# High Capacity System for Precision Agriculture Reconnaissance and Intelligence

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**Abstract**

Icaros-Demeter has developed a lightweight, compact remote sensing system with a potential for producing 100,000 acre (400km$^{-2}$) thematic maps per day with high resolution digital RGB/CIR CMOS sensors. The Icaros-Demeter system enables fast, precise location of multiple area and spots types. The system's ability for producing high precision Digital Surface Models (DSM) over vast areas, offers a direct method for computing agricultural biomass via volume calculations, instead of common indirect methods.

This unique ability to compute volume changes at high precision gives the user the ability to measure the field's biomass directly, instead of second degree evaluation from radiometric data.

The Icaros-Demeter system is installed and operated in less than 25 minutes on any type of light aircraft with no modification required. The system comprises full flight planning and control modules – so no blank spots are created in the covered area map, even though it uses a small frame size camera. Further the use of light aircraft enables Icaros-Demeter to fly in almost all types of weather conditions and below the cloud canopy.

The imagery created by the sensor is processed in a ground station unit – enabling the creation of 100,000 acre ortho-rectified thematic map within a 12 hour period. This 12 hour processing period may be shortened by an increase in processing units. The precision of the map is 3-5 Meter – without GCP's (ground control points), 1Meter with GCP's. The ground resolution is 25cm/pixel – using a 50mm lens from 6600' above ground in flight level.

The Icaros-Demeter system allows the farmer to receive rapid and precise data which current space/airborne systems can only provide with a much longer lead time and processing procedure. In addition the ability to create volume based calculations makes the Icaros-Demeter system the next generation of thematic map production system for Precision Agriculture.

The Icaros-Demeter system was successfully used in 2006-2007 in large scale (5,000,000 acres) projects with rapid turn-around of rural area mapping – for forestry and infrastructure engineering clientele. In Q1 2008 the Icaros-Demeter system performed agriculture reconnaissance and intelligence missions over more than 500,000 acres of Eucalyptus groves and wheat fields. The deliverable product given to the farmer contained a level of data heretofore unavailable, allowing the farmer the ability to treat current conditions of the field as well as enacting preventative measures for the future.

**Keywords**: orthophoto, photogrammetry, RGB, NIR, automatic mapping, thematic maps, precision agriculture

## Introduction

Precision agriculture had made extensive progress over recent years. Technologies and tools exist that would enable large scale acceptance and realization of precision agriculture techniques. Why then, have these available resources, remained largely untapped? It is our opinion that there is a gross parity between existant and variable-rate PA technologies, and actionable data containing site-specific and rapid intelligence, delivered to the farmer, so that he/she knows what the problems are, where with exactitude they exist, and how to treat them. Lack of large-scale monitoring tools and insufficient, imprecise, and cost-effective services also contribute to PA’s low popularity. If an agricultural service company wishes to employ current PA information technologies it is generally burdened with:

- Complicated and heavy apparatus with manually driven processing.
- Over-long time periods in the attainment of actionable products.
- Extensive human resources.
- Dedicated airplanes
- High cost of production

Despite our previous statements, great strides have been made in the acceptance, usage and appreciation of the value of satellite imagery, aerial photography, and remote sensing. The great potential and promise of these technologies are realized by both large cooperatives and individual farmers. The problem, as stated, has been the ability to deliver these services on a simple but comprehensive and cost-effective platform, delivering rapid response actionable data in real time.

By giving the farmer real time and scrupulous data he can respond quickly to early stage plant stress, enhance-by orders of magnitude- water management, pesticide and herbicide treatment, as well as plan with more certainty and confidence upcoming land use.

Icaros-Demeter has developed a lightweight, compact remote sensing system with a potential for producing 100,000 acre (400$km^{-2}$) thematic maps per day with high resolution digital RGB/CIR CMOS sensors. The Icaros-Demeter system enables fast, precise location of multiple area and spots types. The system’s ability for producing high precision Digital Surface Models (DSM) over vast areas, offers a direct method for computing agricultural biomasses via volume calculations, instead of the common indirect methods.
This unique ability to compute volume changes at high precision gives the user the ability to measure the field's biomass directly, instead of second degree evaluation from radiometric data.

This paper examines the performance of the Icaros-Demeter system in production of geo-rectified ortho photos, thematic maps and digital surface models in various types of agricultural fields, forestry, and natural landscapes.

## Materials and methods

The Icaros-Demeter reconnaissance and intelligence system is composed of an aerial sensor unit and mobile ground station unit that work in unison to create rapid, accurate, and geo-referenced thematic maps. The aerial unit can be mounted on any standard light aircraft with 30X30cm opening in its floor, or without any special preplanning through the passenger door.

The Icaros-Demeter ground station unit is a complete photogrammetric engine, containing a 19” rack with 4 blade-computers, running in parallel with a data storage unit of 6 Tb (figure 1). The ground station unit is comprised of 3 main modules managed by integrated framework software. The 3 modules are: a mission planning module, a data storage management module, and a map generation module- which contains a unique and proprietary image matching component named ‘Mach-Me’.

**Figure 1 – Ground station**

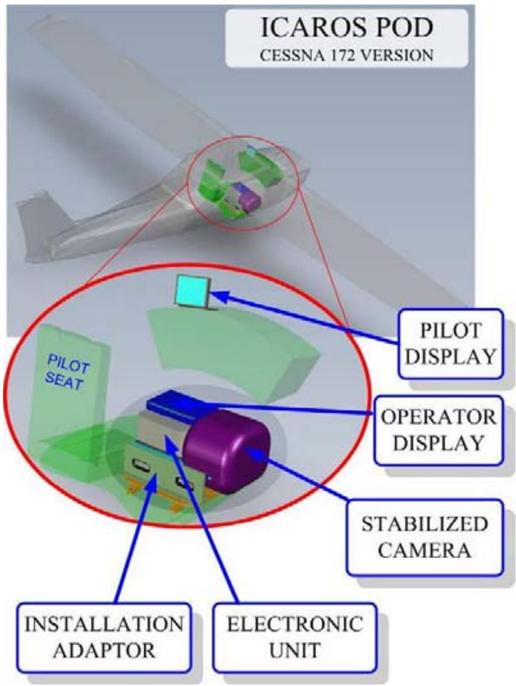


**Figure 2 – Aerial unit**

The Icaros-Demeter aerial unit is composed of 3 main sections; a stabilized payload, an electronic unit and an installation adapter (Figure 2).

The triple axis, digitally stabilized payload carries a commercial RGB/NIR high-resolution camera (Cannon EOS-Mark III) with several lens types, calibrated for photogrammetric use. The electronic unit contains lightweight PC104, GPS units, power supply adaptor, and backup batteries for 4hr independent system operation. A specially designed GPS controlled guidance system is integrated in the Icaros-Demeter aerial unit (Figure 2). Using an on-screen interactive display, the system guides the pilot into mission area and onto virtual grid of imaging positions according to the pre-programmed route. Imaging acquisition process is automatically controlled by the aero-unit computer without operator interference. Simultaneously, the system notifies the pilot and operator upon each image acquisition performance by displaying its properties on the screen (Figure 3).

**Figure 3 – Flight control screen**

The Icaros-Demeter mapping system was used for several extensive mapping projects during 2007-2008 (Table 1).

| Project's geographic location | Carrying out time | Landscape type | Existence of pre-requisite data | | Requested Ground resolution ($cm^{-2}$/pixel) | Total area to be mapped ($km^{-2}$) |
|---|---|---|---|---|---|---|
| Israel | January, 2008 | Field crops, Bare soil, Orchards | yes | RGB, NIR | 6-25 | 850 |
| Brazil | February, 2008 | Eucalyptus forestry | no | RGB | 6-30 | 300 |
| Uganda | February, 2008 | Natural forest, Bush, Coast-line, River banks | no | RGB | 45-50 | 2600 |

Table 1: Characteristics of projects which used for exercising the Icaros – Demeter mapping system.

As shown in Table 1, the Israeli and the Brazilian projects served agricultural applications before and during cultivation, and the Ugandan project served basic infrastructure mapping of the local natural environment.

The Brazilian forestry mapping project was part of an ongoing mission with a Brazilian cellulose company. Its mapping goals were the detection of tree development problems(indication of fungal and bacterial infections), and serving as a tool for tree counting and biomass evaluations.

The Israeli project consisted of 35 agricultural fields located at the center of Israel's most intensively cultivated regions (Emek-Izrael, the lower Galilee and the northern Negev). Field areas ranged between 242.4 to 15,581 acres and consisted of 70,000 acres of fields of spring wheat at early development stages (12 and 13 on Zadoks-scale), 80,000 acres of bare soil fields (before and after tillage), and 30,000 acres of almond and citrus orchards. A total of 5 fields (one of each type) were selected for high-resolution mapping.

Raw data collection and mapping process

The Israeli mapping project is presented herein as a case study for the Icaros-Demeter reconnaissance and intelligence system.
Selected fields were delineated with a geo-referenced polygon (Google Earth, Arc view,). Rectangles were sketched around the field's perimeters which defined the final designated area to be mapped and named as 'aerial missions'. Adjacent fields surrounding the target area were grouped together as a single block.

Aerial mission polygons were further divided into blocks of equal areas and fed into the Icaros-Demeter Mission Planning module. These blocks were inputted according to requisite resolution, and surface altitude, and the module's software automatically calculated a virtual 3D grid of points (with XYZ coordinates) in which the camera is located above the ground during imaging (Figure 4). The Mission Planning module also planned the course of the flight along the 3D grid and on the mission area.

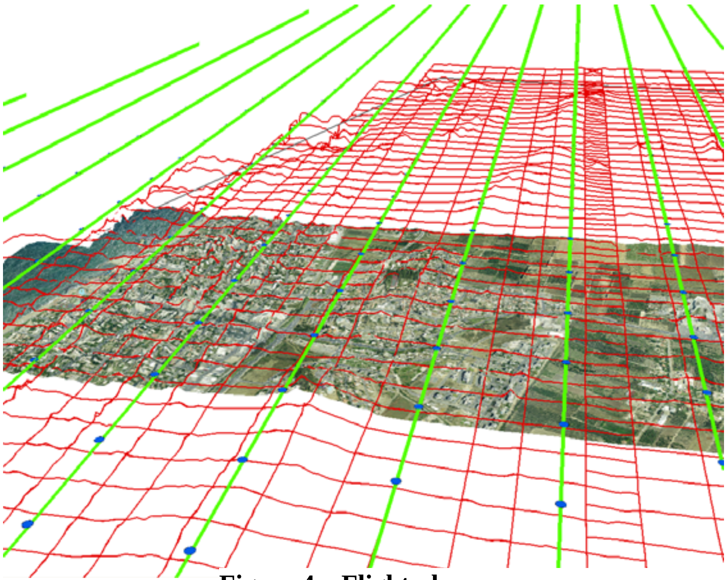

**Figure 4 – Flight plan screen**

Two teams of two persons each worked sequentially during the mapping process. The aerial photography team consisted of a regular pilot and one operator who were in charge of the aerial mission. The aero-unit operator was in charge of planning the flight missions, the onboard installation of the aerial unit, and of the supervision over imaging procedure during flight.
A second team consisted of two ground-base operators who received the aerial raw data and handled the data storage and management as well as the automatic orthophotos, and DTM production processes.

Several teams with different persons were employed in the aerial and ground station unit. In some cases, teams were working in shifts.

Nine types of light aircrafts served as platforms for the two mounting types of the Icaros-Demeter photogrammetric aero-unit; Cessna 172, 172R6, 182, 206, 207, 310, Piper Aztec, Shayne and Partenavia P-68.

Final orthophoto products were delivered to customers for agricultural analysis and action.

**Results**

Performances of the Icaros-Demeter aero unit and its team are brought in tables 2 and 3

| | Israel | Brazil | Uganda |
|---|---|---|---|
| number of aerial missions | 35 | 28 | 14 |
| Flights altitude range (ft) | 3000-9000 | 1500-8000 | 4000-9000 |
| number of flights | 16 | 8 | 9 |
| Total flights time (hours) | 43 | 25 | 36 |

Table 2: Summary of the aerial unit performances and Icaros-Demeter mapping system performance

| Ground resolution (cm/pixel) | Single Picture Area (Km3) | frames for 1 km long | Net Time for 1 km long (sec) | frames for 1 km long | fram each … (sec) | Picture length(m) | Picture width(m) |
|---|---|---|---|---|---|---|---|
| 5 | 0.025 | 13 | 36.01 | 13 | 2.77 | 194 | 130 |
| 10 | 0.101 | 6 | 22.62 | 6 | 3.77 | 389 | 259 |
| 25 | 0.630 | 3 | 20.31 | 3 | 6.77 | 972 | 648 |
| 45 | 2.041 | 1 | 10.77 | 1 | 10.77 | 1,750 | 1,166 |

Table 3: Summary of camera/flight performance
*

| Module | Process | Processing capacity (min/block) | | | | | | | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | rural landscape | before tillage | after tillage | wheat at early stages | Orange orchards | Almonds orchards | (eucalyptus) | Natural forest | Natural Bush | Average | Comments |
| Mission planning | Planning, and organizing flight mission data | 26 | 20 | 20 | 20 | 21 | 21 | 26 | 15 | 15 | 20.4 | |
| | Data acquisition time | 37 | 40 | 41 | 39 | 27 | 35 | 38 | 45 | 35 | 37.4 | |
| | Flight mission quality control | 40 | 35 | 32 | 41 | 37 | 43 | 32 | 38 | 31 | 36.6 | |
| Data storage and management | GPS data synchronization and images rendering | 12 | 6 | 8 | 11 | 9 | 7 | 13 | 9 | 9 | 9.3 | |
| | Tie points finding process ('Match Me') | 87 | 103 | 85 | 92 | 75 | 70 | 116 | 90 | 88 | 36.6 | |
| | DSM calculation | 65 | 70 | 64 | 83 | 68 | 59 | 44 | 51 | 55 | 62.1 | |
| Map generation | Final geo-rectified solution | 166 | 150 | 173 | 180 | 145 | 132 | 149 | 153 | 150 | 155.3 | |
| Total ground unit processing time (hours/block) | | 7.3 | 7.0 | 7.0 | 7.4 | 6.3 | 6.1 | 7.0 | 6.6 | 6.3 | 6.0 | |
| Average horizontal-XY precision (meters) | | 1.2 | 1.3 | 1.1 | 0.8 | 0.9 | 1 | 0.6 | 0.6 | 0.6 | 0.9 | No GCP's |
| Average vertical precision (DSM) | | 0.5 | 0.6 | 0.5 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 1 | 0.6 | |

Table 4: Summary of average time-lengths for the Icaros-Demeter ground processing unit (units are in minutes per square kilometer unless otherwise noted).

Tie Points Automatically detected :

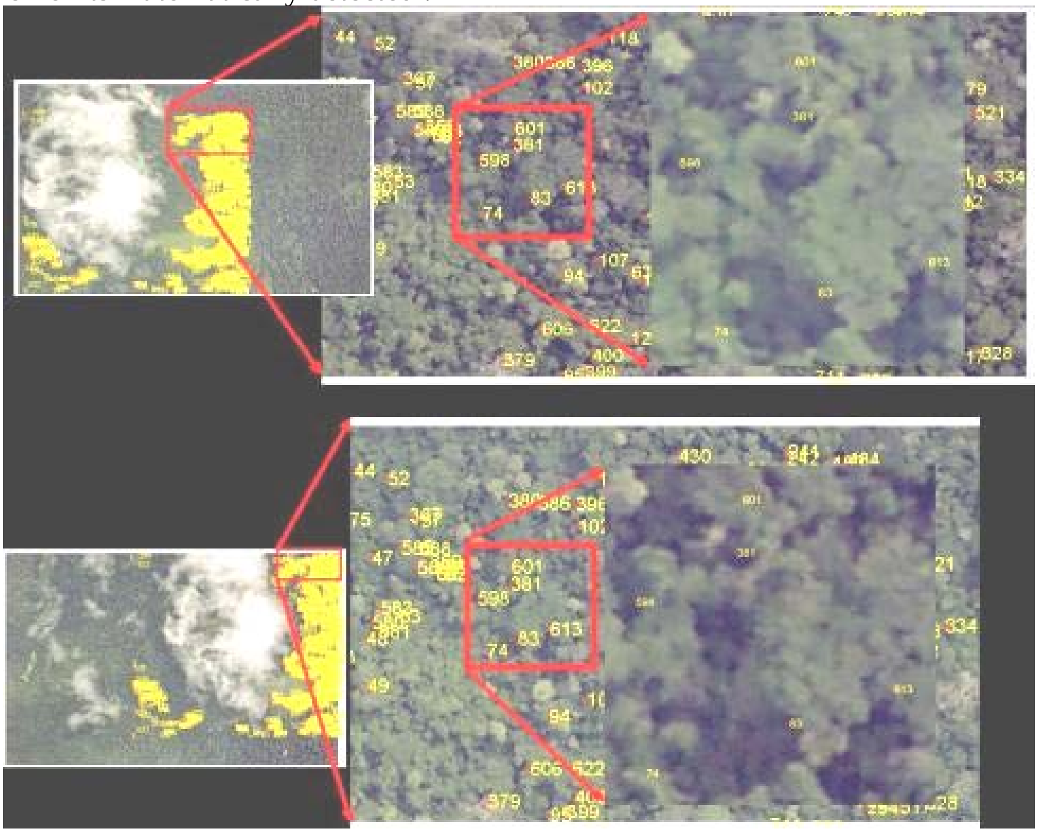

**Figure 5 – Automatic tie points production**

<u>Agricultural applications</u>

The Brazilian forestry orthophotos were later converted by customers into classification maps using NDRGI (Figure 6), and were further processed by Icaros-Demeter using proprietary algorithms for segmentation and calculation of tree number and biomass, using both geometric and radiometric parameters. The Israeli spring wheat field orthophotos were used for generating germination-failure maps using NDRGI (Figure 7). Bare soil orthophotos were used for tracking anomalies in soil composition (Figure 8), and orchard orthophotos were used for detection of inhibitory tree developments (Figure 9).

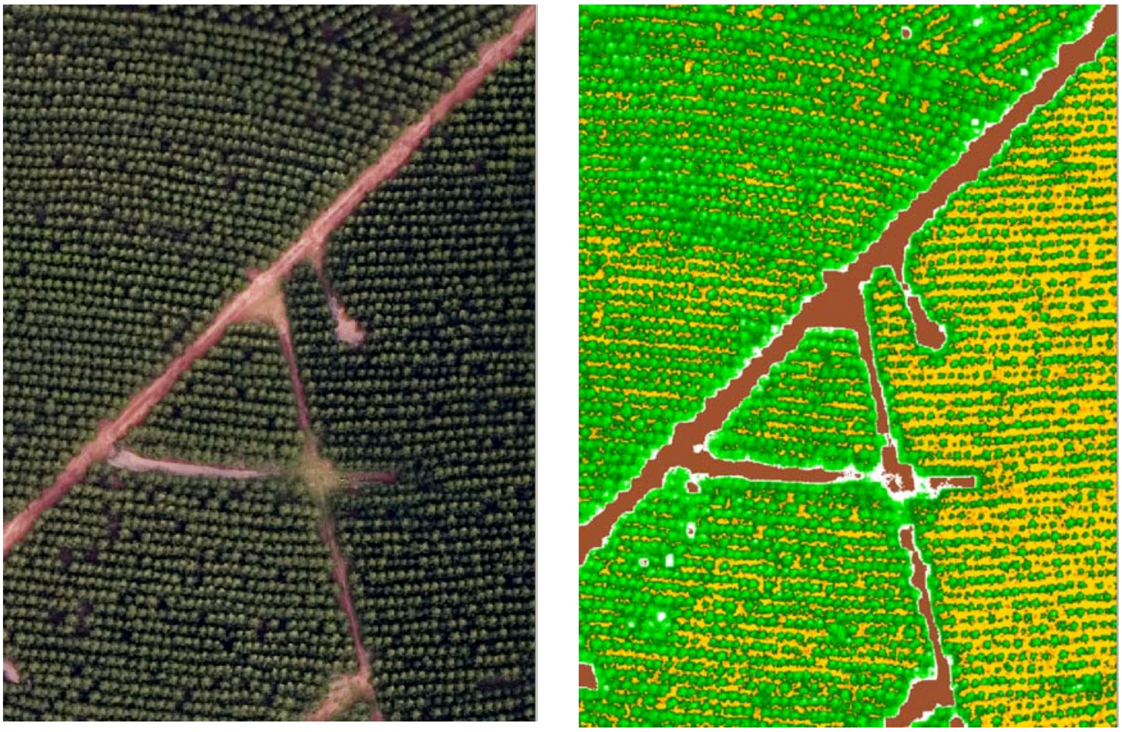

**Figure 6 – RGB conversion to NDRGI**

Figure 7: Part of RGB (left) and NIR (right) 6cm/pixel orthophoto of field plot with spring wheat at early development stage. This NIR image was taken using special IR camera with 930nm filter.


**Figure 8 – Lime patterns in bare soil area.**

**Figure 9 – Orchard orthophoto for tracing tree development**

## Conclusions

This paper illustrates the capability and capacity of the Icaros-Demeter Reconnaissance and Intelligence system in the production and acquisition of large-scale mapping in high-resolution and rapid production time. The Icaros-Demeter system is field proven in its ability to contend with high amounts of remote sensing information over vast areas and proves its potential for serving as a low cost monitoring tool for long-term informed decision making on the part of the farmer .

Components, listed in order of action performed :to plan, collect, store, process produce, restore and retrieve geographic information and knowledge

System capabilities:

1. Fast orthophoto creation.
2. High spatial resolution.
3. High automatic vertical resolution.
4. High throughput.
5. Short system response time (Hours)
6. Plane type flexibility.
7. High mobility.
8. Vertical view – no occlusions among dense objects
9. Bad weather operability: can fly below cloud base and according to survey's area topography.
10. System Creates Precise mapping with or without previous geographic database
11. ±2 meter precision of the geo referenced data without ground control points, and ±0.5 meter precision with ground control points

System applications for Precision Agriculture:

1. General management on precise, updated orthophoto.
2. Early detection of plant stress.
3. Fast thematic map creation.
4. Easy tracing of field development.
5. Direct connection from the map production to the VRT vehicles of all types.
6. Multi sensor operation.