A Toolbox for Aerial Image Acquisition and its Application to Precision Agriculture*

Onofre Trindade Júnior, Luciano O. Neris, Luís F. C. Chavier, Rosane Minghim and Kalinka R.L.J. Castelo Branco

Abstract— **Precision farming has increasingly focused on lowering production costs. Remote sensing techniques, mainly aerial imagery in the visible and infrared bands, have been employed to achieve this goal. The GPS (Global Positioning System) system allows easy geo-referencing of these images, making it possible to produce maps showing problems in the crop that can be easily located and corrected. The main problem is the high cost associated with the acquisition of aerial photographs with the necessary periodicity.**

This paper introduces TIA, a Toolbox for aerial Image Acquisition. TIA adds tools to manned and unmanned aircraft, easing tasks associated with acquisition and processing of aerial imagery. The first step towards implementation of TIA was a requirements analysis that produced a list of useful functions. These functions include mission planning, automatic mission execution, pilot guidance and geo-referencing of photographs and video frames using a GPS receiver. TIA was implemented in an architecture composed of three computer modules: a Palmtop computer that acts as a display/keyboard unit, a main computer and a camera controller. Each computer module has a corresponding software module. The toolbox has been tested onboard a ultralight aircraft and is currently being integrated into a fixed-wing unmanned aerial vehicle (UAV).

To evaluate the usability of TIA, a test mission was carried out at a big farm, in the central savannas of Brazil. About 360 photographs were taken from an 800 ha crop area. Images were segmented using a technique based on neural networks. Results have revealed several problems on the fields, including nematode and weed infestation, irregular seeding, and water erosion. It is expected that its use in the next season at the farm will result in substantial gains in productivity, through the periodical analysis of the aerial imagery collected and the adoption of intra season corrective measures. Further work on TIA includes new tests using a near infrared camera, a stability augmentation system for light aircraft flying, an altitude laser sensor for photographic scale correction and a self-levering camera support.

I. Introduction

This paper introduces TIA, a Toolbox for aerial Image Acquisition. TIA adds tools to manned and unmanned aircraft, easing tasks associated with acquisition and processing of aerial imagery. TIA is a toolbox that can be coupled with different kinds of systems or equipment to execute applications. Different applications to be executed need different kinds of sensors to be coupled to the equipment and these sensors will determine the quality of the missions. Mission examples include crop and plants identification, erosion and vegetation ground cover, disease and weed detection, etc. For each specific mission an array of sensors can be integrated to provide the desired information in real time. At a systems level TIA is a decision-making tool, in this case being applied to improve precision agriculture.

Conventional crop management techniques, based on sampling, use soil analysis and on-site scouting for pests, diseases and level of plant development. Depending on the size of the sampling grid, results can mask small but still representative areas on the field. It is presumed that each cell presents uniform properties such as infestation level or soil composition. Consequently, fertilizers, herbicides and pesticides are applied uniformly on a cell, possibly leading to application errors. Reducing the cell size (a few square meters) makes the spatial variability of the properties more evident and this technique is known as precision farming [12]. Despite being easy to understand, precision farming makes use of a complex set of technologies including data acquisition devices, data handling strategies and geographic information systems.

Remote sensing is a data acquisition technique that has been used extensively to identify, document and solve several problems in agriculture. Aerial images are a very precise and convenient source of data for agricultural management. Direct image acquisition of aerial images has become a useful resource for aerial photography [9] [10] [11] [18] [20]. These images can be useful to detect problems that can be corrected in the same or in the next agricultural season.

Intra-season corrective measures need high periodicity imaging missions to be effective, normally once a week or half a week. This periodicity generally leads to unacceptable costs, mainly for small to medium farms. Costs are associated with the aircraft, the pilot, and the image acquisition and processing. The costs associated with image acquisition and processing have been substantially reduced in the last years due to digital photography and powerful computers that can be used for automatic image processing. Reducing aircraft and pilot costs is the main task to make the use of aerial images for precision farming feasible.

Due to GPS improvements the use of direct geo referencing techniques for aerial imagery has been yet recently studied and applied [3] [4] [5] [6] [13] [14] [15] [16] [22]. These techniques use onboard equipment, such as GPS and Inertial Navigation Systems (INS) to match acquired images with some reference coordinate system. Direct geo referencing is especially useful for aerial line scanner devices. Nevertheless, it is also useful with frame-based image devices. Traditional geo referencing using aerial triangulation needs a large effort on interactive editing and supervision of highly skilled operators. In contrast, direct geo referencing techniques can be highly automated, needing less post-processing [7]. The main problem with direct geo referencing is the accuracy of GPS and inertial measurement equipment. However, with the high resolution of some modern GPS receivers and the possibility of using differential GPS

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(DGPS), many of these problems are now being addressed. Some experiments with a system for automatic image acquisition with direct geo referencing were already made using DGPS and inertial sensors (gyros and accelerometers) [19]. Automatic operation of a small format camera is provided. The aerial platform used is a small, single-engine airplane [18].

Small format cameras have been used in UAVs [10] and even in kites [1]. Some research was already made on the use of ultralight aircraft as a platform for aerial photography [8] [2]. This platform is useful for applications where compact equipment can be used and not many resources are available. The use of conventional aerophotogrammetry equipment is not feasible in this type of aircraft, because of size limitations.

Aerial image acquisition for precision farming has been done in Brazil using UAVs [17]. In the ARARA project [21], developed jointly by the University of São Paulo and Embrapa, some specific UAVs has been developed for this application (Figure 1).

Figure 1: The ARARA aircraft. Wingspan: 3 m; Engine: two-stroke, 40 cc, 5 HP, AVGAS; max weight: 20 kg; payload: 3 kg; flight endurance: 4 h; cruise speed: 100 km/h; stall speed: 40km/h; autonomous or remote controlled; emergency parachute.

Several farmers or farm workers own ultralight aircraft that have been used for small monitoring tasks. Furthermore, a second-hand unit can be purchased at a very low cost in many countries. A license to pilot these aircrafts is very affordable and easy to obtain. Another advantage of ultralight against larger aircrafts is that it needs small fields for takeoff and landing. This allows aerial surveys over areas away from the airfields [8]. On the other hand, ultralight aircraft has poor instrumentation, low stability and normally no power supply for on-board instruments. There is the need for enhancing the aircraft facilities to accomplish useful image acquisition missions.

This scenario led to the development of the TIA (toolbox for image acquisition). The basic concept is a black box filled with the necessary tools to facilitate the acquisition of geo-referenced images. These tools support three main tasks: automatic image acquisition, pilot assistance and sensor control (stabilization and positioning).

Figure 2 presents the use of TIA in different kinds of mission and vehicles. As shown, we have different kinds of vehicles (mainly autonomous vehicles) that have sensors and actuators that could be used for all the categories of these vehicles. In the same way, there are a lot of missions or application that can use these vehicles with some systems to allow the decision-making, like TIA.

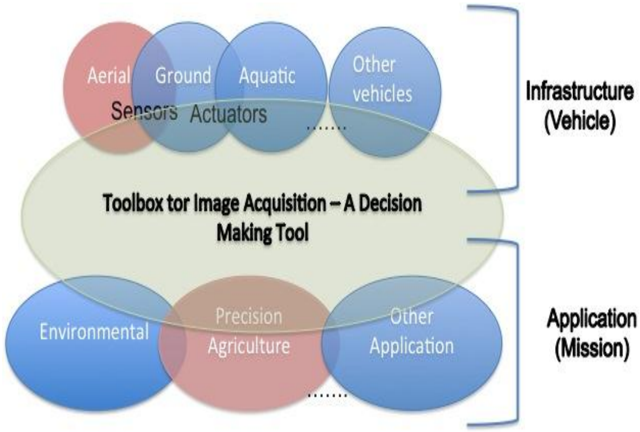


Figure 2: The relation of TIA with the application and the vehicle used to provide a plataform/infrastruture for a decision making tool.

In this context this paper presents the TIA concept. The main objective is to provide an easy, low cost and accurate decision-making tool to acquire small format aerial imagery used for precision farming. The next sections present TIA requirements, software and hardware design and the report of a test mission to evaluate its feasibility. Image samples are presented, revealing significant problems detected on the crop areas under monitoring.

II. METHODS

The following items summarize the results of the requirements analysis carried for the TIA concept:

I. The TIA should use a GPS receiver as the main sensor;

II. TIA should provide mission planning based on the GPS coordinates (latitude, longitude, altitude) of the field corners and the grid size used to acquire digital photography. This software establishes the location of aerial photographs, using a regular grid. The flight altitude also should be calculated based on the pixel size, focal length of the lens, and sensor resolution in pixels;

III. Digital photographs should be geo referenced by GPS coordinates at the time they are taken;

IV. Video frames should be geo-referenced at the time they are shot;

V. The magnetic heading, the GPS altitude and the speed of the aircraft should be stored and associated with each photograph and video frame.

VI. There should be an improved panel for pilot guidance of the route;

VII. There should be software for video frame extraction, with the associated coordinates.

The amount of blur control in an image acquired by an aircraft, cruising at the ground speed V_g, at an altitude above ground H_g, with a camera lens of focal length F and trigger time t is given by:

$$B = FV_g t/H_g$$

The amount of blur control should be smaller than the pixel size to get reasonably focused images. It is important to keep the aircraft speed low and the shutter speed high. Ultralight aircraft cruises at about 60 mph, helping to keep blur under control.

Photographs can be geo-referenced storing the GPS coordinates at the time they are taken. With low rate GPS receivers (1 Hz), it is important to keep the trigger command synchronized with coordinate updates from the GPS receiver to minimize the error due the motion of the aircraft. For a cruise speed of 60 mph, the motion during 1s is 26.8 meters, better than the position precision of most receivers. The same approach must be used to geo-reference video frames. In the NTSC video standard, there are 30 frames per second. It is necessary to take care to synchronize frames with GPS updates. After a referenced frame, subsequent frames can be referenced using interpolation from consecutive referenced frames. A better approach to reference photographs and frames is the use of a GPS receiver with higher update rate. This is particularly important for DGPS receivers, normally providing sub-meter precision. GPS receivers with update rates up to 20 Hz can be easily found at 5 to 10 times the price of a 1 Hz unit. TIA hardware block diagram is shown in Figure 3.

The main processor is a micro controller module commercially available. Its only requirement is to have enough serial ports to connect the GPS receiver, the camera controller, the modem and the keyboard / display unit.

The display and keyboard unit implements the graphical user interface of the system (GUI). A hierarchy of menus enables mission planning, pilot guidance and camera control (including taking a photograph when a key is pressed). The camera controls available depend on the brand and model of the camera (both video and still). The minimum set includes the trigger of a still camera and the start/stop button of a camcorder. The camera controller has a micro controller that can be programmed to control common protocols such as Lanc, available on some Sony camcorder models.

Video frames are geo-referenced storing data in the audio track using a modem. The same modem can be used later to recover the data along the frame extraction process. Data stored include GPS coordinates, GPS altitude, GPS ground speed, magnetic heading, time, date, number of satellites in view, number of satellites in use, and dual vertical and horizontal DOP (Dilution Of Precision).

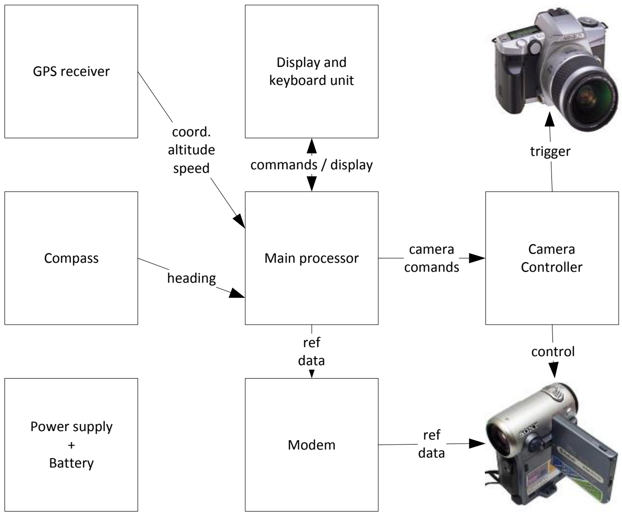


Figure 3 – TIA Hardware Block Diagram.

TIA was partially implemented using hardware modules from the ARARA aircraft. The display and keyboard unit makes use of a palmtop computer. This makes it possible to use the touch screen as a keyboard to enter commands. Making the “screen keys” large and context-related, it is easy to enter these commands in flight with a fingertip, without using the stylus provided with the palmtop—which could be accidentally left on ground or dropped during flight.

The GPS receiver used is a low-cost unit, giving a horizontal precision of about 5 to 10 meters. This precision is satisfactory for agricultural applications. The TIA circuitry is shown in Figure 4. The box with the electronic modules includes a 12 V, 7 Ah battery capable of powering the system for 14 hours.

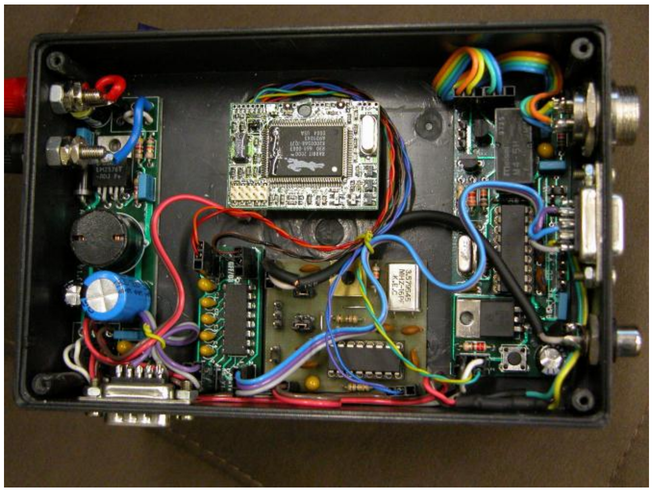


Figure 4 – TIA Hardware Implementation.

III. SOFTWARE COMPONENTS

There are three software components in TIA running on the Display and Keyboard Unit, on the Main Processor and on the Camera Controller. The software running on the Display and Keyboard Unit (Palm) has the Data Flow Diagram (DFD) presented in Figure 5. It interacts with the user and the Main processor. A GUI is included in this component and has the following menu structure:

- Main – this menu presents task information (video camera started/stopped, photo #, date, time, speed, altitude, latitude, longitude, heading), and commands (take a picture, start/stop the video recorder, start/stop the mission);
- Guidance – the main objective of this menu is to assist pilot's work presenting a target that must be followed in order to keep the flight course for the mission. Task information includes photo number, speed, altitude, and heading; commands include take a photo, start /stop the video recorder, change flight shot number);
- Mission – this menu allows the user to enter data about the mission including coordinates and altitude of the corners of the field, grid size, speed of the aircraft, heading of flight, lens focal length, pixel size and sensor size. It calculates the coordinates of the center of each grid (where a photo must be taken), the number of photos, the shutter speed necessary to keep blur under control, the flight altitude and the number of flight shots. It also presents an overview map of the mission, showing grids where plane is flying and grids where photos were taken. Task information includes photo number, speed, altitude, and heading and commands include take a photo, start/stop the video recorder;
- Photo – this menu is related with the commands to the photographic camera. It depends on the type (conventional, digital) and the brand/model of the camera. Commands are as simple as "take a shot", for conventional cameras. Additional commands such as zoom in, zoom out, set speed, set aperture, among others, are available for digital cameras;
- Video – the content of this menu depends on the camcorder's remote control capabilities, normally provided by a custom protocol, such as the Lanc from Sony;
- Compass – the compass needs a calibration procedure in order to compensate for the proximity of magnetic metals and other sources of interference on the earth's magnetic field. This menu provides a dialog to make this calibration;
- GPS – this menu presents all data collected from the GPS receiver including date, time, heading, latitude, longitude, altitude, speed, HDOP, VDOP, PDOP, satellites in view and satellites in use.

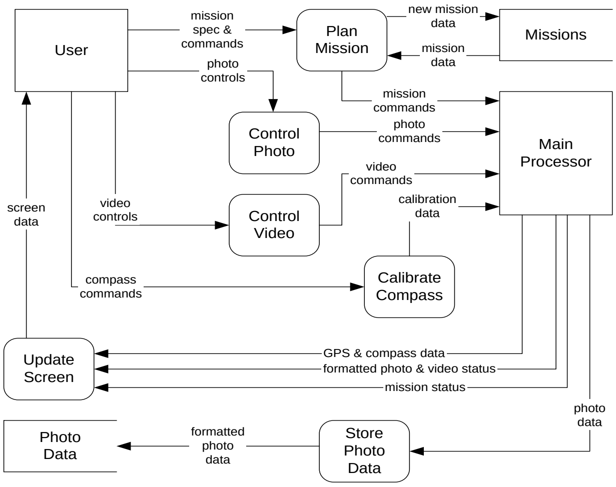


Figure 5 – Display & Keyboard Data Flow Diagram. Round-corner rectangles indicate software or action processes; the others indicate hardware or user elements.

Figure 6 shows TIA main menu.

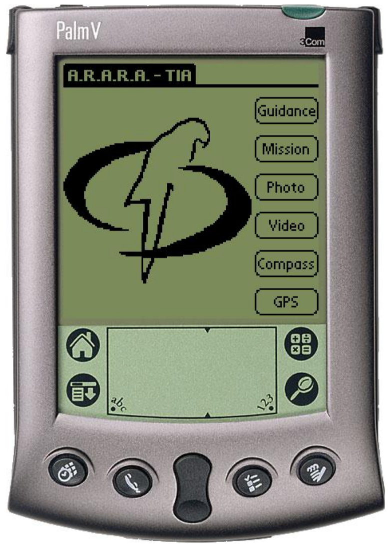


Figure 6 - TIA Main Menu

The DFD corresponding to the software component running on the Main Processor is shown in Figure 7. Most of the work done by this component is related to the mission control, sensor communication and the interface with the camera controller. Figure 8 shows the TIA Camera Controller DFD.

Software implementation was done using three different programming environments. The Display and Keyboard Unit was programmed in C using Code Warrior (for Palm computers). The Main Processor was programmed in C using the Dynamic C programming environment for Rabbit processors. Finally, the camera controller was programmed in Assembly language for PIC microcontrollers using Microchip Mplab.

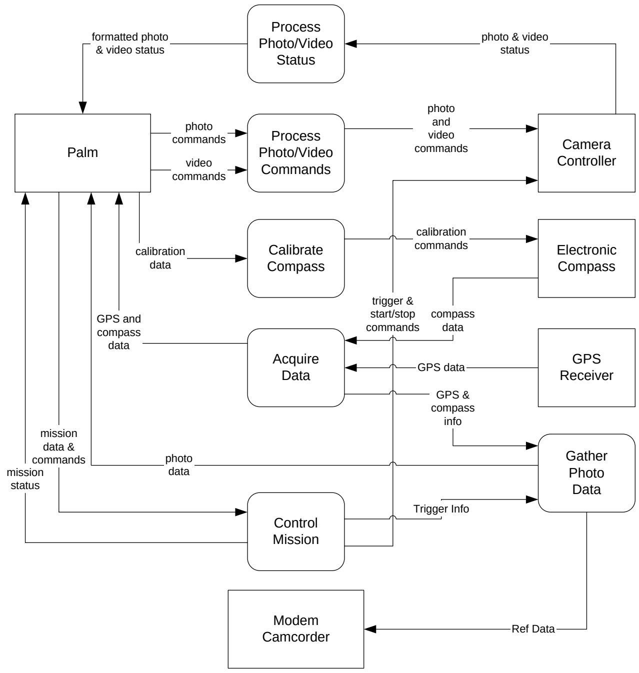


Figure 7 - Main Processor DFD

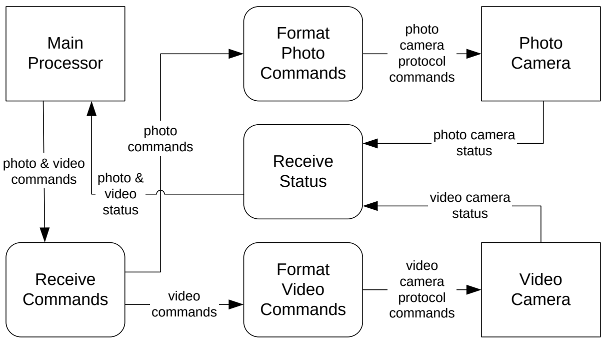


Figure 8 - Camera Controller DFD

IV. TIA IN PRECISION AGRICULTURE

In order to evaluate the usability of TIA, a test mission was done at Campo Bom farm. Located on the Brazilian midland savannas, the Campo Bom farm makes use of no-tillage planting and precision farming techniques. It has a cultivated area of about 20,000 ha, half of this area producing soybean, half producing corn in alternating years. The farm is divided in areas of about 200 ha. Four of these, two sowed with soybean and two sowed with corn, were selected for study. Two of the selected areas presented good plant development, without pests and weeds, and the other two presented some degree of pest infestation and weeds.

Mission was accomplished using a conventional, high-wing, two-seat ultralight aircraft. Images were obtained using an automatic, 35mm, single lens reflex camera (Minolta Maxxum 5 with 50mm f1.8 lens), and a Sony PC110 digital mini-DV camcorder. A pilot and a co-pilot carried out the missions. The use of a co-pilot is optional. In the test mission, the co-pilot took the photographs manually at places where there were visible problems on the field (Figure 9).

Figure 9 – TIA pilot and co-pilot (handling the TIA display and keyboard Unit).

The TIA is mounted on the ultralight aircraft using a steel bar and nylon bands attached to the aluminum tubes near the landing gear (see Figure 10 where the cameras are pointing down). Rubber mats were used over the bar to decrease vibration. The cameras and the main TIA device were fixed over the bar. The GPS unit was fixed with nylon bands on the wing structure. Therefore, the grid of photographs is non-uniform, as can be observed in Figure 11.

Figure 10 – TIA setup.

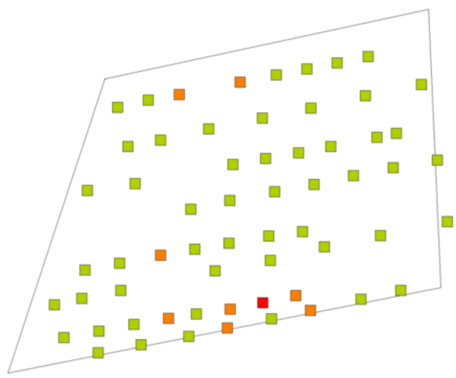


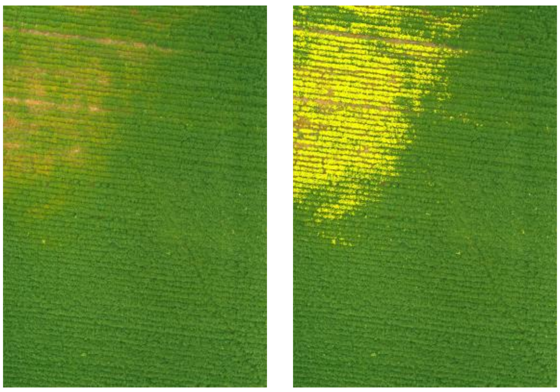
Figure 11 – One of the Campo Bom areas under monitoring showing photograph locations. Green represents areas without any problems; orange represents areas with non-critical problems such as in Figure 12e; red represents areas with critical problems such as in Figure 12a.

Figure 12 shows some pictures and some problems found on the field. Pixel size is 1 cm on the original images. All pictures shown were taken from a soybean field. Column 1 refers to the original images and column 2 to the processed images.

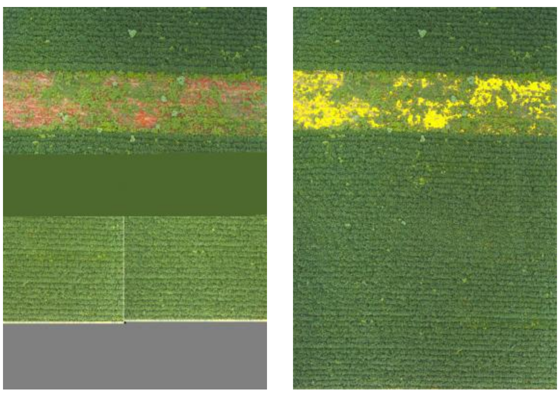
The lighter stain in photos of Figure 12a is due to a Nematode infestation. The segmented image makes possible to measure the infested area. Figure 12b presents a seeding machine fault, leading to some unsown soil. Figure 12c shows irregular plant development of unknown cause. Figure 12d shows soil erosion caused by running water. Some weed infestation is presented in Figure 12e.

Image processing was done using neural networks, speeding up considerably the process and allowing quick problem finding. Problem identification sometimes needs on-site checking by trained personnel. Problem solving can be done promptly, saving costs and time.

About two hours of video images were also obtained at a pixel size of 10 cm. Videotapes have the advantage of storing many gigabytes of images in a small package. More images result in finer grids and higher sampling. On the other hand, the low resolution of the video images (320 x 240 pixels) makes soil coverage small if compared to photographs, leading to the necessity of a large number of images. Digital photographic cameras have undergone impressive development in the last years, making them ideal for the application.

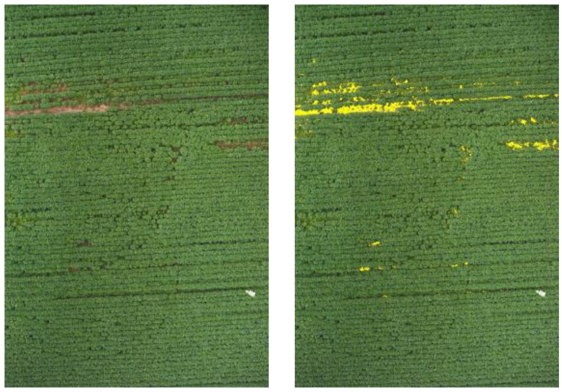


a. Nematode infestation



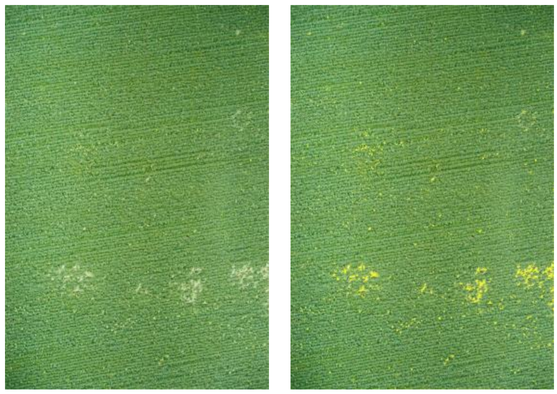
b. Seeding fault

Figure 12 – Examples of problems found on a soybean field with TIA.



c. Irregular development

d. Soil erosion by water



e. Weed infestation

Figure 12 – Examples of problems found on a soybean field with TIA.

V. Conclusion and Future Work

Equipped with TIA, ultralight aircraft proved to be a good alternative to obtain aerial images for precision farming tasks. TIA provides several tools for aerial image acquisition, including mission planning, automatic image acquisition and geo-referencing of photographic and video images. It is small enough to be mounted on most aircraft and low-cost, thus affordable for growers to use frequently. for precision agriculture, allowing intra-season corrective measures.

TIA is in use at Campo Bom Farm, embedded in ultralight and ARARA aircrafts. Applying the corrective measures indicated by the aerial photographs obtained using TIA, we expected a noticeable increase in productivity at the farms.

Work on TIA is still on going, including stability augmentation system for light aircraft flying, an altitude laser sensor for photographic scale correction, a self-levering camera support and tests using a near infrared camera. TIA is also being integrated on the new electric, low cost UAV "Tiriba" we are developing in cooperation with the National Institute of Science and Technology - Safety-Critical Embedded Systems and AGX Technology (Figure 13) [20]; an example of a soil image captured with TIA onboard Tiriba is shown on Figure 14. We are also experimenting with TIA on terrestrial platforms such as motorbikes and agricultural machinery to acquire very high-resolution imagery.

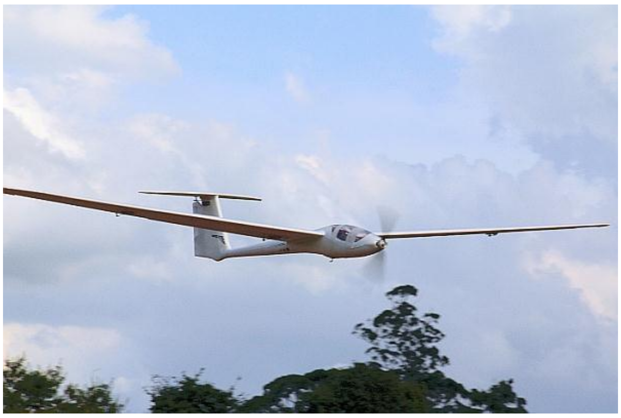


Figure 13 – The Tiriba Aircraft.

An important point in the development of Tiriba is the focus on the simplicity of the operation. Our goal is to eliminate the need for an expert in aero-photography and flight guidance for precision agriculture, allowing anyone with a little training to collect geo-referenced images. It is simpler and safer than its predecessor ARARA because we it does not require remotely-controlled take-off or landing—the vehicle is hand-launched and lands with a parachute.

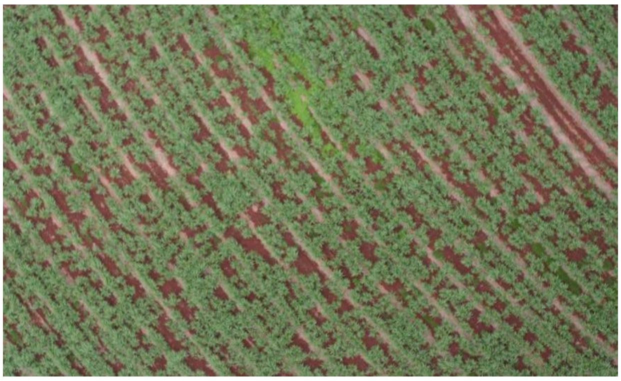


Figure 14 - Soil culture image captured using TIA onboard the new Tiriba UAV at a cruise speed of 100 km/h.

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REFERENCES

[1] J.S. Aber, S.W. Aber, F. Pavri. 2002. Unmanned Small-Format Aerial Photography from Kites for Acquiring Large-Scale, High-Resolution, Multiview-Angle Imagery. In FIEOS 2002 Conference Proceedings.

[2] E. Bartholomé, J. M. Gregoire, R. Zeyen. 1988. Small Format Air Photo from Ultralight Aircraft as an Aid for Data Collection of Agricultural Statistics in Sahelian Countries. In Proceedings of IGARSS 88 Symposium, Edinburgh, Scotland.

[3] H. Burman. 1998. Image Orientation by GPS and INS. In International Archives of Photogrammetry and Remote Sensing, v. 32, Ohio, US, July.

[4] M. Cramer. 1999. Direct Geocoding – Is Aerial Triangulation Obsolete? In Photogrammetric Week 1999, 59-70, Institute of Photogrammetry, University of Stuttgart, Germany.

[5] M. Cramer, D. Stallmann, N. Haala. 2000. Direct Georeferencing Using GPS/Inertial Exterior Orientations for Photogrammetric Applications. International Archives on Photogrammetry and Remote Sensing, 33, 198-206.

[6] M. Cramer. 2001. On the Use of Direct Georeferencing in Airborne Photogrammetry. In Proceedings 3rd International Symposium on Mobile Mapping Technology, Cairo.

[7] Graham, R. 1986. Manual of Aerial Photography. Focal Press.

[8] H. Heier. 1998. Applications and Market for Digital Airborne Cameras. In Photogrammetric Week 1998, 43-49, Institute of Photogrammetry, University of Stuttgart, Germany.

[9] E.N. Johnson, P.A. DeBitteto, C.A. Trott, M.C. Bosse. 1996. The 1996 MIT/Boston University/Draper Laboratory of Autonomous Helicopter System. In Proceedings of the Digital Avionics Systems Conference, 15th AIAA/IEEE, 381-386.

[10] D.J. King,. 1995. Airborne Multispectral Digital Cameras and Video Sensors: A Critical Review of Systems Design and Applications. Canadian Journal of Remote Sensing, Special Issue on Aerial Optical Remote Sensing, 21, 245-273.

[11] F.R. Leiva, J. Morris, B.S. Blackmore. 1997. Precision Farming Techniques for Sustainable Agriculture. In Proceedings 1st European Conference on Precision Agriculture, Warwick. 957-966.

[12] J.F.G. Monico. 2000. Posicionamento pelo Navstar-GPS. Editora Unesp. (In Portuguese.)

[13] M. Mostafa, J. Hutton. 2001. Airborne Remote Sensing Without Ground Control. In Geoscience and Remote Sensing Symposium, 2961-2963.

[14] J.F.C. Silva, P.O. Camargo, M.C. Guardia, M.L.L. Reis, R.A.C. Silva, R.B.A. Gallis, R.A. Oliveira. 2001. Mapeamento de Ruas com um Sistema Móvel de Mapeamento Digital. Revista Brasileira de Cartografia, 53, 82-91.

[15] J, Skaloud, 1993. Direct Georeferencing Aerial Photogrammetric Mapping. Photogrammmetric Engineering and Remote Sensing: Journal of the American Society for Photogrammetry and Remote Sensing, 68, 3, 207-210.

[16] O. Trindade Jr., M. S. Carmo, R. E. Ribeiro. 2000. Small Aircraft for Application in Agriculture, In: Proceedings (electronic format) of the ASAE Annual International Meeting. Milwaukee, USA.

[17] W. S., Warner, R. W. Graham. 1996. Small Format Aerial Photography. Whittles Publishing.

[18] L.S., Monteiro, T., Moore and C., Hill. 2005. What is the accuracy of DGPS?, The Journal of Navigation, 58, 207-225.

[19] K. R. L. J. C. Branco; J. Pelizzoni,; L. O., Neris,; O. Trindade Jr; F. S. Osório; D. F. Wolf. 2010. Tiriba A New Approach of UAV based on Model Driven Development and Multiprocessors. In: IEEE International Conference on Robotics and Automation, Shanghai. China, p. 1- 4.

[20] O. Trindade Jr; L.O. Neris; L. Barbosa; K. R. L. J. C. Branco. 2010. A Layered Approach to Design Autopilots. In: IEEE-ICIT - International Conf. on Industrial Technology, Viña del Mar. Chile, p. 1395-1400.

[21] M. Rieke, T. Foerster, J. Geipel, T. Prinz. High-precision positioning and real-time data processing of UAV systems. Conf. on Unmanned Aerial Vehicle in Geomatics, Zurich, Switzerland, 2011. p 1 – 6.

[22] L. C. P., Barbosa. 2001. SiNaCoM – Sistema de Navegação e Controle de Missão do Projeto ARARA. MSC Thesis, University of São Paulo. (In Portuguese.)