LESSONS LEARNED IN EMERGENCY REMOTE SENSING AND BP RESPONSE DURING DEEPWATER HORIZON

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ABSTRACT

As BP activated the emergency response cleanup efforts for the Deepwater Horizon Oil Spill, Icaros Inc, an expanding technology developer in the Photogrammetry and Remote Sensing field was assigned to engage in the fast response data collection efforts. Between June 3rd and August 9th Icaros employed its sensor capabilities and processing software to deliver to the BP event response center actionable data in an expedited delivery in order to assist in damage assessment and operation of the cleanup services throughout the Gulf of Mexico.

This emergency event required quick mobilization and deployment, in-situ processing and fast delivery, continual development and calibration of technology and methodology, schedule management and efficiency, flexible capabilities and technology, and creative solutions and problem solving.

Icaros mobilized its system and crew within 2 days of activation, and was able to install and deploy the system on a non-designated Cessna 310 aircraft within 3 hours. As part of the unique Icaros solution, the data was delivered no later than 3-4 hours from the completion of the flight, including in-situ processing of the data on the flight using mobile lap-top processing stations. During this project, Icaros incorporated three different sensors (RGB/NIR/TIR), utilizing multi-spectral data fusion for accurate and distinct analysis of oil-contaminated areas. During the last two years Icaros also participated in a number of emergency related projects including floods and forest fires. In this paper we will try to review our experience as emergency remote sensing requires a different approach than historically was addressed to date.

KEYWORDS: Emergency, Remote Sensing, Icaros, deepwater Horizon, IDM200, IPS2.0, Thermal, Multi Sensor, Data Fusion, Mapping, Multi platform

INTRODUCTION

When a disaster happens, whether as a result of a natural cause such as Hurricane Katrina or man-made like Sept. 11, 2001, getting the right information to the right people to make the right decisions is crucial in saving lives as well as helping authorities restore life as usual for the affected communities. Remote Sensing data and supporting technologies have proven to be an invaluable resource in disaster management and response effort. However, analysis of current approaches, available solutions and the lessons learned during BP Deepwater Horizon oil spill and other emergency events that Icaros has participated in during the last few years, reveals that additional steps are needed to better prepare for the next event.

DEEPWATER HORIZON OIL SPILL

Deepwater Horizon triggered one of the most massive ecological disasters ever documented in this part of the world. BP understood the magnitude of the event fairly fast, and being a private company it could allocate resources and budgets to respond and control the damage by designing a solution to stop the spill and plan the cleanup efforts.

The response, as expected, relied on high quality updated imagery that was used to establish and manage the mitigation plan a well as implemented means in the approximately 90,000 square mile addressable area.

BP fairly quickly established a base for its Geospatial requirements:

- Aerial remote sensing had to be utilized. Satellites that could provide valuable data were challenged by the Gulf weather and in many cases could not provide sufficient imagery as a result.
- An actionable product containing useful information was required within 3 hours from acquisition for analysis and continuous dynamic planning efforts.
- Flexibility in tasking was mandatory as there were constant changes in priorities, affecting the targeted area for the collection.
- Flexibility and adaptability were required as the implemented sensors and processing mechanism had to be constantly calibrated and adjusted to the local environment and the required deliverable.

These measures were crucial to utilize the operating cleanup assets and measures in an effective and swift response.

EMERGENCY CHALLENGES

Similar to other types of emergency, a marine cleanup operation is a very challenging assignment that requires a specific calibration and approach in every aspect of the operation; the oil concentrates in different aggregation stages, ranging from very thin layer seen as sheen on the water, to a very thick, viscous layer. The main target for collection was the thick, viscous oil layer, as the cleanup efforts capabilities focused on collecting crude oil efficiently and applying dispersants and other oil-degrading mechanisms in more general areas of contamination. These measures were deployed throughout the Gulf of Mexico, while BP's main engineering efforts concentrated on stopping the MC-252 spill and drilling relief wells for the decompression of oil build-up in the spill source's main rig base.

One of the main challenges in the cleanup operation was to position cleanup vessels in relevant areas given the fact that ocean currents and winds disseminate and mobilize the oil over a vast area rapidly (measured: 7 mile shift over night). In general, oil in marine environments constantly changes its position. This created a significant challenge as delivery schedule became challenging as needed to prove itself as a true mission critical support tool. A tool that was able to detect and identify the various oil stains, and deliver to BP operation command real geographic mapping and priorities of the targeted phenomena, all within 3 hours from data acquisition. For this project Icaros used the IPS2.0 system that enabled us to initiate processing before landing, in many cases processing was performed on laptops that provided the mobility needed to continue processing on rout to the emergency response center where the final Mosaic was uploaded to the response team ftp site.

As part of the immediate nature of the response, Icaros mobilized within two days of activation to the BP headquarters in Louisiana. The Icaros Digital Mapper-200 (IDM-200) aerial photography system was installed on a non-designated Cessna-310 aircraft in under 2-hours, and a pilot flight was performed on June 8th, 2010. Icaros utilizes an approach for its payload-stabilization that does not require an IMU. Instead it receives accurate pitch/roll angles from an aerial gyroscope, which communicates with the stabilizing engines in order to maintain a high level of image nadir. The stabilizer has a correction speed of up to 90° per second, and a range of ~20° in every direction, enabling very robust orientation between the captured block of images, and an ability to produce actionable data even above marine areas, or during long flight lines in unfavorable weather. This flexibility is important in emergencies as the system can switch between different platforms as was needed throughout the project twice, the switch to a new aircraft was completed within 1h without any effect on the operation.

3-Jun	6-Jun	7-Jun	8-Jun	9-Jun	12-Jun	13-Jun	15-Jun	16-Jun	9-Jul	13-Jul	14-Jul	27-Jul	28-Jul	7-Aug	9-Aug
Icaros Engagement Approval	Installation, system certification, and set-up in Louisiana		Pilot project completed			Experiments with NIR Sensor		Main sensor shift to twice-a-day NIR collection and delivery					Forensics project, collection and delivery of geo-referenced RGB + NIR + Thermal data		
Preparation of crew and equipment, mobilization to Atlanta, Georgia			Twice-a-day RGB collection and delivery, 400-700 Square Miles per flight, and 3 hours from landing to delivery					Research and Testing with Thermal IR Sensor for night-time collection			Night-time Thermal IR collection and delivery, incorporated with NIR			Demobilization of system and crew	

Figure 1. Icaros Operations in the Deepwater Horizon Response Efforts.

In the initial stages of the project Icaros employed its RGB sensor, collecting between 400-700 SqMi (1,000-1,800 SqKm) per flight. The schedule for delivery was critical for the response timeline of BP's cleanup efforts, and operational flexibility was essential for continuous coverage and delivery of remotely sensed data. Icaros deployed a twice-a-day flight and delivery schedule, which required efficient mission planning, quick deployment, and fast processing and delivery. Tasking for the morning flight was received sometimes at 06:00, with the flight takeoff scheduled for 07:00-08:00. Then during the morning time, the tasking for the afternoon flight would be assigned, with takeoff scheduled for 15:00-16:00. This created a continuous cycle of deliverable data, for analysis and monitoring by the BP operations headquarters.

During the initial collection with the RGB sensor, Icaros suggested testing its Near-Infrared (NIR) camera in an attempt to utilize the additional spectrum capabilities in order to differentiate contaminated areas with more observable patterns. Following several test flights with the Icaros NIR sensor, the main focus of the data collection shifted to NIR.

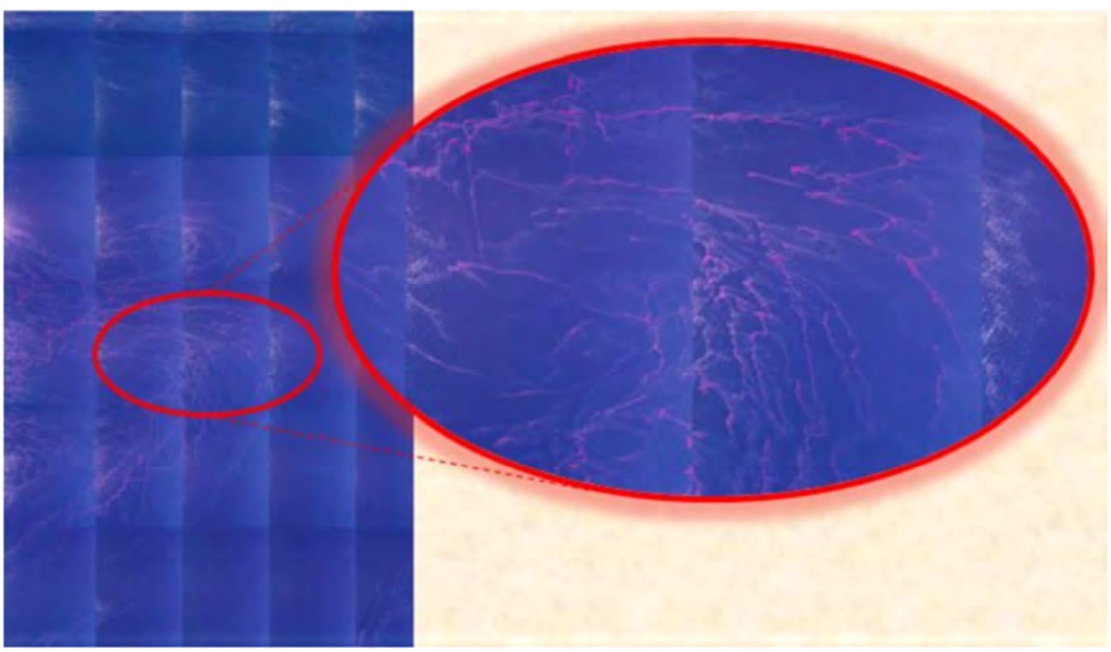

Figure 2. Oil Detected in Near Infrared.

Image

Additionally, through the early phases of operation, the Icaros R&D team conducted research with the IR-TCM 640 sensor by Jenoptik, which captures Far-Infrared spectrum of 7.5-14μm. The objective was to use the unique advantages of the Thermal collection in measuring the surface emissivity vs. the water temperature, detect deviations in measurements over the water that corresponds to presence of oil. The use of this approach enabled also the expansion of the collection efforts to the night time. The use of the TIR sensor enabled clear differentiation between sheen layers, thickness of measured oil slicks, as well as the direction they were drifting. In critical areas, such as around the source, night time monitoring of the shifting of the oil slick was central in determining the focus area for the cleanup forces the following morning. With Thermal capabilities enabling a measurement threshold of 0.1°, and an absolute accuracy of 0.5°, the Thermal mosaics produced a very definitive gradient map, depicting the exact area of heavy concentration of oil, and the general shifting direction of the oil slick. As shown in Figure 3, red areas represent colder temperature and blue areas represent areas of average water temperature. During night-time the different surface emissivity created due to the presence of oil in the water, results in the contaminated water areas to cool down and heat up faster, meaning that during peak temperature hours, such as midday or midnight, the temperature difference between the oil and water was greatest. This allowed for a very accurate representation of the oil concentration, as Figure 3 shows, the right side of the slick is entering clean water, while leaving a thinner sheen layer in the direction it was coming from, resulting in the conclusion that the area of the thick oil slick was shifting towards the east.

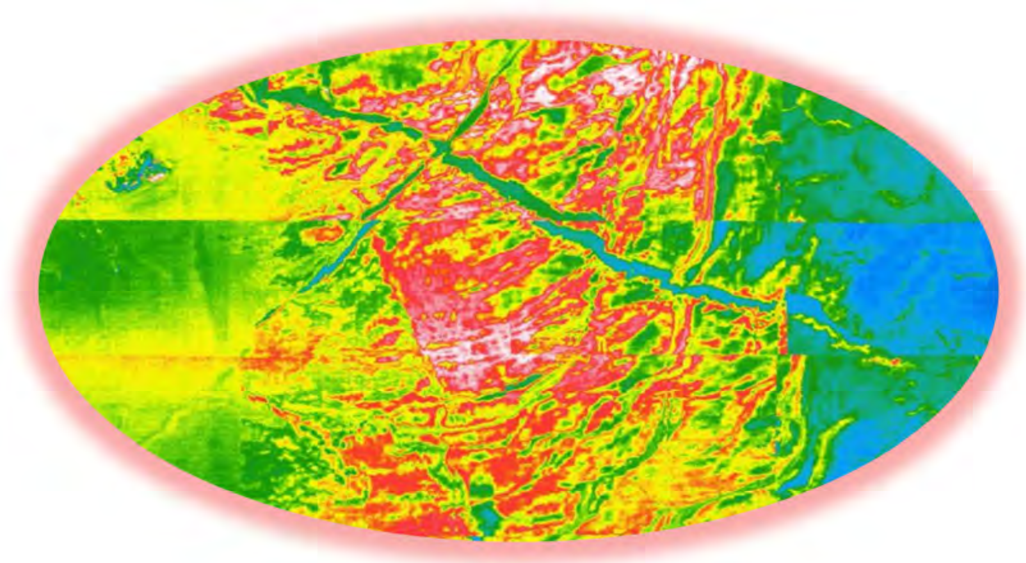

Figure 3. Thermal Geo-referenced Mosaic of the MC-252 Spill Source, Displaying Temperature Difference Between Relatively Clean Areas (seen as blue) and Heavily Contaminated Areas (seen as red).

As night time collection became available, Icaros operation revolved around a two to three flight schedule per 24-hours, with the day flights being performed with the NIR sensor, and the night flights with the Thermal IR. The timeline for a typical day of operation is depicted in the following table:

Time	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
Mission 1 (RGB/NIR)	Morning tasking	Mission Planning	Morning flight				Processing of morning data			RGB/NIR Delivery			
Mission 2 (RGB/NIR)			Afternoon tasking						Mission Planning	Afternoon flight			
Mission 3 (Thermal IR)													
Time (Cont.)	**19:00**	**20:00**	**21:00**	**22:00**	**23:00**	**00:00**	**01:00**	**02:00**	**03:00**	**04:00**	**05:00**	**06:00**	**07:00**
Mission 1 (RGB/NIR)													
Mission 2 (RGB/NIR)	Processing of afternoon data			RGB/NIR Delivery									
Mission 3 (Thermal IR)		Night tasking		Mission Planning	Night flight				Processing of night data			Thermal Delivery	

Figure 4. Icaros Daily Collection Schedule, as Performed During the Final Stages of the Response Effort.

LESSONS LEARNED

- *Better preparation in evaluating the qualities of different technologies in the planning phase will enable maximum utilization of deployed assets immediately following first mission.* In order to detect the oil contamination and classify its density, on shore and offshore, Icaros provided BP multi sensor data collection and fusion. Icaros supplied RGB, NIR and Thermal mapping (5-Band mapping). However, the first days of operation were performed using an RGB sensor that turned to be less effective in this environment. It was clear almost from the start that the most effective channels would be NIR and Thermal. Due to the different emissivity of the oil water and soil Icaros could better detect the areas that have oil concentration and classify the areas that has thick layer of oil. -- During another event this year supporting a forest fire Icaros was also tasked to execute the mission using RGB and only after we demonstrated the benefits of the TIR sensor in both day and night collect the customer shifted the requirement.
- *The 3-hour delivery challenge required a special operational consideration.* This was only achievable with the use of the IDM sensor package and IPS processing software enabling Icaros meet these challenges where traditional products could not. The NIR and Thermal layers where supplied to BP 3 hours after flight as a full ortho-mosaic product. The average area cover in Thermal mapping was 500 KM2; the average area covered by NIR was 1000-1800 km2 per flight. Most of the Thermal mapping was done at night allowing better differentiation between oil and other materials that are covering the surface.
- *The challenge of multi-sensor data fusion is well known in the geo-industry.* Combining the visible spectrum (RGB + NIR) is common in many aerial cameras and it is usually done by mounting an array of different spectrum cameras, opening the shutters at the same time, in known angles. Icaros IDM200/600 was developed in order to combine the visible spectrum the Near Infrared (in real high resolution), RGB and the Thermal (8-12 micron) spectrum. The challenge of fusing\superimposing the Thermal data with the visible channels comprising two main factors. During light hours the geometric solution should be derived from the RGB superior geometry and resolution; however due to different sensor physics, shutter speed is different, so in order to ensemble all 5 bands, timing differences between shutters opening time had to be addressed. The second challenge of fusing\superimposing the Thermal channel with the visible channels is night mapping. Night mapping is achievable only with Thermal sensors when, in this case, it is not accompanied by the RGB data to provide the geometry and night Thermal mapping generates vast amounts of images that needs to be aero-triangulated and solved (the Thermal sensor matrix is very small 640X480 with 1024X768 expected to be

introduced this year). The Icaros IDM200\600 is designed to respond to all of these challenges; some of the answers are dealt with via mechanical & electro-optical innovative hardware engineering; while the other challenges like night mapping is solved with the Icaros photogrammetric software suite (IPS2.0) and the MatchMe^{TM} aero-triangulation module & Solution Manager^{TM} that can triangulate and superimpose tens of thousands of images automatically without the need to input accurate external orientation.

- *The importance of having a spatial data infrastructure in place prior to any event is vital to insure successful mapping during emergency rescue, relief, and recovery phases.* Significant progress was made in recent years in state and local spatial infrastructure. These datasets need to be made available for use and analysis in a GIS environment where the importance of this data for a variety of applications apart from emergency management is obvious. GIS is a data-driven technology. Consequently, the environment will be as supportive as the data that was injected into it. This is a continuous effort that has many uses outside the emergency environment, however, if implemented properly can play a significant role in saving lives and guide first responders through the many unknowns of an event. The quality of available GIS data varies extensively across departments, jurisdictions, and communities in the U.S. In addition, many desirable data sets simply do not exist. For example, forest fire heat source maps are delivered to the event managers needed to be layered over routes to the different heat sources and this data wasn't available. These data gaps must be filled for effective response using GIS.
- *Another important point is that data collection is a continuous effort with new data made available every minute.*
- The need for properly managing the growing data sets is also important. During Deepwater Horizon, Icaros collected close to 5TB with over 20,000 SqMl collected with some areas covered a number of times with different bands. Alongside Icaros there were a number of additional assets generating a huge volume of data. The system was not designed to easily review past collection, and past data sets were mainly used locally for specific missions. Furthermore, data sharing protocols must be cleared and approved in the planning phase to ease the transition to real-time, response-based activities. During emergency response efforts, privately held data, such as utilities, as well as previously classified data should be included in the sharing protocol. A mechanism for obtaining geo-sensitive data as well as the collection of data over these areas should already be incorporated.
- *Emergency collection efforts are usually based on pre-existing contracting vehicle; however, recent events indicate that there need to be a different comprehensive holistic approach in addressing emergency remote sensing.* For example Hurricane Katrina ended in Aug. 29 2005, however the aerial collection started only on Sept. 3rd, mostly due to contracting issues and tasking mechanism.
- *Traditionally emergency remote sensing relies on the availability of existing assets.* This approach may be economically safe, however, it also compromises the ability to obtain new, necessary and life saving data as soon as it may be needed. Additional approaches should be considered putting into place the appropriate contracting vehicles to make collection assets made available to support any emerging event, enabling immediate mobilization and availability of this needed information. In a recent forest fire, Icaros assets were pre-positioned in close proximity to the affected area, thus enabling Icaros to initiate collection over targeted area 3 hours from first contact made by the Forest Service.
- *One of the main objectives is to improve emergency first responder's abilities to do their jobs by giving them useful tools.* If technologies fail on this account, then they have not effectively supported response efforts. There is a clear need to ensure that products, including maps and analysis, meet the needs of end-users and that appropriate tools make it into the hands of the right users. It was unclear in Deepwater Horizon, as well as many of the other emergency events we participated in recent years; to what extent the maps were effectively used in the response.
- *One affect of the Deepwater Horizon event was the sharing of the information through GIS infrastructure with the general public and media.* This trend is expected to grow in the future as updated geospatial information

incorporated in the appropriate GIS infrastructure can become an important tool in the public's ability to deal with the event while receiving relevant information over a geo-spatial framework.

- *The reality of forming integrated accessible data sets can be quite difficult for operational, political or economic reasons*. Deepwater Horizon events highlight the potential value of enabling a holistic multi-platform working environment. The challenge in the creation of integrated data sets across multiple jurisdictions still remains unanswered in Deepwater Horizon as well as many of the other events we have participated in the past. While the databases were maintained by various agencies during the project, they were not challenged with the integration of spatial data from multiple jurisdictions to provide a holistic view of the unfolding events.
- *For future events it recommended to establish the contracting vehicles after validating and matching the different needs with different technological approaches.* During the first month of the Deepwater Horizon response, BP engaged a number of mapping companies in search of the appropriate solution for the detection of oil over water, a task that many of the mapping companies have never had the previous experience in executing, only a month later after a number of failed attempts, BP settled on the right vendors for the task.

SUMMARY

Deepwater Horizon cleanup response efforts in the Gulf of Mexico posed an enormous challenge on the workers and the population that lives in the polluted vicinity. For the geo-spatial community this effort demonstrated the advances made in recent years in both collection enabling technologies as well as the progress made in the photogrammetric software market, all contributing to shape the increasing role and importance of geo-spatial technologies in support of emergencies. The project managers worked with the selected vendors to improve the ability of collected imagery to support the critical mission. BP insisted in receiving mosaics to improve the quality of the collected data to enable more accurate quantitative analysis, which Icaros provided within 3 hours.

Initially collection focused on satellite, SAR and ultraviolet and then fairly quickly the focus shifted to aerial collection combined with in water and aerial spotters. The implementation of 5-band collection proved to be optimal and enabled the incorporation of the additional reflected energy measurements to be used for volumetric analysis providing better information for the support team. All provided and collected data in all 5 bands was mosaiced to provide the exact location, additional processing enabled a fast overview of the entire mission with the main affected areas prioritized and marked. The information could then in short order transform to a task order.

Emergencies require a different approach than the regular projects we meet in our business. Icaros was able to support this mission and other emergency response tasking it has received over the last years due to two main factors: (1) the automation, speed and reliability of the IPS processing suite that enable a 3 hour turnaround time, and (2) the IDM200/600 aerial collection system that provides the reliability, flexibility, and quality needed in these often unstable environments.

In future events we expect that aerial mapping and all of the available supporting technologies including LiDAR, oblique hyperspectral and others will play a significant role in supporting first responders and decision makers. Finding and filtering the right approach and sensor mix is a challenge that if addressed ahead of time could save lives then next time we are called. There are still gaps in available processing software to support "processing on the fly" type of requirements, and additional work needs to be done on the architecture of the production environment throughout the different possible events.