THE ARCA OF IRIS: A NEW MODULAR & SCALABLE
DIGITAL AERIAL IMAGING SENSOR ARCHITECTURE

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ABSTRACT

There is growing demand in the geoimaging industry for all types of imagery and data collection with more efficient and economical technology. Aerial imaging sensor users have the challenge of rising operational costs and many of the sensors in the market today are single task or single mission oriented –not to mention very costly, with proprietary monolithic architectures and with a high rate of obsolescence. So new sensor systems are needed; systems that can also be flown at the same altitude and conditions of other optical or non-optical sensors (co-mounted and co-registered) to save time and expense; systems that open up new business opportunities and turn into reality the paradigm of “geoimaging the world online”. This paper introduces such new sensor, the ARCA (“Arched Retinal Camera Array”) of Iris (Integrated Retinal Imaging System); a new, modular and scalable digital aerial imaging sensor architecture. Based on U.S. Pat. Application No. 11/805,109, as a divisional application of U.S. Pat. App. No. 10/229,626- the ARCA sensor architecture along with being photogrammetrically compliant and scalable from small, to medium to large frame format, is a “Lego-like, plug & play” architecture which yields an unprecedented sensor configuration that is smaller, lighter, faster and economical.

INTRODUCTION

In 2002 Leberl and Gruber expressed “The future of photogrammetry may result in a confusing variety of non-standard aerial camera systems, each to be associated with a different workflow and in need of different analysis tools. This is at least the impression one has to get as one reviews the variety of ideas and products currently proposed. None of the proposed solutions promises to replace the conventional aerial film camera.

1. Either the productivity of the new cameras is too low to compete,
2. or the cost of the new camera contrasts with an economic justification vis-à-vis the traditional film camera,
3. or the workflow with a new camera conflicts with current traditions in the field.

We believe that a novel and successful digital aerial camera will have to create a digital image much as if it had been obtained by a film camera and then scanned, thus offering a field-of-view and a geometric resolution commensurate with a traditional aerial camera. But in addition there are other important factors that should accelerate the acceptance of such a novel aerial camera. We believe that a successful digital aerial camera will have to:

1. be a photogrammetric measuring tool and thus produce geometrically predictable imagery in a rigid coordinate frame, much as traditional aerial photography does;
2. cost significantly less than a new film camera, perhaps by a factor of 2;
3. offer better radiometry;
4. produce images at a sustained rate of 0.5 seconds per image or less;
5. be smaller and lighter than conventional aerial cameras, perhaps by a factor of 4, and thus be easier to handle;
6. support the aerial operation by providing on-line image based navigation, verification and quality control, and by reducing the need for a second highly trained specialist during survey flights;
7. be easily calibrated in a self-calibration approach;
8. be financially advantageous over the operation by an already existing film camera, even if that camera is entirely written off, simply by the savings in cost of film and cost of scanning, over a period of 2 years or less.

In following years Leberl (Leberl et.al. 2005, page 2) states “…we have been arguing that the new procedures and products should not be seen just as “icing on the cake”. Instead, they should be seen as the basis for fundamental changes of the photogrammetric value system, and we have been advocating the idea that this is resulting in a paradigm shift.”
In examining the outcome 6 years later after the commercial introduction and put into operation of aerial digital sensors/cameras, we find that the state of affairs of the digital aerial imaging technology market is that of the computer industry 15+ years ago with a mix of non-standardized and proprietary computing technologies… disruptive and expensive for the end-user.

There are however at this time forces in favor of change: miniaturization, digitization, solid state and convergence (integration / assembly). These forces yielding smaller, faster, more for less. digital commercial off the shelf components (COTS), sensors.

There are also a series of converging factors towards a paradigm shift in digital aerial sensor technology:
1. Photogrammetry and Remote Sensing - well known and implemented practical solutions.
2. Increasing Processing Power - faster and more powerful systems in smaller packages.
3. Increasing Bandwidth - wireless networks enabling faster data transfers and sophisticated integrated COTS application architectures.
4. Smaller form factors - digital devices are becoming smaller and cheaper, enabling cost-effective integration into mainstream applications.
5. Transition of Applications from Technical Users (metric) to Business / Consumers (pictures) – high quality volume demand.
6. The successful deployment of object oriented methods, technology and software platforms coupled with new evolving multi core hardware architectures.

This paradigm shift is also being catalyzed by a rapidly maturing customer base that is now faced with the following challenges:
1. Rising operational costs (more expensive technology entry point digital vs. film; trend to lower technology cost – simply better, faster, cost-effective)
2. Imagery acquisition and base product becoming a commodity (trend to industry roll-up, transaction based data delivery and turnkey solutions)
3. Complex manual procedures (trend to increased automation; outsource)
4. Long delivery times (trend to automate/speed up workflow)

Hence a new sensor architecture (paradigm shift) is required that will enable:
1. Lower cost of entry (investment) for the user base that is still using film cameras and better technology ROI.
2. Improved operational performance to collect high-value “imagery commodity”
3. Lower exploitation cost.
4. Lesser value depreciation.
5. As good in value as film camera
6. Slower digital obsolescence

All in all, there is growing demand in the geoimaging industry for all types of imagery and data collection with more efficient and economical technology. Aerial imaging sensor users have the challenge of rising operational costs and many of the sensors in the market today are single task or single mission oriented – not to mention very costly, with proprietary monolithic architectures and with a high rate of obsolescence. So new sensor systems are needed; systems that can also be flown at the same altitude and conditions of other optical or non-optical sensors (co-mounted and co-registered) to save time and expense; systems that open up new business opportunities and turn into reality the paradigm of “geoimaging the world online” (www.mapss.org)

INTRODUCTION TO IRIS

The Iris aerial digital sensor system is a unique patented design which is being implemented with an integrated imaging workflow that is about 30% hardware and 70% software (system integration and workflow is primarily software driven) using as much as possible Commercial Off The Shelf components (COTS).

Iris and its software processing platform Isis, are being built on the foundation of object oriented technology engineering principles, with sensor & software complying with the Object Oriented - concepts of re-usability, modularity and scalability – targeting to deliver a “plug and play, Lego-like” imaging architecture that is smaller, lighter, faster.
Iris with its modular and scalable architecture delivers color - multispectral orthos, stereo or oblique imagery (not pan sharpened); very high resolution with accurate and precise geometric and radiometric properties at the pixel level.

Iris One is made of three key components:
1. The ARCA – “Arched Retinal Camera Array”
2. Multispectral (RGB/NIR) camera modules. No moving parts – all solid state system.
3. Software and hardware that enables the ARCA arrays to act in tandem as one at the exposure rate as fast as one array (frame) per second. Software assembles the resulting imagery into a ready-to-use ortho-rectification (rectified) mosaic.

FUNDAMENTALS OF MODULARITY AND SCALABILITY
WHAT IS OBJECT-ORIENTED TECHNOLOGY?

M7 Visual Intelligence’s Iris & Isis Research and Development is focused and based on competent and precise design criteria that resolve the concern on how to meet the goals for increasing the correctness, robustness, extensibility, reusability, and usability of system components (modular and scalable hardware and software components). Object-Oriented (“OO”) design and development is in essence a technique for encapsulating ideas (concepts, algorithms, parts) in modules (components) which allow to achieve the aforementioned goals.

As time has progressed since the introduction of OO and experience has been gained, the promise of “being a silver bullet” went the way of all “silver bullets”. OO technology requires thinking in different ways and needs to be tempered with experience from other programming (SW & HW) methodologies and other disciplines. There are definite benefits to using OO technology but it isn't a cure-all that solves all engineering problems (Booch 2007, page 54).

Object-oriented technology does provide benefits to software development and there are instances where it can be extended to hardware (“plug-and-play” approach). And these benefits are derived directly from the concept of encapsulating information (flow) and operations on that information within a single entity, the object. One benefit of using OO technology is a possible increase in component reuse, though producing reusable components. Another major benefit is decreased maintenance costs because of the itinerant abstraction of a system that components introduce. Naturally it is still possible to develop a poor system using OO technology, but there is greater support with OO technology to produce better designs and implementations. Also, one of the big benefits of OO technology is that it is harder to hack code together, thus a greater emphasis is placed on design, and the engineer is more likely to be forced to spend more time on design.

Some design aspects that gain greater attention in Object-Oriented Design are (Booch 2007, page 72):
- **Reusability** – Emphasis is being placed on supporting modular components to support general tasks that can be reused in different applications. And with the use of inheritance it is possible to take an existing class/component and customize it very easily for use in a new situation. Experience is showing though that developing general reusable classes is quite difficult without careful design.
- **Modularity** - A component (class) provides a construct to group representing some entity (object) with the operations (methods) that manipulate that data. By encapsulating the data and code together, the abstraction that the component (class) represents becomes easier to understand and recognize. A component (class) is a template for a single conceptual idea that is cohesive and is used to indicate what objects of this class really are.
- **Maintenance** - The modularity of a component (class) makes the system more understandable. Internal modifications made to a component do not affect clients who use it.

THE ARCA OF IRIS
DEFINITIONS AND ARCHITECTURAL COMPONENTS

The “System for Mosaicing Digital Ortho-Images Having At Least Three Imaging Sensors” U.S. Pat. No. 6,928,194 is the basis for the Arched Retinal Camera Array (“ARCA”) architecture. This Patent issued on August 9, 2005, is generally directed toward Iris’ method of improving mosaiced images both during and after imaging. One conventional method ofortho-imaging involves rendering a composite image of a target by compiling varying sub-
images of the target. Typically, in aerial imaging applications a digital imaging device records images of fixed subsections of a target area. Those images are then aligned according to some sequence to render a composite of the target area. Such renderings are generally time-consuming and labor intensive. In addition, prior automated balancing systems proved to be susceptible to image anomalies, e.g., unusually bright or dark objects. Therefore there is a need for an ortho-image rendering system that provides efficient and versatile imaging for very large field of views while maintaining image quality and clarity.

One embodiment of the invention is directed toward a method for maintaining desired image intensity. The method includes evaluating a target image and identifying green-dominant pixels. Then, the average intensity of those green-dominant pixels is determined, and evaluated against the desired image intensity. With such information, the exposure time of the imaging system can be adjusted to reduce the difference between the average and desired image intensity.

In another embodiment, the invention is directed toward a method of mosaicing two overlapping digital input images. The method includes providing a reference image and a secondary image that overlaps the reference image. The reference and secondary images are correlated to compute a balancing matrix. Then, the intensity of the pixels within the overlap area of the secondary image can be scaled to match the intensity of the pixels within the overlap area of the reference image.

In a further embodiment, the invention is directed toward a method of processing color input images to reduce bias. The method includes selecting green-dominant pixels from a first and second input image, and computing each of their respective average intensity values. The average intensity values of the first and second input images are then compared, and the first or second input image is processed responsive to the results of the comparison.

In its first phase of implementation Iris addresses the need for an ortho-image rendering system that provides efficient imaging for a large field of view and that maintains image quality and clarity. Some conventional digital imaging systems have attempted to address these issues with large-scale single lens cameras. These cameras typically comprise a large primary optical lens, behind which a number of optical sensors are embedded. The characteristics of these configurations, especially the optical properties of the primary lens, tend to render images of very small cross sectional area. Generally, sensors in these systems have either identical or coinciding lines of sight. However, such systems have the problems of being quite costly and inefficient when a wide a field of view is desired. Rapid development of new sensor technologies renders these systems obsolete or requires cost upgrades to such systems (Cramer 2006).

Other conventional systems have attempted to address the shortcomings of such primary lens configurations through the use of divergent sensor arrays. Usually, optical sensors are outwardly mounted along a convex brace or housing such that their focal axes diverge outwardly from the imaging device. Based on the intended scale factor for the images, the individual sensors in the array can be disposed such that their focal planes adjoin or slightly overlap at a desired distance from the target area. Although such a configuration can provide a wider field of view for imaging, it is still limited in application. The sensor arrays must be mounted within a host aircraft, and thus require a portal in the craft through which to obtain image data. Large sensor arrays require large portals to provide proper optical access for all the diverging sensors in the array. In many cases, however, large portal spaces are impractical, if not impossible, to provide within the small confines of a host craft. Furthermore, larger portals allow a relatively high degree of light backscatter in the array, causing ghost images and degrading the overall quality and reliability of the images obtained.

The U.S. Pat. App. No. 10/229,626 was filed on August 28, 2002, and originally included thirty-three claims generally directed to Iris’ inventive camera system. The U.S. Patent Office reviewed the claims, and determined that they actually represent six patentably distinct inventions. In one embodiment, one of the claims of this patent is directed toward at least two imaging sensors disposed within a housing that is mounted to a vehicle. The imaging sensors each have a unique lens, and a separate focal axis which independently passes through an aperture in the housing. In another embodiment, the claims are directed to a focal axes interest within an intersection area. The various embodiments led to exploring with different angle configurations, lenses (cameras) to see what could be achieved, giving rise to functional definitions of the ARCA and as the base for an aerial digital sensor architecture that could be modular and scalable - Iris.

The Arched Retinal Camera Array (ARCA) is the foundation of the Iris sensor system architecture. It comprises a complete and integrated software plus hardware modular system workflow from data collection, processing, to delivery.
CAMERA MODULES

Camera modules are units with a given resolution CCD with electronic shutter and reconfigurable lenses.

Iris camera modules are Bayer color (RGB) and near Infrared (multispectral) machine vision computers with electronic shutter and software driven integration. The ARCA camera array system has very fast (1 frame/sec) performance with precise geospatial metric accuracy.

- Camera modules are geometrically calibrated using calibration cage and Australis software.
- Formal radiometric calibration is also performed.
- ARCA is calibrated using flight calibration range.
- The power is in the software - 64bit multi core.

ARCA frame pixel capacity can range from [(11, 16, 39 to 50 Megapixels) x 5] x N

Camera modules are configured in the ARCA forming a linear array of cameras with an “hour glass imaging effect”, not only on individual camera, but also on integrated camera array; given it the advantage of imaging a larger swath whilst looking through a smaller aperture.

SIMAGE

Each camera module CCD has a defined (finite) number of pixels and resolution. The output image generated by each camera module is called a Single Image or “SImage”. The geographic coverage and resolution (Ground Sample Distance or GSD) of each SImage will depend, among other base parameters, on flight altitude.
FRAME

The aligned union of the SImages in the ARCA arrays is called a Frame. The number of pixels in the Frame will be directly proportional to the number of SImages (i.e. camera modules), less the overlapping between the adjacent SImages in the same array.

ARRAY OF CAMERA MODULES

The current ARCA design holds a maximum of 5 RGB and 5 NIR camera modules. Each array of camera modules (up to 5) represents an ARCA Array. In the current version of Iris there are two arrays. Both arrays are aligned in parallel in the ARCA, are co-registered and each array covers, within pre-established accuracy parameters, the same imaged space with a pre-established pixel offset of less than 5%, one array in the RGB domain and the other in the NIR domain.

The current Iris system has two arrays as one block. Future versions of Iris will have single arrays with different angle configurations and form factors to allow for distinct geographical or spectral coverage, including but not limited to, for example, hyperspectral, thermal, oblique or panoramic arrays.

The two arrays (i.e. 10 camera modules) are fired at once (in tandem) as fast as both arrays per second. Each camera module generates a single image or “SImage”. The SImages generated from all camera modules are contiguous, next to each other and these SImages in the same array then can be processed to become co-registered strip mosaic or “Frame”. Any one SImage on the ARCA array can be assigned as the "reference unit", typically the nadir camera module, that gets attached the navigational and positional information (positional metadata), where all other SImages in the same array will have relative position to the assigned "referenced unit".

The graphic below depicts the outcome of different array and camera configurations, allowing Iris to escalate from a medium format frame camera system to a large frame format camera system, to go from color to multispectral, and further into hybrid type systems, all using the same base architecture.
CONCLUSIONS

This paper has introduced a new modular & scalable aerial imaging sensor architecture based on the concept of the ARCA – the arched retinal camera array. This architecture allows for great flexibility and efficiencies.

In evaluating all the converging factors mentioned in this paper and the state of the art of computer, optic and electronic technology among other, we are firm in the believe that at present an aerial digital sensor paradigm shift is viable using the ARCA technology.

Expanding on Leberl’s (2005) list above, this new aerial digital sensor technology must be:
1. A metric camera and a remote sensing device.
2. A truly modular and scalable sensor that can be escalated from medium, to large frame, to very large frame (VLF) format using the same base architecture.
3. Reconfigurable from single task to multitask.
4. A hybrid sensor that can evolve and integrate color and NIR with thermal, hyperspectral and other types of imaging sensors to collect various types of imagery in a single flight mission.
5. Allow for the Co-mounting and Co-registering of other types of sensors such as LiDAR that can be flown and used during a single imaging mission.
6. Cost ½ to buy and operate than any other equivalent digital sensor in the market today.
7. With equivalent or larger collection capacity in less time. Collection capacity can be increased (increasing frame size) by adding more arrays to the ARCA or larger CCD camera modules. All using the same base architecture.
8. Imagery can be ingestible by any photogrammetric or image processing system (open system).
9. Capable of producing on-board information products, “from the camera to the desktop” (orthos, change detection, oblique, stereo DEMs, imagery fusion, feature extraction, other).
10. Smaller and lighter than conventional digital aerial cameras, at least by a factor of 2, and thus easier to handle.
11. Costs ½ to acquire and operate than any other equivalent digital sensor in the market today.
12. Equivalent or larger collection capacity in less time. Collection capacity can be increased (increasing frame size) by adding more arrays to the ARCA or larger CCD camera modules. All using the same base architecture.

13. Imagery can be ingestible by any photogrammetric or image processing system (open system).

14. Capable of producing on-board information products, “from the camera to the desktop” (orthos, change detection, oblique, stereo DEMs, imagery fusion, feature extraction, other).

15. Smaller and lighter than conventional digital aerial cameras, at least by a factor of 2, and thus easier to handle.

Is able to use “DigitalFilm”

In summary the Iris ARCA based aerial digital sensor system:

1. Is modular and scalable from medium frame to very large frame (VLF) format. It enables hybrid imaging applications.

2. Has more performance and efficiencies than any other comparable technologies in the market at half the acquisition and operational cost.

3. Has no moving parts (all solid state).

4. Is COTS integration based via software (64-bit, multi core).

5. Is economical, reliable, smaller, lighter, faster.

6. Can be operated using Digital Film.

REFERENCES


