR module automatically orthorectifies/corrects image scenes that contain a valid math model segment.

SAR Change Detection module

The SAR Change Detection module automatically detects changes between two SAR images ('new' and 'reference'). The two input images must overlap, align at the pixel level, and have the same spatial resolution. The two input files should be radiometrically calibrated to the same units (that is, one of sigma, beta, or gamma). The same number of channels must be processed from both the input test and reference images.

The output area will be the spatial intersection of the two input images.

Polarimetric Parameters module

The Polarimetric Parameters module generates a number of radar parameters from fully polarimetric data. The multi-parameter output is automatically orthorectified to facilitate change analysis.

Supported Satellite Sensors

Sensor	Ortho	Pansharp	DEM Extraction	ATCOR	Notes
ALOS-Prism	•		•		Level 1A, 1B1, 1B2R (Use level 1A or 1B1 for greatest accuracy)
Cartosat-1	•		•	•	L1 (radiometrically corrected)
CBERS 2B	•	•			
EROS A/B	•		•		Level 1, 1A standard
Formosat	•			•	Level 1, 1A standard
Gaofen-1	•	•		•	Level 1, 1A standard
Gaofen-2	•	•		•	Level 1, 1A standard
GeoEye-1	•	•	•	•	Standard GC Level 1, or Standard 2A/LV2A
HJ	•	•			Level 1 and Level 2
IKONOS	•	•	•	•	GEO product in GEOTiff, NITF format with or without RPCs
Kazeosat-1	•	•			Level 1A
KOMPSAT-2	•		•	•	Level 1R and 1G, level 1R gives highest accuracy
KOMPSAT-3	•	•	•	•	Level 1R and 1G, level 1R gives highest accuracy
LANDSAT 5 TM	•			•	LMTX Data with .txt and .tif files
LANDSAT 7 ETM+Data	•	•		•	LMTX data with .txt and .tif files, L1G data, and FST data
LANDSAT 8	•	•		•	LMTX Data with .txt and .tif files
OrbView-3	•			•	OrbView Basic product
Pleiades	•	•	•	•	Level 1A and Level 2
QuickBird	•	•	•	•	Basic 1B format in TIFF and NITF, Ortho-ready standard in TIFF and NITF
RapidEye	•			•	Level 1B (Basic)
ShiJian 9A	•				
SPOT-5	•	•	•	•	
SPOT-6	•	•	•	•	
SPOT-7	•	•	•	•	
Thaichote	•	•			Level 1 / 1A
TH-01	•	•	•		Level 1A, 1B, 2, 3A, 3B
TripleSat	•	•			
WorldView-1	•		•		Level 1B and Ortho-ready standard
WorldView-2	•	•	•	•	Level 1B and Ortho-ready standard

Sensor	Ortho	Pansharp	DEM Extraction	ATCOR	Notes
WorldView-3	•	•	•	•	SWIR bands not support for ATCOR
Yaogan-14	•				
Yaogan-2	•				
Yaogan-8	•				
ZY1-02C	•	•			
ZY-3	•	•	•	•	

Supported Radar Sensors

Sensor	Ortho	Polarimetric	Notes
Cosmo-SkyMed	•	•	Level 1A (SCS) Level 1B (DGM) Level 1C/1D (Geocoded)
Kompsat-5	•	•	*Satrec Initiative Image Services (SIIS)* L1A Single-look complex L1B detected multi-looked L1C Geocoded L1D Terrain corrected
Radarsat-1	•		SGC (SAR Georeferenced Coarse Resolution) SGF (SAR Georeferenced Fine Resolution) SGX (SAR Georeferenced Extra Fine Resolution) SLC (Single Look Complex) SCN (ScanSAR Narrow Beam Product) SCW (ScanSAR Wide Beam Product)
Radarsat-2	•	•	SLC (Single Look Complex) SGF (SAR Georeferenced Fine, ScanSAR Narrow Beam, and ScanSAR Wide Beam) SGX (SAR Georeferenced Extra Fine) SGC (SAR Georeferenced Coarse) SSG (SAR Systematic Geocorrected) SPG (SAR Precision Geocorrected)
TerraSAR-X	•	•	*ASTRIUM Level 1B products* SSC_SM_D Single Look Slant Range Complex - Strip Map - Dual Polarized and Single Polarized SSC_HS_D Single Look Slant Range Complex - High-resolution Spotlight - Dual Polarized and Single Polarized SSC_SL_D Single Look Slant Range Complex – Spotlight - Dual Polarized and Single Polarized

Supported Airphoto Sensors

Sensor	Ortho	DEM Extraction	Notes
Applanix DSS	•	•	DEM extraction requires AT
Leica ADS	•		ADS-40, ADS-80 - Level 0 and Level 1 ADS-100 - Level 1 only
Microsoft UltraCam	•	•	DEM extraction requires AT
Z/I Imaging DMC	•	•	DEM extraction requires AT

IT architecture

GXL uses industry-standard, commercial, off-the-shelf (COTS) hardware, including all parts of the system. Acquiring COTS hardware from reputable manufacturers (for example, DELL, IBM, HP) offers several key benefits:

- Easy and quick acquisition of new, additional and replacement parts results in lower installation and maintenance costs.
- 24/7 on-site support from vendor means less hardware-related downtime.
- Alignment with larger IT industry means better systems integration and migration path within an organization.
- Industry standards mean smoother upgrade and longer product lifespan than custom-built components or systems.

In addition to the hardware standards, architecture standards are used for the multi-core (OpenMP) and GPU (CUDA) programming. The benefits to the users are:

- Guaranteed development roadmaps from the larger IT industry
- Smooth transitions to next-generation computing (for example, NVidia Fermi)
- Lower total cost of ownership
- Fast implementation of updated technology

GPU Technology

By moving to the GPU-based architecture employing NVidia GPUs, GXL software has gained remarkable speed and performance boosts. Graphical Processing Units are uniquely suited to complex mathematical transformations with greater speed and precision than traditional CPUs. PCI has witnessed exceptional performance improvements by taking advantage of modern, multi-core processor architecture and NVidia Graphical Processing Units (GPUs).

Hardware configuration for GXL

The following hardware configuration is suitable for GXL systems:

Desktop system

Operating system: Windows 7 Pro 64-bit or Windows 10 Pro 64-bit

CPU: CPU can be configured based on customer's needs

- Single 8, 10, 12 or 14 Core Intel Xeon 2.6GHz or better
- Dual 6-Core Intel Xeon 2.6GHz or better
- Dual 4-Core Intel Xeon 2.6GHz or better

Memory: 48GB or 64GB DDR4 RAM

Storage: 256GB Pro SSD for OS
1TB SSD for Temp/Scratch data

	4, 6, or 8TB 7200 Enterprise Class HDD (Input/Output data)
GPU:	Optional NVIDIA GPU graphics card

Rack-mount Example

The following is intended to be the 'base' hardware configuration for a GXL rackmount system, expandable with additional GPU or CPU processing nodes scalable up or down, depending on production throughput requirements. The hardware architecture would consist of the rack illustrated below.

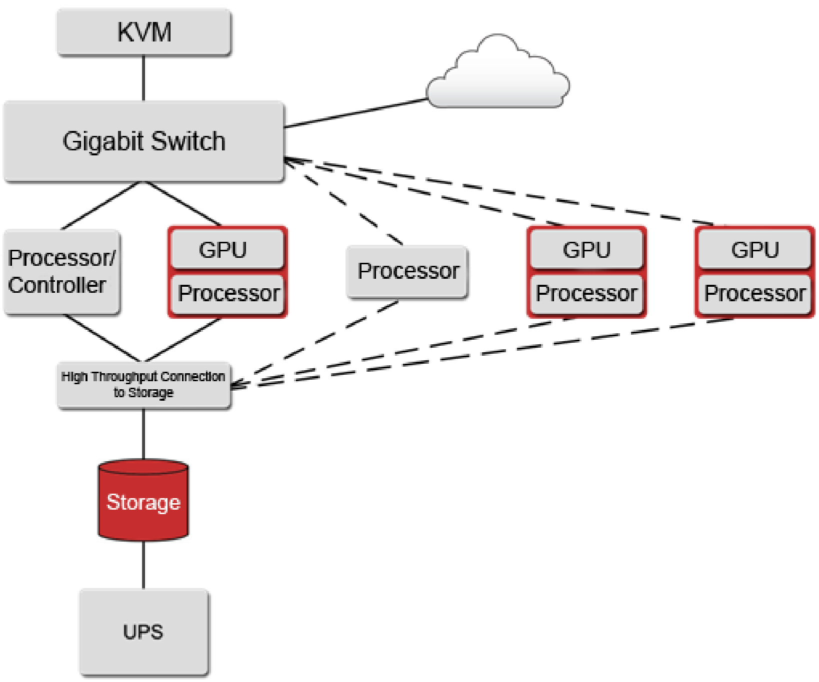


Figure: Rackmount hardware configuration for GXL

Component	Technical Specifications
KVM	KVM Console Switch with LCD and Keyboard
High Speed Switch	Gigabit Ethernet Managed Switch
Processor	1x 1U Intel Platform Single or Dual Socket Rackmount Server Intel Xeon 2.XGHz Six, Eight, Ten, Twelve, Fourteen, Sixteen-Core Processor Min 48GB of Memory Optional NVidia GPU Card or GPU Server Enterprise Level Hard Drive for Local Storage Microsoft or Linux (RedHat, CentOS, Suse) OS
SAN/NAS/Direct Attached	Sustained throughput of 80Mbit/sec minimum
UPS	1x Suitable Uninterruptible Power Supply

Physical architecture

This section describes a typical GXL hardware configuration. It is for illustrative purposes only; the final hardware configuration will be confirmed after review of the client production requirements. The figure below illustrates the typical deployment configuration of the GXL system.

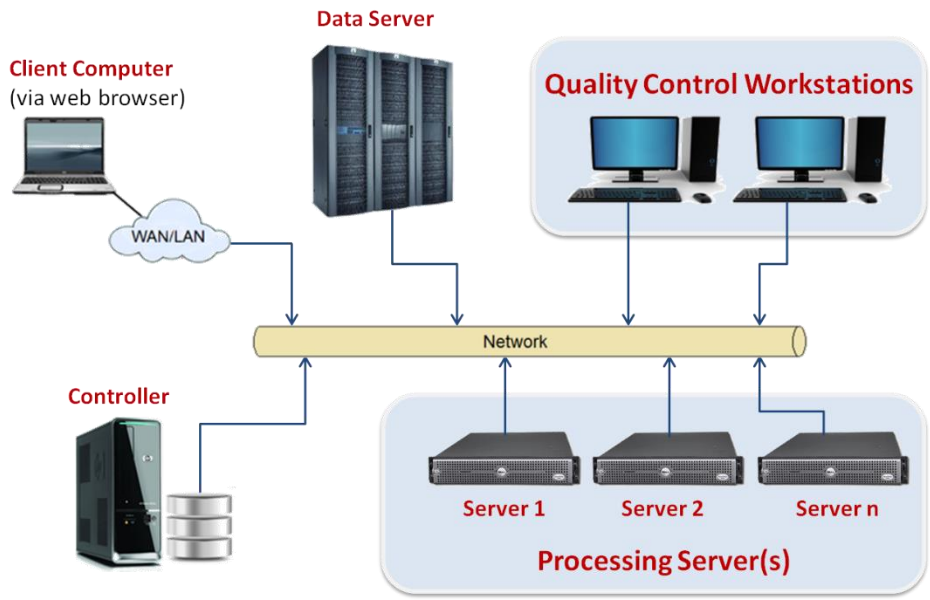


Figure: GXL Server physical architecture

Data server

The data server is the central storage area for the input scenes; it stores control data required by the system, output image products, and logging information. The data repository is file-based and does not include a database management system for the storage of vector and image data used.

Controller workstation

The Controller workstation initiates the automated modules in the workflow. The automated modules include Data Ingest, Orthorectification, Mosaic Preparation, and Mosaic Generation.

The Job Processing System is installed on the Controller and is the central control workstation for the processing servers.

Processing Servers (1, 2,…n)

The processing servers are used to execute a processing job, such as data ingestion, orthorectification, mosaic preparation, and mosaic generation. These processing servers poll a central Job Processing Server to determine if a job is available to process. For example, the Data Ingest module can specify a folder containing 100 scenes to ingest. This will create 100 data ingest jobs in the JPS, which then distributes the jobs over the processing servers for processing.

The number of processing servers deployed typically depends on the throughput requirements of the production system. This proposal contemplates the use of three processing nodes to build into the existing system the ability to handle ever increasing image processing requirements.

The GXL processing server is actually a collection of three processing nodes. Each processing node requires a runtime license. Depending on processing requirements (required throughput), more processing nodes may be added; these would subsequently require more runtime licenses.

Quality Control workstations

Quality Control workstations are typically used by operators for manual inspection of any intermediate and final products and will generally run PCI Geomatica.