UAS Applications: Disaster & Emergency Management

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ABSTRACT

Decision makers in emergency management agencies must be able to access large volumes of highly current geospatial information to effectively respond to disaster situations and ensure strong collaboration between agencies. Current photogrammetric solutions using manned aircraft for data acquisition and post-mission processing are limited in their ability to meet these requirements. The use of Unmanned Aerial System (UAS) technology during acquisition, combined with state-of-the-art techniques for automated data processing and delivery, promise the ability to meet the requirements of decision makers. This paper discusses a number of innovative components that form such a system: a modular image acquisition payload equipped with radio communications suitable for UAS missions, two strategies for accurate estimation of camera poses, a fully automated and real-time ortho-mosaic production system, and a collaborative web-based interface to distribute map information. This system will radically advance emergency response capabilities and help to save human lives by providing information and intelligence to disaster managers in a safe, timely, and critical manner.

INTRODUCTION

When a disaster threatens lives and livelihoods, emergency responders require large volumes of information about the situation in order to inform their decision making. This information must be delivered into the hands of decision makers at the speed of the disaster and with sufficient accuracy to enable correct analysis of the situation. Up-to-date visual images and other remotely sensed data are particularly important in planning the response as they allow quick analysis of the geospatial extents of the event as well as high detail of each affected region. Unfortunately, these data are currently costly to acquire, both in the time required before exploitation and monetary price, and may also pose a significant danger to the remote observer which, in the past, has typically been a manned aircraft. The only alternative currently available is satellite sensing; however, this type of data is not available for capture on demand, and can be affected by atmospheric conditions, such as cloud cover. The devastating Hurricane Katrina of August 2005 demonstrated the shortcomings of current geospatial information delivery systems for the disaster management task. A recent report produced by the US Government Accountability Office cited the long delay in assessing the situation and lack of coordination as two of the five most serious impediments to the disaster response [GAO 2006].

There are several key emergency response information requirements which are unaddressed by current systems. The first is a flexible, reliable, rapidly deployable and reasonably priced image acquisition system that does not place human life at risk in the hazardous situations surrounding ongoing disasters. The second is an automated data processing system that can rapidly transform raw image data into an accurate and correct geospatial image product to minimize delays in analysis introduced by the need for manual intervention. The final requirement is a collaborative data distribution system which makes the processed data available to decision makers across the globe as quickly as possible, and facilitates the coordination of response efforts.

UASs have strong potential to be a solution for disaster management image acquisition tasks, but they are not widely deployed in this role at present. Low cost UASs such as tactical class vehicles (described below) are a particularly good match for this problem due to their small size, low cost, flexibility in deployment and reasonable payload capacity. The extremely low cost and ease of deployment means that many unmanned craft can monitor a given region, leading to rapid coverage of the area and fast delivery of useful information to decision makers. Also, the ability of tactical UASs to launch from unprepared fields or even from roads makes them excellent candidates to deal with situations involving damage to traditional launching strips or remotely located situations.

This paper describes several recent innovations that have enabled the assembly of an end-to-end UAS-based disaster management system meeting the requirements stated above. **GIDE** - a UAS borne **G**eo-**I**ntelligent Collaborative Decision Support System for Real-Time **D**isaster and **E**mergency Management has been designed to change the face of disaster management information production. This system has been developed at GEOSYS Technology Solutions, together with its partners. With partial funding from Precarn Incorporated, GIDE is an ongoing research project (hence many results are still forthcoming). GEOSYS leads the project team and is responsible for integration and algorithm development. It is supported by a diverse team of partners, including Universal Wing Geophysics Corporation, which is responsible for providing and customizing their Thunderchild UAS platform for the project. The British Columbia Provincial Emergency Program participates in the project as an end-user and customer, helping to define requirements and project scope. Base Mapping Geomatic Services provides the project with high-resolution BC DIM image data. The final partner is the University of Calgary Positioning and Mobile Information Systems Group (PMIS), which develops and tests its Real-time Precise Point Positioning (RT-P3) software, and aids with integration.

Example Scenario

The principle of operation is best introduced by a representative use-case. Though it will be of much broader applicability (flood, hurricane, tornado, earthquake, industrial or terrorist disasters, for example), assume a wildfire is blazing in a British Columbia forest, and is rapidly encroaching on a human settlement. The scenario is illustrated in Figure 1. First, a GIDE team is deployed in the field and launches an autonomously-controlled UAS instructed to fly over the affected region. Since it is unmanned, the aircraft can fly for longer and navigate closer to the blaze than would otherwise be safe. The UAS is configured with a modular payload incorporating a high-resolution digital imaging sensor along with an integrated GPS, Inertial Measurement Unit (IMU) for direct online geopositioning. The payload is controlled by an autonomous embedded system, which geocodes all data readings. As data is acquired, it is compressed and transmitted by radio downlink to a ground-based Mobile Data Processing Station (MDPS) co-located with the GIDE team, which georectifies the incoming imagery in near real-time, forming an orthophoto map. The MDPS will perform the georectification without human intervention, using a parallel architecture developed by GEOSYS to rapidly generate the output.

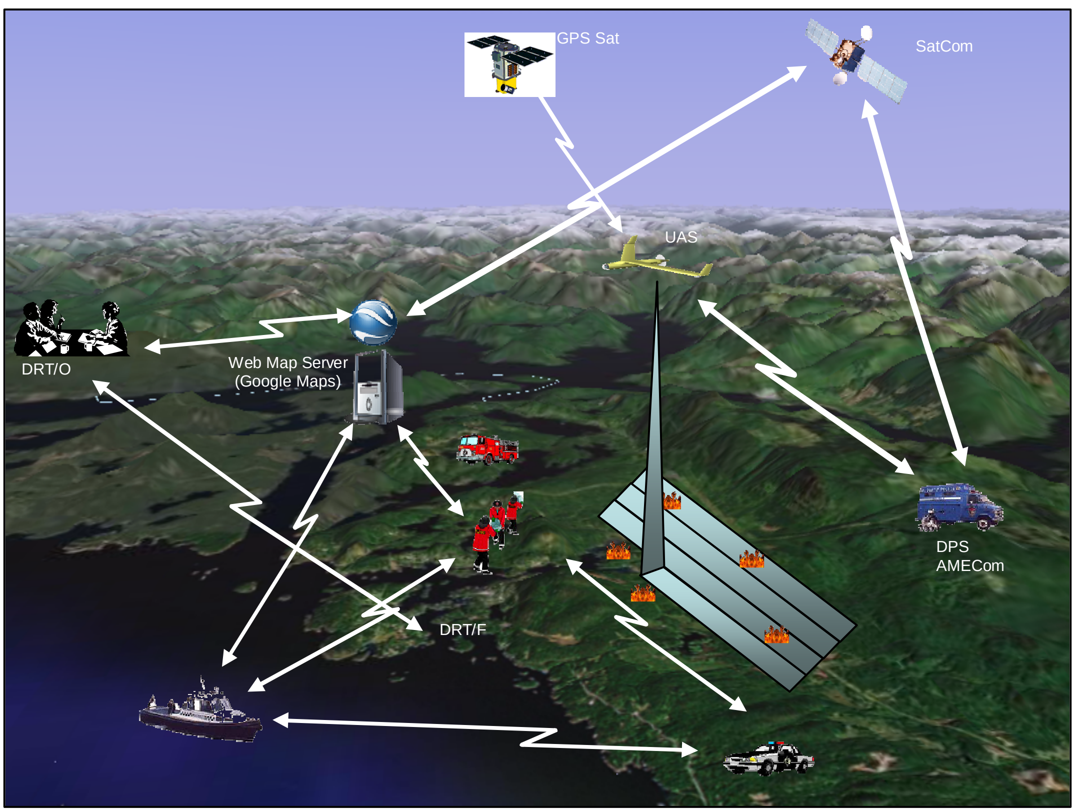


Figure 1 - GIDE applied to a wildfire disaster

These maps are then sent to a centrally-located Web Map Server (WMS) via the fastest available secure internet connection (wired, cellular or satellite). The WMS makes the data immediately available to the appropriate Disaster Response Teams (DRT) by the internet. The data is displayed in its web browser on a Google Maps-like interface with the most recently acquired imagery displayed on top of an underlying low-resolution "base" layer supplied by Google Maps or a local mapping agency, such as BC BMGS DIM (BC Digital Image Management) Web Server for the running example. This interface will provide the means to intuitively and rapidly visualize a large volume of image data. Furthermore, it will serve as a basis for inter-agency collaboration, enabling stakeholders to maximize their collective expertise to quickly understand the disaster and respond accordingly.

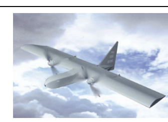
UAS BORNE IMAGE ACQUISITION

UAS Hardware

Use of UASs has existed for many years for a variety of different tasks. In previous years, UAS missions have included reconnaissance, surveillance, bomb damage assessment (BDA), scientific research, and target practice. UAS's were used extensively in both combat as well as reconnaissance roles. However, UASs have never yet been widely used in civilian map production. Current high-tech UASs are well suited for a role in the cost effective and timely production of geo-information products such as orthophoto, DEM, 3D landscape modeling, and change detection, to name a few.

UAS systems vary considerably in size and cost, the missions they are intended to perform, and the manner in which they are employed. Some UASs are small, low-flying, low-endurance vehicles with ranges measured in only tens of miles. Other UASs are relatively large vehicles that can be kept in flight for many hours and travel at high altitudes over distances of hundreds of miles. Some UASs require lengthy, hard runways for takeoffs and landings, while others can be operated from small, unprepared fields or even ships. In addition, UASs differ in terms of the payloads they carry and the manner in which they are controlled. Today's UASs can carry a wide variety of payloads, including TV cameras, radars, EO imaging sensors, lasers, meteorological sensors, as well as sensors to detect chemical agents and radioactivity. Table 1 outlines a typical categorization of UAS platforms.

Table 1 – Categorization of common UAS platforms based on flying height, size and endurance.

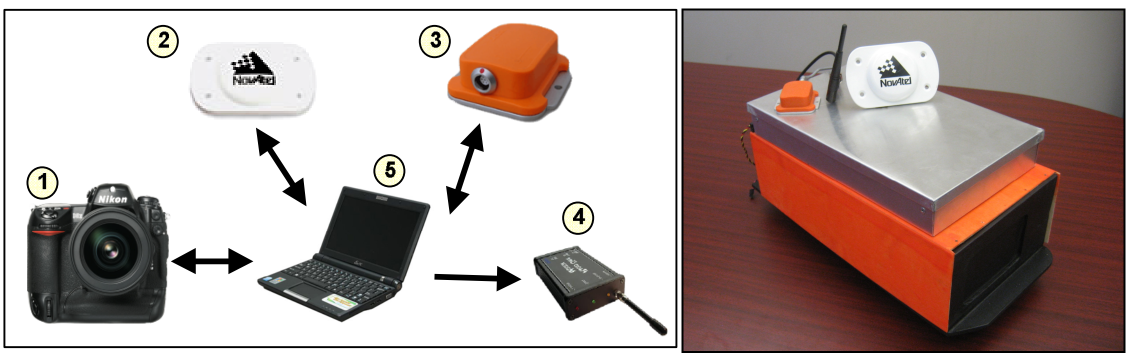
Classification	Flight Height	Endurance	Details	Example Platform
HALE	>45,000 ft ASL	>24hrs	Large payload. Performs complex operations and surveillance.	 GlobalHawk
MALE	>15,000 ft ASL	>24hrs	Large to medium payloads. Performs surveillance, reconnaissance, and targeting.	 Predator
Tactical	<15,000 ft ASL	<24hrs	Medium to small payloads. Performs reconnaissance and targeting	 Thunderchild
Mini	<1500 ft AGL	1-2hrs	10km range. Performs reconnaissance, targeting, protection.	 Dragon Eye
Micro	<500 ft AGL	1hr	5-10km range. Performs reconnaissance, targeting, protection. Operates in urban terrain.	 Microstar

Some UASs fly pre-programmed flight paths, while others can be remotely piloted, via radio link, by pilots on the ground. Sensor-equipped UASs also differ in the manner in which the collected data is retrieved. In some cases the data is retrieved when the UAS is recovered. In other cases the information is transmitted in real time, via data link, from the UAS to the ground station. Compared to manned aircraft, UASs have a number of potentially significant advantages. UASs are smaller, and are much less costly, both to procure and to operate and support. UASs are capable of longer loiter times. Perhaps most importantly, UASs avoid putting pilots and other crew at risk. Compared to satellites, UASs have some significant advantages, including the ability to fly close to the ground, under cloud cover, and to provide coverage on short notice, rather than only on a predictable schedule.

For the purposes of disaster management, the requirements placed on the image acquisition system are primarily availability, flexibility and response time. For the scenario considered by GIDE, a Tactical UAS is the suggested platform since it is: low cost; light-weight so that each vehicle can be transported to the desired location without significant effort; flexible enough to launch in remote and challenging conditions, even without the presence of an airstrip; and simple to use so that specialized technicians are not required. By default, the GIDE platform is designed to fly on a tactical UAS platform; however, the remainder of the system is completely modular, and can also automatically acquire and deliver mapping products when flown on any craft, manned or unmanned.

Image Acquisition Payload

In order to support the near real-time requirements of a disaster scenario, the image acquisition payload must automatically capture imagery and positional information, and transmit this data to the MDPS on the ground. To achieve this, GEOSYS has developed sophisticated, on-board payload software that supports near real-time acquisition, packaging and transmission of data to a ground station. Figure 2 shows current payload hardware configuration consisting of a global positioning system (GPS), inertia measurement unit (IMU), wireless modem and camera, all connected to an ultra portable subnotebook which runs the GEOSYS payload software.



(a) (b)

Figure 2 – (a)**:** Onboard payload components: (1) camera, (2) GPS, (3) IMU, (4) modem (5) subnotebook. (b) An image of the actual payload box when removed from the UAS platform.

Prior to takeoff, the software is initialized with a set of pre-determined flight points that are strategically distributed along the UAS path to provide full coverage of the disaster area. Once in flight, the software continuously records sensor readings from the GPS and IMU. When a GPS positional reading matches a pre-determined flight point, the camera is triggered. Figure 3 below describes how the data is acquired, packaged and transmitted to the ground station. The following section will describe the automated data processing solutions that are deployed at the MDPS to transform raw data into a final map product.

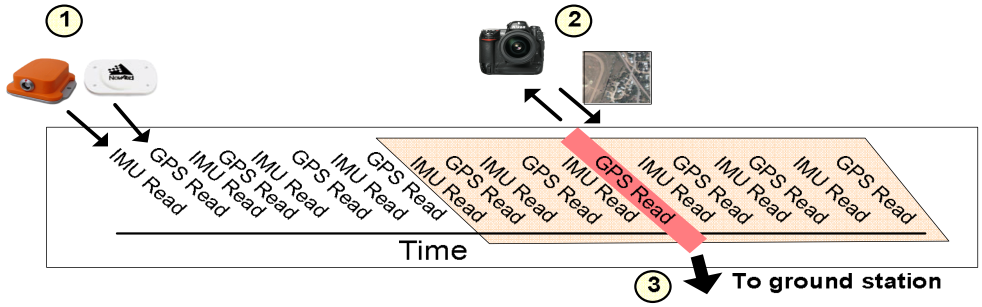


Figure 3 – The GIDE information collection payload software packages geo-spatial information with collected imagery for distribution to the MDPS via radio modem. (1) GPS and IMU readings are continuously received and recorded by the payload software. (2) A GPS reading matches a pre-determined flight point and triggers the camera. (3) All surrounding GPS and IMU readings are packaged, along with the acquired image and transmitted to the ground station using a radio modem connection.

MOBILE DATA PROCESSING GROUND STATION (MDPS)

The MDPS receives imagery and sensor position via radio communication and automatically carries out all processing required to deliver consistent geo-information products suitable for disaster managers. This processing is primarily composed of two steps: correction of positional information necessary to achieve suitable accuracy and the use of corrected positions for near real-time map production which seamlessly blends raw imagery into a consistent final product. **Error! Reference source not found.** illustrates the data flow and software modules employed for this task. The remainder of this section will describe each component in detail.

Improvement of Position Information

While estimates of the camera poses are provided by the Inertial Measuring Unit (IMU) and GPS aboard the UAS, the readings can be unreliable due to the relative instability of the platform compared to a piloted aircraft (e.g. yaws of ±12 degrees are common), the temporary failure of the GPS/IMU signal (e.g. due to the loss of GPS satellite line of sight), or other factors. Furthermore, achieving a low payload cost is an important design goal, and precludes the use of high-precision miniature sensors. Two approaches for intelligent algorithmic correction of positional information are being developed as part of GIDE:

1. Direct Geo-referencing without ground based receiver, leveraging existing PPP technology from PMIS partners, will improve the measured position data directly, providing decimeter-level final position accuracy (this component operates in near real-time).
2. Automated Aerial Triangulation and Bundle Adjustment will utilize image information to further improve position estimates (this component is run off-line when higher data quality is required for post-disaster analysis or as close to real time as possible if the Direct Geo-referencing method has failed).

Method 1 - Direct Geo-referencing without ground based receiver

Direct geo-referencing of airborne sensors using an integrated GPS/IMU system is now a widely accepted approach in the airborne mapping industry. Currently most of the direct geo-referencing systems are based on the integration of double differenced GPS (DGPS) and INS, which rely upon the availability of double differenced GPS. Double differenced GPS measurements are obtained from two receivers. Taking airborne mapping as an example, one receiver is used as the base receiver and is set up at a precisely surveyed control point on the ground while the other roving receiver is installed on the airborne platform. Differencing of GPS measurements is necessary to eliminate or significantly reduce satellite orbit and clock error, atmospheric error and GPS receiver clock offset. Double differenced GPS is the most accurate available solution; however, due to the requirement of a ground based receiver, DGPS/INS has two drawbacks which often limit its application for many applications. First, it increases the system cost and complexity since a base receiver must be set up at a control site whose position has to be precisely determined. Second, the baseline (separation between the two receivers) must be short in the range of several kilometers to make sure the high correlation between the measurement errors at the base and rover receivers. This is a problem, in particular for the disaster scenario where mapping operations may need to span large areas with limited ground access due to presence of active hazards.

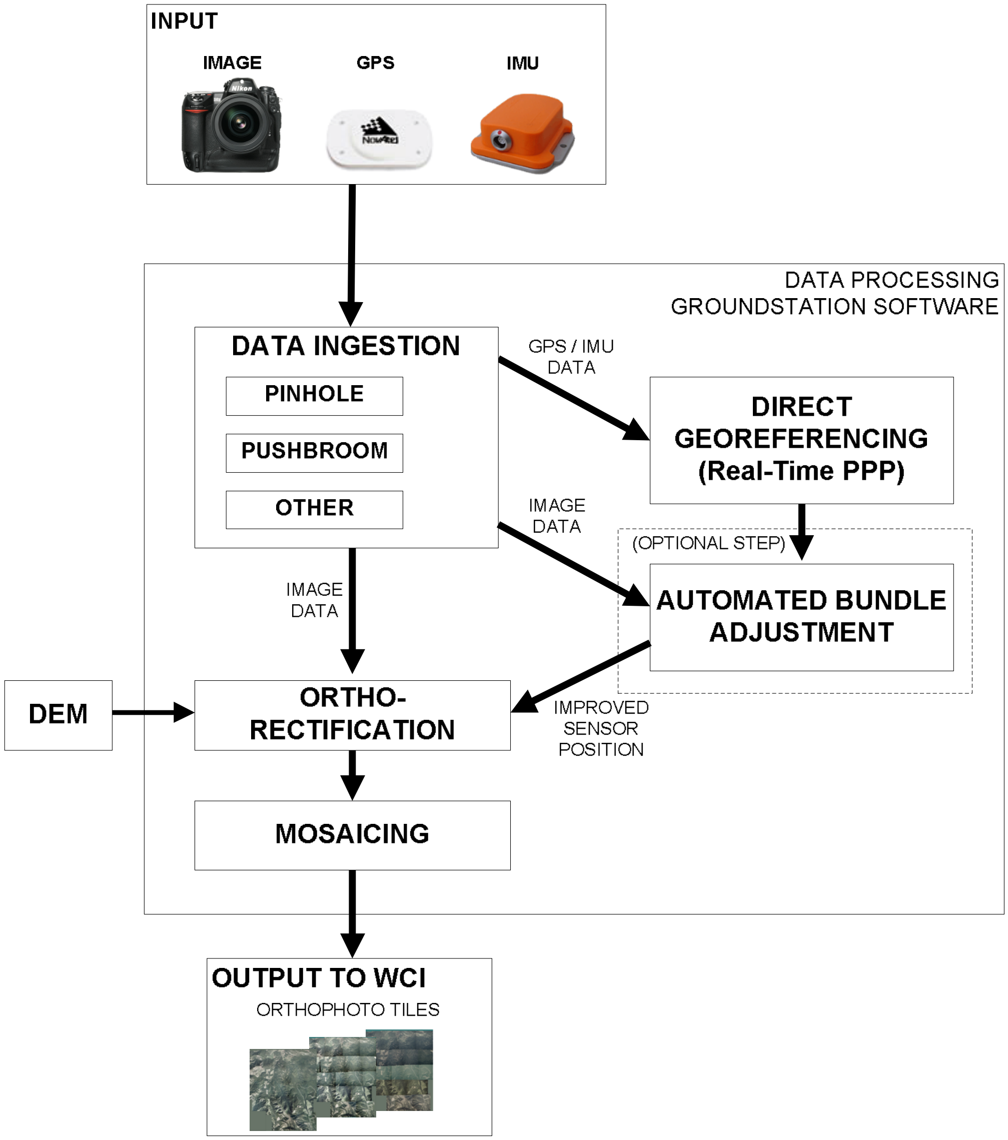


Figure 4- Block diagram for GIDE data processing ground station.

With the advent of precise orbit and clock products, a positioning method known as Precise Point Positioning (PPP) has been developed at PMIS. Unlike double differenced GPS positioning, PPP processes the un-differenced GPS measurements from a single receiver and applies precise orbit and clock products to eliminate errors in GPS satellite orbit and clock. PPP is able to provide decimeter to sub-decimeter accuracy position solutions, depending on the quality of the GPS receiver.

A direct geo-referencing system based on PPP/INS integration has been investigated in this project and will be applied to derive the position and orientation information of the imaging sensors to support disaster monitoring applications. A loosely coupled integration scheme has been adopted and the system configuration is demonstrated in Figure 5. A UAS imaging platform collects raw data and sends this to the loosely coupled PPP/INS direct geo-referencing system via TCP/IP communication (internet) at the MDPS. After receiving the raw data from the UAS platform, the PPP sub-system downloads the SP3 file from the International GNSS Service (IGS) website and processes the GPS data to calculate the position and velocity of the airborne platform. The INS sub-system applies the PPP position information for initial attitude determination and processes the INS data for position, velocity and attitude determination. A Kalman filter is applied to combine the INS and GPS solutions to derive improved position and orientation information.

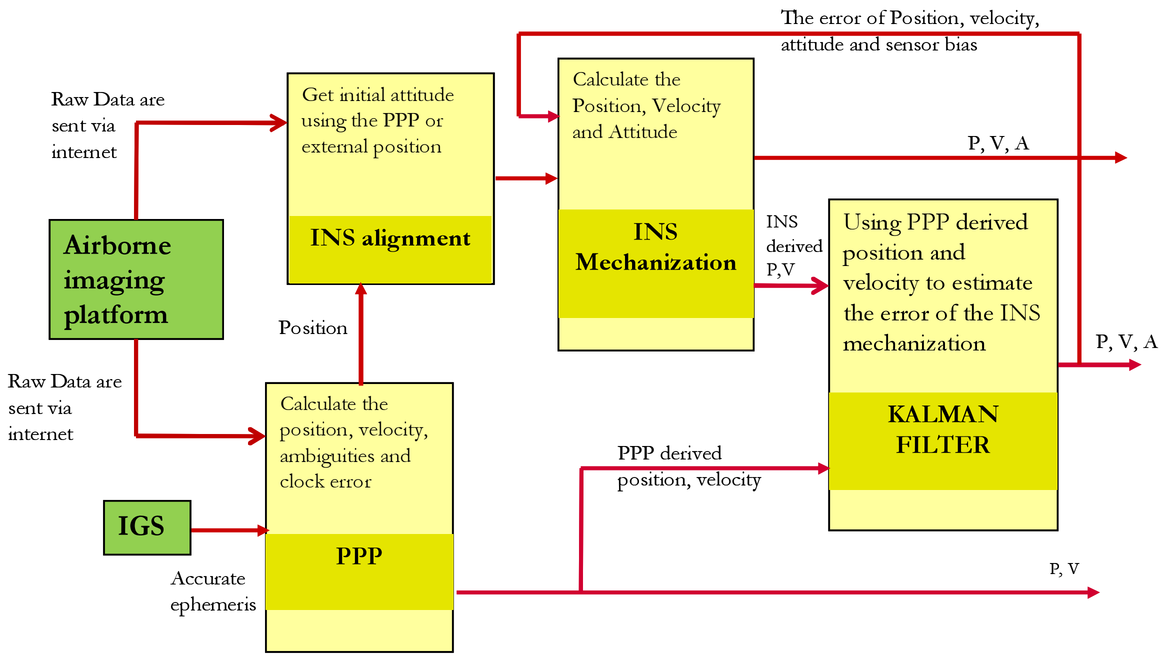
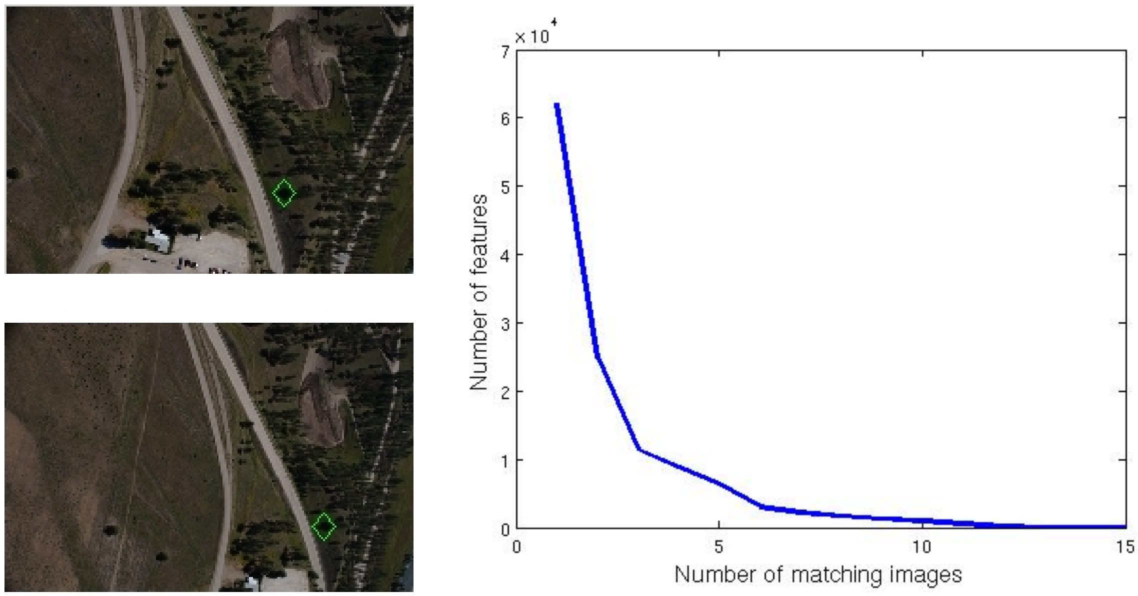


Figure 5 - Loosely coupled integration of PPP and INS for direct geo-referencing.

Method 2 - Automated Aerial Triangulation and Bundle Adjustment

Aerial Triangulation (AT) is the process of matching corresponding points across collected images, and the use of these matches by a Bundle Adjustment package to increase the accuracy of sensor position estimates. Manual or operator assisted Aerial Triangulation to provide accurate sensor positioning has long been a standard practice in photogrammetry, but is far too time consuming to be used during the disaster management process. Completely automated AT is possible in some applications, but has not previously been applied for scenarios with gross initial errors, such as the use of a low-cost UAS. Recently, techniques for automated matching of local image features [Lowe, 2004] have become sufficiently robust to allow, for example, fully automated scene reconstruction from unstructured tourist photos [Snavely, 2007]. GIDE has leveraged this technology for our UAS collected imagery to provide an additional phase of improvement for UAS sensor poses, which is capable of achieving sub-pixel accuracy in image registration. Due to the computational complexity required by Bundle Adjustment of a large number of sensor positions, the automated AT module does not run when data is being delivered in near real-time. Instead, this module can be run post-mission to produce an accurate final product or periodically during the mission when increased accuracy is required in a particular location. The process of automated feature matching and position correction can be decomposed into a number of steps.

1. Computation of corresponding locations in image-space (see Figure 6):
   a. Locating interest points in images in a fashion that is invariant to image transformations and describing the local patches surrounding these interest points by invariant SIFT descriptors [Lowe, 2004].
   b. Matching those interest points which appear in multiple images, by initially selecting nearest-neighbors in descriptor space and subsequently verifying these matches with a geometric consistency check (RANSAC).
2. Incremental addition of cameras into a global model using point correspondence information and multi-view constraints:
   a. 5-point algorithm for initial computation of fundamental matrices.
   b. Initialization of 3D feature locations through ray intersection.
   c. Non-linear optimization to solve for the solution which minimizes re-projection error (Bundle Adjustment).



(a) (b)

Figure 6- (a) A single example of a feature match with cardinality 2 is shown as a green diamond – where cardinality indicates the number of images containing the matched feature. (b) Shows a histogram depicting the number of feature matches versus cardinality.

To demonstrate the effectiveness of the automated bundle adjustment procedure outlined in this section, we have computed camera poses and point positions for set of images collected by our UAS platform over a region near Princeton, British Columbia, Canada. Our system performed this reconstruction without initialization from GPS/IMU. That is, only constraints from matching image locations were used in the computations. The test data was collected at two separate flying heights, 250 m and 350 m above ground level and across 3 parallel flight-lines with nominal 60% forward overlap and nominal 30% lateral overlap between images. Figure 6 (b) shows the cardinality of ray points for each verified match obtained during automated AT. Although the majority (>60,000) matches only represent two intersecting rays, there are still over 40,000 highly dependable matches with 3 or more intersecting ray points. Figure 7 illustrates the final sensor geometry recovered by the GIDE Bundle Adjustment system when applied to these matches.

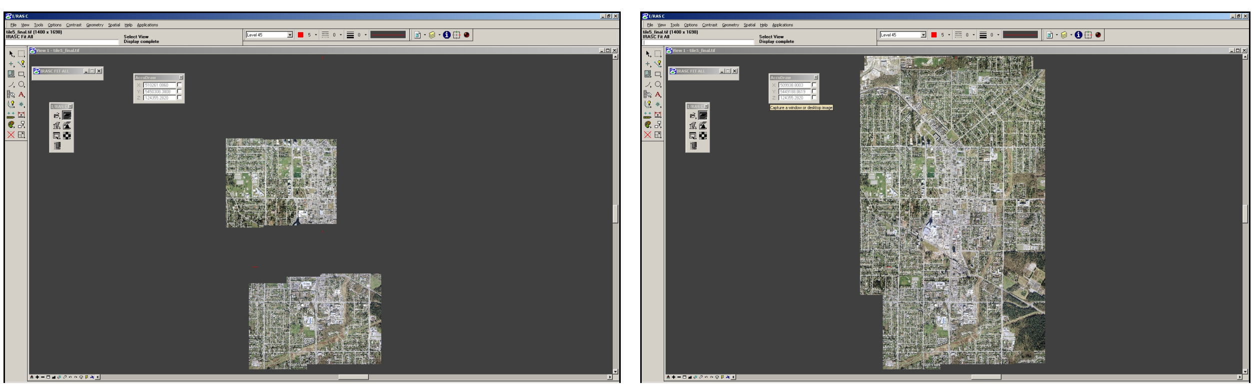
Upon completion, the Automated Tie-Point procedure provides an accurate estimate of sensor positions. This information is fed into a map production system which combines raw imagery into a final product useful for analysis by decision makers.

Near Real-time Map Production

The process of semi-automatic mosaicing is mature [Kraus, 1997]. However, current techniques are slow and unable to autonomously cope with large geo-positioning inaccuracies **-** oftentimes necessitating human intervention. This level of performance is not suitable for the fully automated and extremely rapid processing which must occur in the GIDE ground station in order to transform raw UAS-collected imagery into consistent ortho-mosaic map products quickly enough to meet the needs of decision makers. The GIDE project has developed a completely automated, highly parallelized image processing solution based on previously existing Modular Orthophoto Seamline And Radiometry Tools (MOSART), which is capable of processing UAS imagery nearly in real-time. This allows the GIDE ground-station to deliver data within minutes of the UAS passing over a disaster region.

Figure 7- Geometry of final reconstruction for Princeton test data. Sensor positions along 6 flight lines at 2 different flying heights are represented in red with matched ground points shown in their original color.

Rectification and mosaicing of large volumes of image data is inherently a computationally expensive process. Therefore, to achieve high throughput, the GIDE project has adopted a highly parallelized system design, allowing numerous computational cores to perform on different image data independently. This processing paradigm extends both to ortho-rectification, where sub-tiles within input images can be processed separately across cores, as well as mosaicing, where partial results from various images can be seamlessly blended as soon as they are available. In order to reduce implementation time during development of our ground-station software, GIDE system designers have developed highly modular and loosely coupled components which require minimal effort to synchronize between concurrent processes. In addition, several state-of-the-art open-source libraries and toolkits have accelerated our implementation efforts. Figure 8 shows two snapshots of an orthophoto map produced during the processing of a test dataset of urban imagery.



(a) (b)

Figure 8 - Snapshots of the online mosaicing process at two different stages for data collected over the city of Surrey, British Columbia, Canada. Each frame is added to the mosaic incrementally, within minutes of the input imagery arriving at the ground-station.

DATA DISSEMENATION THROUGH WEB COLLABORATIVE INTERFACE (WCI) AND WEB MAP SERVER (WMS)

Once a set of orthomosacics is generated in near real-time, it must be rapidly disseminated to disaster response stakeholders. Conventional dissemination methods introduce significant delays which are unfavorable in a situation where every second counts. Currently, during typical disaster response efforts, once orthomosacics are produced, the data is copied to external hard drives and flown to disaster agency headquarters across the country. Once critical disaster response data is delivered, disparate disaster response organizations often need to share data among each other and effectively collaborate their response efforts. For example, organizations often need to share maps and locations of resources.

GIDE addresses the issue of timely delivery of data and collaboration of response efforts through an intuitive Web Collaborative Interface (WCI) system. As new orthomosaics are generated in near real-time, they are immediately accessible through an OGC standard Web Map Service. Using a standard web browser, disaster responders can log into the GIDE web-based system to view data as it is delivered, add and share their own data sources and create custom data by creating points of interest or highlighting areas directly on an interactive map. For example, a responder could add the information from their own WMS containing agency specific data. The data is then available for all responders to view and analyze. The GIDE generated data and any shared WMS data can also be ingested into existing geospatial software systems already in use by disaster response organizations. To facilitate discussion and interaction between responders, a virtual message board provides a means to share important information such as status updates, announcements, analysis results, etc. Figure 9 below provides a view of the flow of information during collaborative system operation.

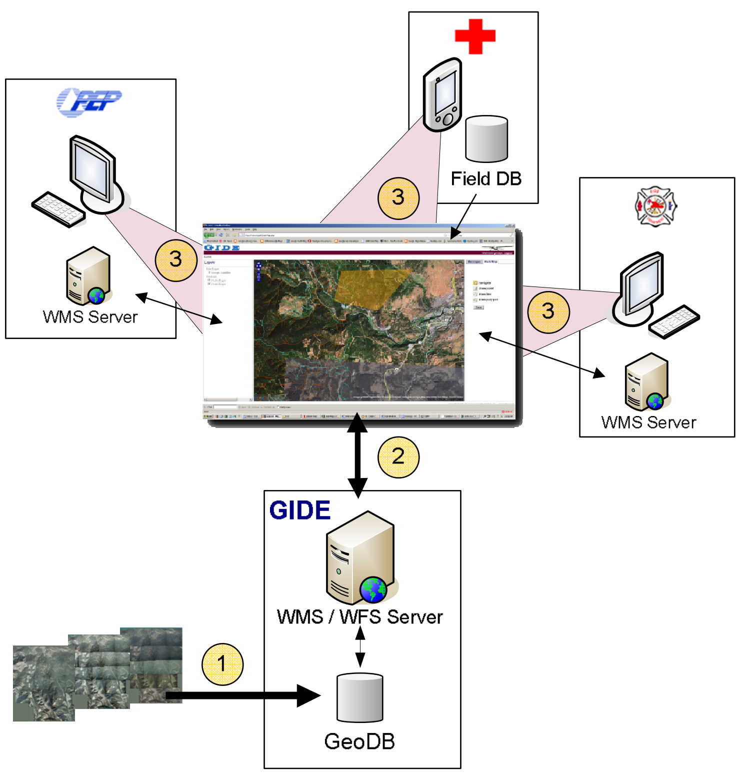


Figure 9- Component diagram for GIDE collaborative web-mapping interface. (1) The MDPS processes the imagery and final orthophoto tiles are sent to the GIDE geospatial database (GeoDB). (2) Once stored within the GeoDB, the ortho imagery and any supporting data can be accessed through the WMS / WFS enabled server. (3) Disaster responders collaborate by logging into the user-friendly web interface to view and share critical decision support data in order to make fast, informed decisions.

The WCI system consists of a database, web server and web mapping system. The database is PostGIS/PostgreSQL and manages user login information, raster metadata, vector overlay data and user shared data. UMN MapServer delivers raster and vector data to the web using the OGC compliant WMS and WFS standards. The Open Source OpenLayers API is used to create the user friendly mapping interface. The interface offers full map navigation including zoom, pan, coordinate display and distance calculator. Layers can be toggled on and off using the layer control. Responders can create custom layers consisting of map markups in the form of points, lines and polygons. This allows a responder to create a polygon around a particular area and share this layer with other users. Responders can also easily add their own WMS or WFS data sources as new map layers. Future interface enhancements will allow adding additional data sources such as KML, GPX and Shapefiles.

CONCLUSIONS

Disaster managers require data in a timely, accurate, and convenient fashion. The GIDE system provides numerous innovations which improve the current state-of-the-art in each of these aspects. The project is currently ongoing and further system tests and results will be presented in the near future. Once completed, our integrated system will provide a complete data management and collaboration solution which will drastically change the information space of emergency managers and help to save human lives.

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