VOLUME 2

AERIAL VIDEOGRAPHY

Principles and implementation

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Foreword

This document outlines the principles of acquiring aerial data using digital videography. It describes the implementation of this method, the preparation of a flight for images acquisition and the integration of the aerial mosaic in a geographical information system (SAVANE). An executive summary gives a quick look of the method and results. A detailed technical guideline describes all the operations. The example highlighted throughout this document is on the refugee camps of Kenya, in which this method of acquiring images has been used to come up with a precise cartography of the camps.

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Executive Summary

Aerial Videography and cartography of the Refugee camps in Kenya

The method of air data acquisition trough numerical videography suggested in this document makes possible to obtain aerial images with a possible resolution (i.e. size of a pixel, element of image) variable from 3 meters to 0.2 meters. It is located thus between the resolution of the current civil satellites of observation most powerful and traditional aerial photography. The developed method aims answering constraints often met in the developing countries, to minimise the deadlines, the costs and the infrastructure necessary to the catch of air sight.

The light air remote sensing meets many technical needs : basic cartography, cartography of soil using on a large scale, thematic cartography, sampling, updating, etc. Many disciplines are concerned by these techniques : one can quote hydrology (irrigation and water stock management), environment and natural resources management, rural development, urban development, land tenure ...

The principles of the method presented in this document are the following : after having prepared a detailed flight plan (2), the overflight by light plane with a numerical video camera and directed towards the ground in a roughly orthogonal way (3) makes it possible to have a video film covering wished surface, by parallel traces with a certain overlap between traces (4). From numerical video film, one can extract directly digital images and download them on a computer. The user has the choice of the images to capture : he must only ensure himself of the correct overlap between the images and their best horizontality.

After downloading the images on a computer (6), it is necessary to find points of geographical reference to locate, readjust and rectify the images in order to eliminate the deformations due to the catch from sight (optical deformations, horizontality, altitude). One associates position of a point in the captured image and real geographical position to create points of landmark. The real geographical position can be given directly by GPS on the ground (5), or on an already readjusted and positioned photograph, on a chart, etc. Lastly, thanks to the landmarks, the captured images are rectified (i.e. put in geographical conformity), readjusted (i.e. positioned in space), then joined (7) (i.e. integrated in a whole of images) to constitute a geo-referred mosaic (8). This mosaic is integrated in a geographical information system, which makes it possible in its turn to use the mosaic as a basic map for later work (9) (digitisation, representation, thematic cartography, etc.).

The method described above was used to carry out the cartography of the refugee camps in Kenya (Kakuma, Dadaab), within the framework of the research agreement on the refugees being the subject of a convention between the UNHCR and the IRD (ex-ORSTOM).

Many difficulties were joined together on this site : difficult access (the camps are far away from the great agglomerations), unstable weather conditions (El Niño consequencies), lack of cartography to large and average scale, logistical difficulties, security concern, etc. Nevertheless, the method of catch of sight was effective in spite of these difficult conditions : we thus could carry out geo-referenced mosaics of the four refugee camps of Kenya : Kakuma, Ifo, Dagahaley, Hagadera. The method as well as the results obtained are presented in the second part of this document.


Dadaab satellite image (1)


Hagadera's flight plan (2)


Preparing the flight (3)


Flight plan GPS survey (4)


Field GPS survey (5)


Downloading the pictures (6)


«Mosaiquing» *(7)*


Global mosaic (8)


Digitisation on the screen (9)

Technical Guideline

Chapter 1

Generalities

From aerial photography to satellite images, many are the methods to obtain earth images trough remote sensing techniques. The method of aerial images acquisition trough numerical videography suggested in this document makes possible to obtain aerial images with a possible resolution (i.e. size of a pixel, element of image) variable from 3 meters to 0.2 meters. It is located thus between the resolution of the current civil satellites of observation most powerful and traditional aerial photography. The developed method aims answering constraints often met in the developing countries, to minimise the deadlines, the costs and the infrastructure necessary to the catch of air sight.

This development of this method of acquisition falls under methodological research of Geographical Information Systems (GIS) : it is comprised of development of methods and software for the setting up, «mosaiquing» and integrated management and processing of the images data in a GIS (SAVANE). In this guide, all stages of methodology, acquisition of images to their integration in a geographical information system are explained.

This method of acquiring images was used in Kenya, under the IRD/UNHCR co-operation programme on refugees. This guide gives a detailed description of the example, which also puts together several difficulties in implementation (accessibility, security, infrastructure, and climate.).

Light air remote sensing : many applications

The light remote sensing methods relates to all the techniques aiming at obtaining air images of the Earth by air trough accessible tools easy to carry on. It completes the traditional air photography and satellite images.

The light air remote sensing meets many technical needs : basic cartography, cartography of soil using on a large scale, thematic cartography, sampling, updating, etc. Many disciplines are concerned by these techniques : one can quote hydrology (irrigation and water stock management), environment and natural resources management, rural development, urban development, land tenure ...

To achieve a light air remote-sensing programme, one needs an apparatus of catch of sight (camera) and a mean of transport of this apparatus. Among the means of transport, one can quote : light single-engine aircraft, helicopters, ULM, drones (planes without pilots), balloons, airships and Montgolfiers. The apparatuses of catches of sight form two groups: on the one hand traditional optical cameras, on the other hand numerical captors. The method presented in this document - the aerial videography - uses a numerical video camera embarked on a light aircraft or an ULM.

Aerial Videography : General Principles

The general principle of aerial videography is as follows :

After preparing a precise flight plan, flying using a low airplane with a digital camera, directed towards the ground in an approximately orthogonal manner enables one to have a video film covering the desired area in parallel tracks with an overlap between the tracks. The user chooses which images to download : he must only be sure of the images overlap and ensure proper seating on the airplane.

After the (optional) printing of the images on paper, it is necessary to identify points of geographical reference to confine, correct and set up and thus exclude deformations during shooting (as a result poor seating position on the flight or optical deformations). The position of a point in a captured image and the real geographical position are associated to create the landmark points. The real geographical position can be determined directly by the GPS on the ground or from photography already mounted and positioned, on a map, etc. Finally, using the landmark points, the captured images are set up (that is, put in geographical conformity), mounted (that is, positioned in space) and then integrated into the entire images to constitute a geo-referenced mosaic.

We will first situate this method within the general context of the methods of acquiring images in visible spectrum.

Actual methods of acquiring remote sensing images in the visible spectrum

Today (1999), it does exist many performing methods of acquiring images on the Earth using civil remote sensing techniques in the visible spectrum. By order of resolution (height of pixel, element of image), they are :

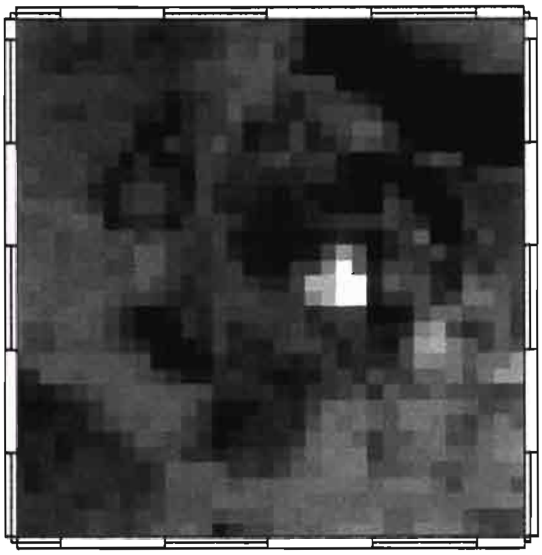
- Satellites with Low Resolution (height of highest pixel up to 500 meters)
- Satellites with Medium Resolution (height of pixel between 500 and 50 meters)
- Satellites with High resolution (height of pixel between 50 and 5 meters)
- Satellite with very high resolution (height of lower pixel - to 5 meters)
- Aerial videography (height of lowest pixel 3 meters)
- Aerial Photography

Aerial videography enables one to obtain resolutions varying between 3 and 0.2 meters. Satellites with low and medium resolution do not fall in this field of operation. Civil satellite images in high resolution have a resolution that can attain 2 meters, but the most current images are those of the SPOT satellite (10 meters in panchromatic mode, 20 meters in multi-spectral mode). The cost is between 0.3 USD/km2 for Landsat (one image cover 34000 km2) and 0.6 USD/km2 for Spot (an image cover about 3600 km2). Other satellites with high resolution (between 5 and 1 meter) will definitely be introduced in the years to come (2000-2005), and could thus make obsolete the technique of acquisition trough numerical videography ; unless the flexibility of the method, the speed of obtaining of the result and the increase in resolution of the video sensors do not continue to make it competitive.

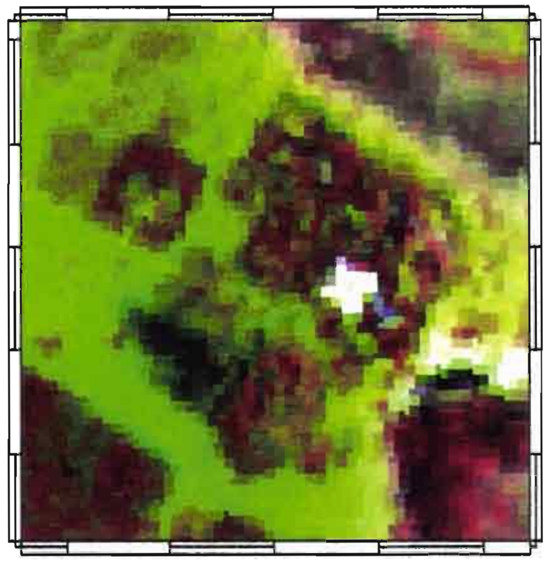
Of all the methods of acquisition, classical aerial photography remains the best as pertains to resolution : a scanned aerial photograph enables one to have a resolution much lower than a meter. On the contrary, cost is an important factor (from 50 $/km2 for a 1000 km2 survey) and implementing an aerial photography campaign calls for the use of heavy means. Since the principal criteria is the resolution and that there already exists a recent aerial photography cover, it is preferable to buy and then scan the photographs than take an aerial view again using another method. Often, the colour is missed out : most of the aerial photographs are in black and white.

Thus, aerial videography enables the classical aerial photography and us to ensure the continuity of the resolutions between the high-resolution satellite images. We can develop a comparative matrix of the diverse methods using various criteria :

	resolution	availability	cost	meteorology	Duration
Satellite	from 30 m to 2 m	Depends of the satellite and meteorological conditions	0.3 à 0.6 USD/km^2	No clouds	From some days to some months
Videography	from 30 m to 0.2 m	Must be managed: light aircraft, video-camera, GPS	5 à 20 USD/km^2	No clouds under the flight plan level	Some days
Aerial photographs	Up to 0.1 m	Classical aerial photograph techniques	10 à 50 UDS/km^2	No clouds under the flight plan level	From some days to some weeks



1. *Landsat TM (30 meters resolution)*



2. *SPOT XS (20 meters resolution)*

3. *Panchromatic SPOT (10 meters resolution)*

4. *Videography (1 meter resolution)*

Fig 1: Examples of images from the same area with different resolutions: Satellite Landsat (30 meters), SPOT Multi-spectral (20 meters), SPOT panchromatic (10 meters), videography (1 meter).

Aerial Videography : Principles and Techniques

Aerial videography uses many techniques whose principles are worth understanding : geodesy and cartography, accurate aerial navigation, digital videography, positioning by differential GPS, correction and re-sampling of images, mosaiquing and geographical information systems.

Geodesy and Cartography

To represent a point on the Earth, a simple mathematical surface, which is close to the real shape of the earth is used. This surface has the shape of a revolution ellipsoid and enables to represent the position of a point using spherical co-ordinates : longitude, latitude, altitude in relation to the surface of the ellipsoid. Practically, several sizes and positions of the ellipsoids are used : it is necessary to be careful with the parameters used (the datum).

To represent a piece of this curvilinear surface on a flat surface, we use cartographic projection exercise, which deforms the curvilinear surface and projects it on a two-dimension plan.

Aerial Navigation

To ensure proper covering of the area to be represented on the map, it is necessary to inform the pilot of the light aircraft, the total number of parameters in order to enable him undertake an accurate navigation. A flight plan should be made using geographical co-ordinates of entry and exit points of the tracks (navigation is then done by GPS following an orthonomy, lines of the shortest curvilinear distance between two points of the same altitude), or using an entry point and a cape (navigation is then done by compass according to a loxodromy provided that the vertical stability of the aircraft is taken into account).

The Principle of Videography and the miniDV Digital Format

A video film is made up of consecutive images (frames) at the rate of 50 (PAL, SECAM) or 60 (NTSC) images per second. Each frame corresponds to the scanning of one line out of two on the screen, which in turn enables one to have a full image every 1/25th (PAL, SECAM), or 1/30th (NTSC) of a second and to make sure that there is a better result of the motion (it is said that the images are intertwined, with both odd and even frames). The miniDV digital video format is made up of 720*576 pixels for each frame.

Acquiring a Fixed Image

An image can be captured from two consecutive frames of the video film, in order to obtain a fixed image. Using digital coding of the signal and DV format resolution, the fixed images are of excellent quality and cannot be obtained when using a video camera, which has almost the same format as the Hi8.

If the speed of the object to be filmed in relation to the video camera is high, two consecutive frames (distance of 1/50th or 1/60th of a second) will show big differences and the fixed image will be constituted from one of the two frames only due to a minor interpolation between the lines.

The Principle of Differential GPS

The GPS system (Global Positioning System) is a system of global positioning using satellite, enabling one to calculate the position of any point whatsoever on the Earth, in the three dimensions. Simultaneously, the GPS system enables the aircraft to have an accuracy of 100 metres, the measurements being obscured by several factors : error on the orbital parameters of the satellite, errors on the satellite clock, errors of propagation of signals due to weather conditions and to the satellite positions, error from the radio clock, errors of reception due to reflections of the signal, voluntary degradation of the signal by the Department of Defence of USA (who manage the system).

To locate one's position with an accuracy corresponding to the resolution of the image, it is necessary to take the measurements with relative accuracy among all the points less than a meter. This accuracy can be obtained using the differential GPS.

Adjusting and re-sampling of images

In determining the correspondence between the points of the image and the points localised geographically (using landmarks), one can calculate the modifications to put on the image to make it concur with the geographical reality following a given geographical projection. With two landmarks, a rotation can be carried out followed by a translation. With three landmark points, a polynomial distortion of 1degree can be carried out. With several landmark points, a local adjusting can be done by covering 1-degree distortion in each triangle emerging from triangulation between the landmark points.

Re-sampling enables one to modify the resolution in the arranged image by choosing the pixels to take into account in the original image in order to calculate the value of an arranged pixel in the target image.

Mosaïquing and Geographical Information Systems

From the rectified images, integrating the pixels of the adjusted images into one whole can constitute one big image. The structure of a mosaic is more complex than that of a simple image because mosaic does not necessarily have the shape of a rectangle. Mosaics are managed by geographical information systems. These systems enable one to manage other types of geographical data (polygons, lines, points) and to compare among them these different data types.

Materials and software required implementing aerial videography

Materials required :

- Digital video camera that can capture fixed images on a computer (SONY type DCR-VX1000E with a DVBK2000E target for capturing image on a computer)
- A waterproof battery 12V7VAH (minimum), a battery charger 12V and a special 12V cable for the camera
- Special mounting that enables to set the camera vertically outside the aircraft with device for adjusting the seating and inclination
- An adjustment instrument for the focal distance (for cameras with different focal distance that does not show the actual focal distance)
- Alternatively, a small 12 V control monitor equipped with a video input
- Two GPS enabling differential measurements for relative positioning of less than a meter (MAGELLAN PROMARK X CM type)
- Two professional antennae with a tripod for the GPS
- A computer to charge the measurements from the GPS (an exercise to be undertaken every half day) to download images from the camera, to rectify, resample, mosaic them and use the mosaic

Required Software

Software for acquiring fixed images (supplied with the camera or capture card),
Software for calculating differential positions for GPS points (supplied with GPS),
Software for preparing a flight, to rectify the images and to mosaic them,
Geographical information system that works with mosaic or a large volume of images.

The SAVANE geographical information system was used for all the exercises presented in this document.

Cost evaluation

To evaluate the total cost of the aerial videography exercise, we will need to aggregate an estimated cost of the materials and software, the costs of infrastructure (hiring an aircraft), manpower costs (basing on the expertise rate of the Institute) and overall transport costs.

Material and Software

Filming : 4,200 $ (camera), 700 $ (capture), control monitor (170 $), other equipment's (170 $)
Differential GPS : two units (20,000 $), two antennae (2,500 $), tripod (340 $)
Lap Top : 4,200 $
Software : depends on the GIS used (2,000 $ for the SAVANE system)

The total estimated cost for the purchase of material and software is 33,000 $. Expecting depreciation in costs within three years, at the rate of 4 exercises by year, depreciation per exercise can be estimated at 1,700 $ (the same is also expected of GPS and Computer on other exercises). Without the GPS, depreciation falls below 800 $.

Preliminary maps and Data

Maps, satellite images or aerial photographs (a Panchro SPOT scene costs between 1,000 and 2,800 $).

Filming

Cost of fieldwork for a few days by an engineer (170 $/day).
Hiring an aircraft with a pilot (between 170 and 670 $/hour).

Countryside GPS Exercise

Cost of a field exercise for several days by an engineer or technician (170 $/day).

Capture and sampling of Images

This depends on the number of images (about 30 images/day per operator) (1KF/day).
This cost of this exercise therefore varies between 3,300 and 17,000 $ to which transport costs must be added.

Perspectives

Digital photography is undergoing rapid change, and especially with increase of cheap high-resolution video cameras (1999, cameras with a resolution higher than 1.3 MegaPixels for an image with a resolution of 1600*1200). If the principles remain valid, the camera can be adequately replaced by a high resolution filming equipment that enables the capture and storage of digital images in a magnetic form within a short time, at a rate compatible to the needs of aerial filming (almost one image per second). This technology would enable one to make filming much easier and to increase the resolution tremendously.

Chapter 2

Planing an Aerial Videography Exercise

Like in the case of aerial photography, it is important to draw an advance plan of all the steps to be undertaken in an aerial videography exercise. This plan entails :

• definition of objectives (area to be covered, required resolution)
• Available infrastructure for filming and extraction of landmark points (accessibility, security, road ground, available aerial transport)
• Weather forecast
• Flying rights for the area to be covered
• Preparing the material on the spot
• Cost evaluation for the entire expected exercise (flight, extraction of points using GPS, existing maps, sampling, GIS)

Definition of Objectives of the Survey : Territory, Resolution, and Accuracy

The area to be covered must be accurately defined. Basic existing maps must be used in this definition. If the area to be covered is not on the map, a geographical description is important : GPS points, single elements, etc. A satellite image, even with a medium resolution is useful in the preparatory phase.

The required resolution must be defined at this stage of the project. The result of aerial videography is a digital image, made up of pixels (elements of the image). The resolution is equivalent to the relative accuracy of the pixels in the image. Giving a resolution is thus giving a size to a pixel (if a resolution is one meter, then this means the pixel is one meter big).

The resolution is fixed depending on the minimum size of the objects which must be visible in the image (if it is estimated that four pixels will be required in each dimension to recognise a car in an image, and that the car measures at least 4 metres long, then a resolution is required to see the car in the image). To fix the resolution, one must evaluate the accuracy by identifying the objects, which must be visible in the image by their real size, as well as the number of pixels required to represent them adequately.

Absolute accuracy corresponds to the accuracy of the geographical location of each pixel (in the geographical projection used). This absolute accuracy must equally be evaluated at this stage, because planning of the exercise of extracting landmark points, sampling and inserting depends on it).

A fixed image captured from a video film has a resolution of 720 over 576 pixels (MiniDV format). Setting the resolution gives the real size of the image projected. While bearing in mind that an overlap between the images is important (around 20 % of the area), an estimate can be made of the number of images necessary for this mosaic in relation to the area to be covered and the required resolution.

The number of images to process must be compatible to the stocking capacity, processing, and rectifying possibilities of the project. Generally, a project should try not to go beyond some hundreds of images.

Example : Kakuma

Thanks to the aerial photographs taken in 1993, mosaiquing using reference points from the ground, the area to be covered in order to represent this refugee camp in Northern Kenya on a map and its immediate surroundings can easily be evaluated (see Fig.1) : the area to overfly is 10 km by 4, totalling 49 km. We hope to use a new mosaic with a resolution of 1.5 meters. With this kind of resolution, every image captured from video film is 1100 by 775 meters. Thus, without overlap, we need a 10 track images and 6 tracks. With an overlap of 20 %, we need 12 track images and 8 tracks, totalling 96 images.

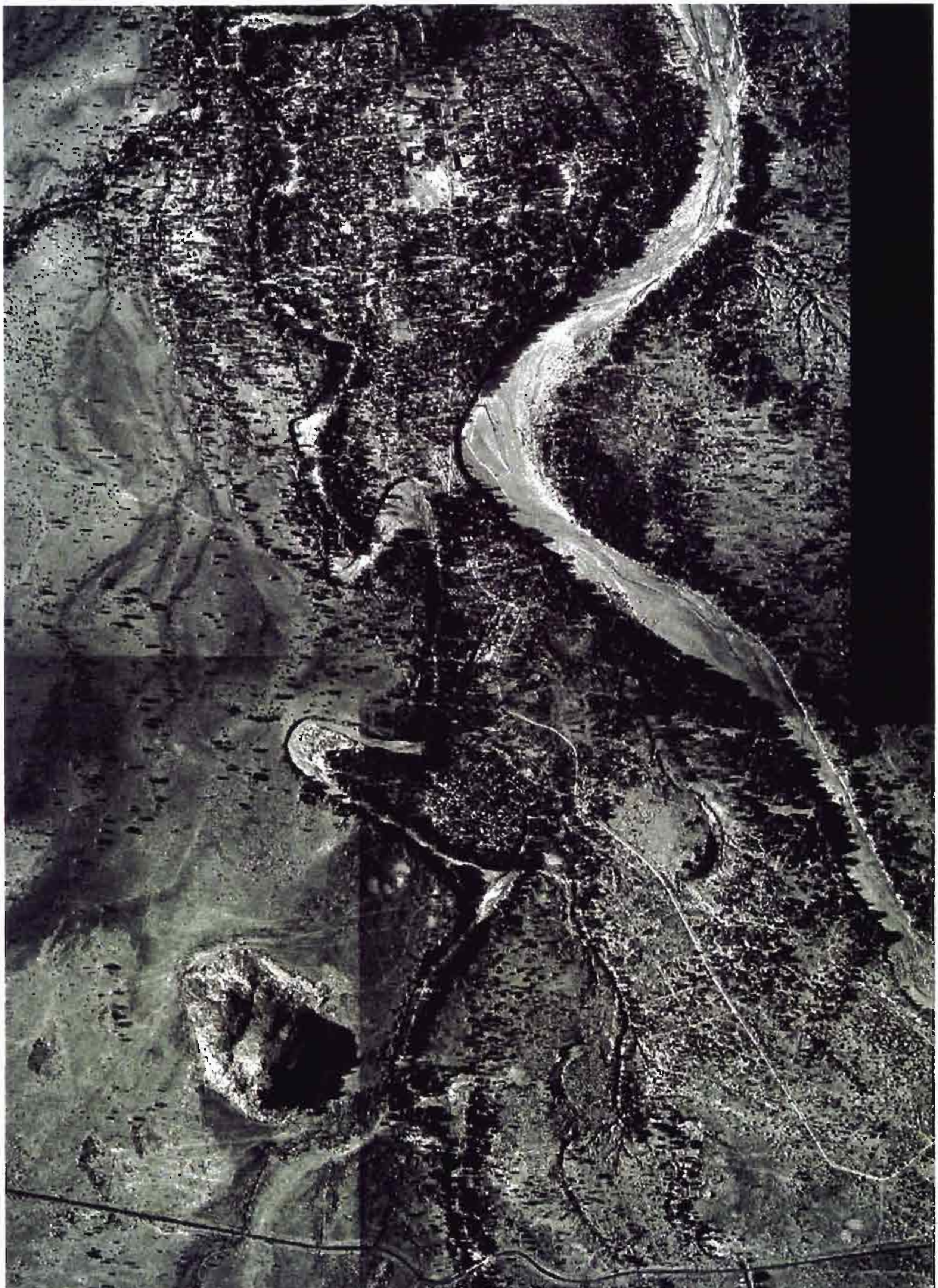


Fig. 2 : Kakuma refugee camp : mosaic of aerial photographs (1993)

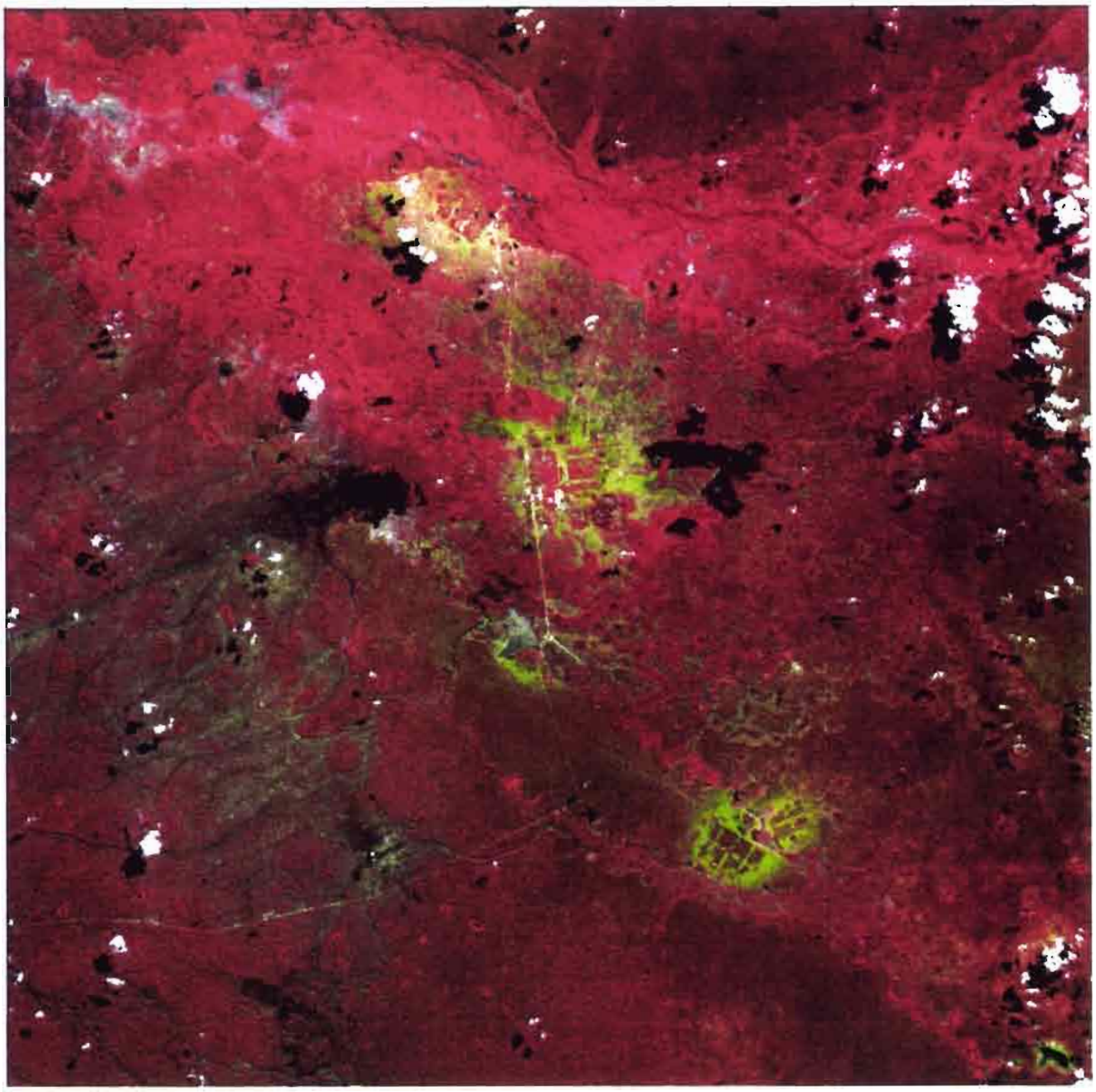


Fig 3 : Spot Image (coloured composition, 20 m resolution) of the Dadaab area

Example : Ifo, Dagahaley, Hagadera

We are using a SPOT satellite image after general correction using some landmark points extracted from the field by GPS (the difference in altitude does not exceed a few meters), enable us to know the general configuration of the area (Fig. 3). We need images with a high resolution (0.8 meters).

Infrastructure

A light aircraft is required for filming. This aircraft must meet several requirements :

• Be locally available
• Allow for fixing the camera, and generally removing one lateral door
• Allow for a flight at the required altitude as required by the flight plan (this altitude varies between 800 m and 3,000 meters above sea level)
• Have instruments on board that enable the flight plan to be followed with the expected accuracy
• Have hiring costs that fall within the project budget

Different Cessna aircraft's meet these requirements (particularly, high wings enable one to fix the camera without problems).
Piloting the aircraft is no doubt the most risky aspect of aerial videography. Aerial navigation must be very accurate to ensure proper overlap between the tracks. (We will look at piloting in more detail later when discussing preparation of the flight and filming).

To ensure absolute accuracy of the pixels and the exact location of images, it is important to know the geographical location of the points in the images. In situations where the existent maps do not indicate this location, one must go to the field with GPS to extract the geographical co-ordinates. In this case, accessibility on the ground must be possible : need for vehicles, problems of accessibility and security must be evaluated. These requirements determine the total accuracy required and the expanse of the area to be covered. We shall discuss this in more detail in the chapter on extraction of points by GPS).

Authority and Weather Conditions

Many flights require special permission to fly. Some are prohibited. Aerial filming is sometimes a reserve of the military. All restrictions and administrative rules must be assessed before undertaking a flight exercise.

It is imperative to know the weather conditions. They must also conform to the flight plan drawn, because it is not advisable to fly above clouds. Turbulence directly affects the seating of the aircraft and the quality of average verticality of the images. Lateral wind also has a big influence, forcing the aircraft to move sideways in order to conform to the flight plan : the images are systematically taken at a horizontal angle that corresponds to the bend of the aircraft.

Intense vertical sunlight often creates "hot spots" in the images. Despite this, sunlight improves the contrast and the sharpness of the video images. It is thus better to undertake a flight exercise on a clear and sunlit day. On the other hand, avoid unsystematic and consecutive exposure to the sun, which will lead to sharp differences in the contrast and brightness of the images.

Preparation of the equipment on the spot

In order to film using a digital video camera, it is necessary to have :

• A digital video camera that can capture fixed images on the computer (we use a SONY DCR-VX1000E camera equipped with a DVBK 1000E card)
• A UV filter for the camera
• Cassette recorders (note that actual filming time should be doubled in this case - one hour cassettes are recommended to avoid changing the cassette during the flight)
• A charger (12 V) for connection to the camera (cigarette lighter type)
• A 12V 7VAH dry battery (minimum) and a special 12V connection cable for the camera
• Special mounting that enables to set the camera vertically outside the aircraft with adjustable device for setting and inclination
• An adjustment instrument for the focal distance (for cameras with different focal distance that does not show the actual focal distance)

• Alternatively, a small 12 V control monitor equipped with a video input, a cable to connect the output of the video camera onto the input of the video monitor, a 12V connection cable for the monitor, a 12V 3VAH battery (minimum)
• A 21V battery charger
• A voltmeter
• Necessary tools for fixing: spanners, screwdrivers
• Adhesive tape, scissors, insulation tape for electric cables. Large rubber band (tube type)

If a high-resolution camera taking only fixed images is used, it is necessary to have a laptop, with PCMCIA type of connection in order to capture images within actual time.

Fig. 4 : required equipment on the spot

Chapter Three

Preparation for Filming

Aerial Navigation

Accurate aerial navigation is a difficult task. In order to be able to prepare a flight plan and follow it to the requirements set, and exploit the technical capacity of the aircraft, the pilot must have good experience in this domain. If the flight plan must be accurate and well followed, it is to avoid missing out any uncovered zones in the area to be represented on the map. From previous research, a slight gap/difference between the flight and the flight plan can engender non-jointed tracks, thus rendering the exercise incomplete.

Generally, the flight must follow regular and parallel tracks to be able to cover the entire territory to be overflown (it would be better to plan the tracks with constant direction). A lateral overlap of the tracks should also be done to undertake a successive mosaic of the images. The tracks must thus be defined with as much accuracy as possible.

In order to follow the tracks, the pilot can use sophisticated navigation equipment (GPS and automatic pilot) or fly using landmarks on the ground. The first method is obviously more inappropriate than the second one, but requires equipment, which is not readily available on light aircraft's.

Automatic Pilot and GPS : the pilot inserts in the aircraft's GPS the points which the plane must overfly (generally, the entries and extraction of points). The pilot must them prepare a flight plan so that the automatic pilot of the aircraft can follow the tracks (entry in the track must take into account the general cap of the track).

Flight on site : the pilot must follow the tracks (entries, exits, cap) basing on the landmarks on the ground (roads, buildings, etc). This type of navigation can be difficult or even impossible if the landmarks are hardly visible, the altitude is very high, visibility of the ground poor, the drift large, etc.

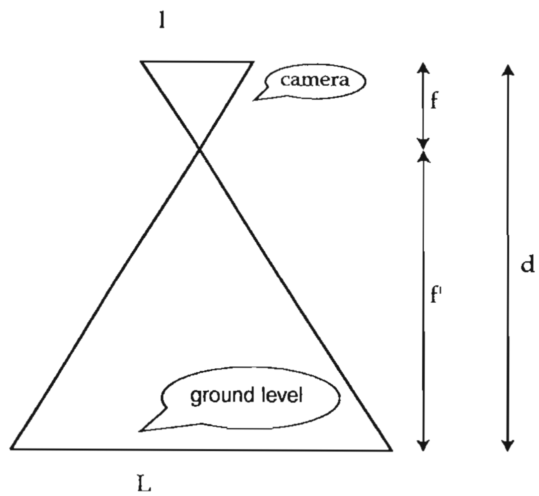
Preparing a flight Plan

Whatever method of navigation one chooses to use, it is imperative to have an accurate flight plan. This plan should include the altitude, the method (flight by view or GPS), entry and exit points of the tracks, speed, adequate time etc.

Altitude

Choosing the altitude to fly the airplane depends heavily on three factors : the resolution of the capture of the camera; the required resolution of the images and the focal distance of the camera (See the Tables). This choice must however be guided by several other factors, among them, the weather conditions (few clouds, little turbulence), excellent focal distance (not too short to reduce the angle of the bright rays on the edge of the images) and the required resolution. When navigation is done on sight, altitude should not be very high (below 2,000 m above sea level).

l : width of camera CCD captor
L : size of track on the ground
F : focal length
f' : Distance of focal plan on the ground
d : Distance of camera CCD on the ground



f=l*(d/L)/(1+l/L) d=L(f/l) + f L=(l/f)*d - l

	0,5	0,6	0,7	0,8	0,9	1	1,1	1,2
45	455	546	637	728	819	910	1001	1092
50	501	601	701	802	902	1002	1102	1202
55	565	678	791	904	1017	1130	1243	1356
60	615	738	861	984	1107	1230	1353	1476
65	674	809	944	1079	1214	1349	1483	1618
70	689	827	964	1102	1240	1378	1515	1653
73	744	893	1042	1191	1340	1489	1637	1786
76	789	947	1105	1263	1421	1579	1737	1895
80	845	1014	1183	1352	1522	1691	1860	2029
83	893	1071	1250	1428	1607	1785	1964	2143

	1,3	1,4	1,5	1,6	1,7	1,8	1,9	2
45	1183	1274	1365	1456	1547	1637	1728	1819
50	1303	1403	1503	1603	1703	1804	1904	2004
55	1470	1583	1696	1809	1922	2035	2148	2261
60	1599	1722	1845	1968	2091	2214	2337	2460
65	1753	1888	2023	2158	2292	2427	2562	2697
70	1791	1929	2067	2204	2342	2480	2618	2755
73	1935	2084	2233	2382	2531	2680	2828	2977
76	2052	2210	2368	2526	2684	2842	3000	3158
80	2198	2367	2536	2705	2874	3043	3212	3381
83	2321	2500	2678	2857	3035	3214	3392	3571

Table I : The altitude of the flight (in meters) in relation to the resolution (in meters) and the focal distance (in mm), for the miniDV format (size of the capture 768 pixels)

In the tables, we consider l = 36 mm in order to obtain a focal distance that corresponds to a photographic format of 24 x 36. The real size of the CCD capture of the video camera is much smaller.

	1000	1100	1200	1300	1400	1500	1600	1700
45	1,10	1,21	1,32	1,43	1,54	1,65	1,76	1,87
50	1,00	1,10	1,20	1,30	1,40	1,50	1,60	1,70
55	0,88	0,97	1,06	1,15	1,24	1,33	1,42	1,50
60	0,81	0,89	0,98	1,06	1,14	1,22	1,30	1,38
65	0,74	0,82	0,89	0,96	1,04	1,11	1,19	1,26
70	0,73	0,80	0,87	0,94	1,02	1,09	1,16	1,23
73	0,67	0,74	0,81	0,87	0,94	1,01	1,07	1,14
76	0,63	0,70	0,76	0,82	0,89	0,95	1,01	1,08
80	0,59	0,65	0,71	0,77	0,83	0,89	0,95	1,01
83	0,56	0,62	0,67	0,73	0,78	0,84	0,90	0,95

	1800	1900	2000	2100	2200	2300	2400	2500
45	1,98	2,09	2,20	2,31	2,42	2,53	2,64	2,75
50	1,80	1,90	2,00	2,10	2,20	2,30	2,40	2,50
55	1,59	1,68	1,77	1,86	1,95	2,03	2,12	2,21
60	1,46	1,54	1,63	1,71	1,79	1,87	1,95	2,03
65	1,33	1,41	1,48	1,56	1,63	1,71	1,78	1,85
70	1,31	1,38	1,45	1,52	1,60	1,67	1,74	1,81
73	1,21	1,28	1,34	1,41	1,48	1,55	1,61	1,68
76	1,14	1,20	1,27	1,33	1,39	1,46	1,52	1,58
80	1,06	1,12	1,18	1,24	1,30	1,36	1,42	1,48
83	1,01	1,06	1,12	1,18	1,23	1,29	1,34	1,40

	2600	2700	2800	2900	3000
45	2,86	2,97	3,08	3,19	3,30
50	2,59	2,69	2,79	2,89	2,99
55	2,30	2,39	2,48	2,57	2,65
60	2,11	2,20	2,28	2,36	2,44
65	1,93	2,00	2,08	2,15	2,22
70	1,89	1,96	2,03	2,10	2,18
73	1,75	1,81	1,88	1,95	2,02
76	1,65	1,71	1,77	1,84	1,90
80	1,54	1,60	1,66	1,72	1,77
83	1,46	1,51	1,57	1,62	1,68

Table 2: resolution (in meters) in relation to altitude (in meters) and the focal distance used (in mm), for the miniDV format (size of the capture 768 pixels)

mètres	feet
1000	3049
1100	3354
1200	3659
1300	3963
1400	4268
1500	4573
1600	4878
1700	5183
1800	5488
1900	5793
2000	6098

mètres	feet
2100	6402
2200	6707
2300	7012
2400	7317
2500	7622
2600	7927
2700	8232
2800	8537
2900	8841
3000	9143
3100	9451

Table 3 : Conversion of meters to feet (1 foot = 0.32806 meters)

Entry and Exit of Tracks

When the pilot flies using GPS and automatic Pilot, it is necessary to indicate accurately the entries and exits of tracks, with the parameters of the ellipsoids and the geographical projection system used by these instruments. The pilot should thus anticipate quite big bends so that the aircraft can follow the track in a rectilinear way. The flight plan is made following a geographical projection. A rectilinear track in the projection plan does not generally conform to the rectilinear trajectory in space. It is important to measure these differences (since the automatic pilot follows the shortest route), or to give the intermediary points that the flight must overfly. The cap is generally not constant.

If the pilot wants to navigate in constant caps, from the point of entry of the track (that is, following a loxodromy), the entry and exit points of the tracks and the trajectories must be carefully calculated : loxodromies are only straight in certain geographical projections. Entering the landmark points on the GPS of the aircraft requires some time (about two hours for a one-hour flight). This work must be done on the ground before the flight and must be anticipated in the preparation of the flight.

Since the flight plan is made using Cartesian co-ordinates in the projection stage, these co-ordinates must be translated into geographical co-ordinates n the system used by the aircraft's GPS (longitude, latitude, WGS 84). Special attention must be paid to the parameters used in this translation : ellipsoid of the projection, ellipsoid of the GPS, parameters of the geographical projection (a difference in the ellipsoid or in the Datum can lead to differences ranging within some hundreds of meters).

The SAVAMER module of the SAVANE Geographical Information System enables one to automatically know the flight plan (from the co-ordinates of the central track), the size of the tracks and the covering required. It also allows drawing the flight plan on an already existing map in the data bank.

Speed

The speed of the aircraft greatly influences filming since the aircraft moves during the opening of the shutter of the camera (The closing up is not mechanical : it corresponds to the time taken to capture the signal). A plane cruising at 120km/hour makes 33,3333 m per second, which is about 3-cm/1000 s, which is low compared to the general accuracy required. On the other hand, the flight will move 0,66 m every 1/50th of a second : the distance flown between two consecutive frameworks of the video film in not negligible. It is thus better to fly at low speed to improve the capture of fixed images, especially if the fixed image is obtained by interpolation between two consecutive frameworks. The choice of the speed to fly thus depends on the capacity of the flight and the time required to over-fly an area supposed to be covered.

The time of the flight

This must be chosen based on sunshine conditions : at most, shades falling within and turbulence caused by heat must be avoided. A flight can thus best be done in the mid morning.

Examples

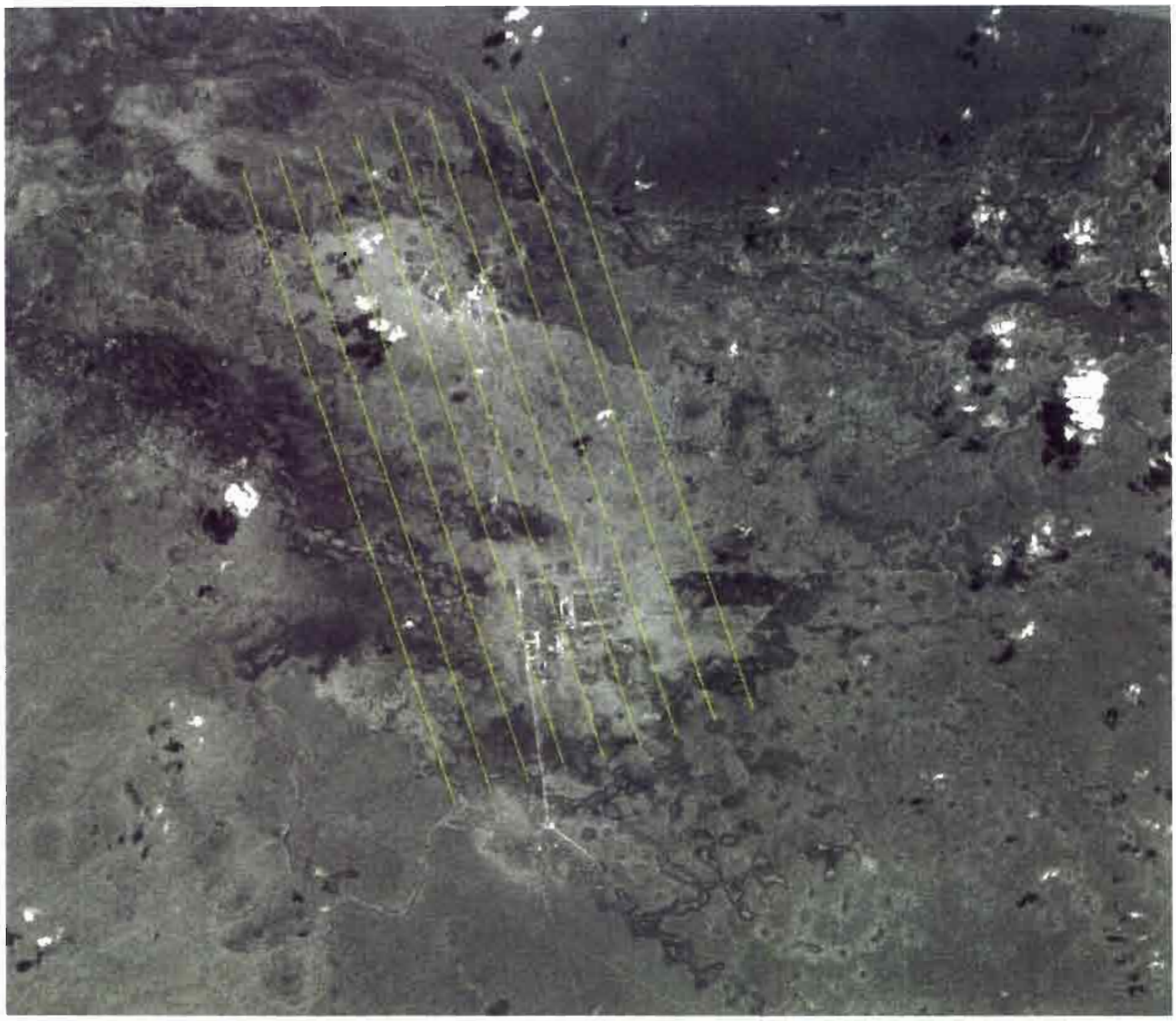
The following examples are picked from flights undertaken by UNHCR in the refugee camps of Kenya. The objective of this survey is two pronged : it is environmental in the case of Dadaab (to evaluate the impact of refugee camps on the natural environment), and cartographic in the case of the other camps (Ifo, Dagahaley, Hagadera, Kakuma) for a population evaluation using visual landmarks in the camps. At the regional level, an accuracy of 2 meters is required. For accurate cartography of the camps and visual landmarks (huts) and infrastructure (blocks), an accuracy less than a meter is required. We have therefore made two flight plans for the two objectives. All the flight-plans have been calculated with the Savamer software.

1. Flight plan over Ifo and Dagahaley with a 2 meter resolution

We want to cover the entire area between the two refugee camps. The result must have a resolution of two meters. We drew a flight plan in which we defined on the satellite image the parallel tracks 18,000 m long and 1,500 m wide, with a lateral cover of 500 m between the tracks. The tracks are oblique (angle of

156 (based on the geographical north). The WGS 84 ellipsoid was used, and the UTM projection (Prime meridian 39° east). The central track has a maximum number of co-ordinates between (642000, 100250000) and (647400, 10008600).

Cap 336° + magnetic deviation (to the north-west) or 156°+magnetic deviation (to the south-east) 9 tracks of 1,500 m of width, 18 km of length, overlapping of 30 % between the tracks (500 m)



N° point	Longitude (deg min)	Latitude (deg min)	X (UTM)	Y (UTM)
1	**40° 14.5131 e**	**0° 12.8898 n**	638200	23749
2	**40° 17.4246 e**	**0° 3.9883 n**	643600	7349
3	**40° 17.9357 e**	**0° 4.1580 n**	644550	7661
4	**40° 15.0252 e**	**0° 13.0585 n**	639150	24061
5	**40° 15.5372 e**	**0° 13.2282 n**	640100	24374
6	**40° 18.4477 e**	**0° 4.3277 n**	645500	7974
7	**40° 18.9597 e**	**0° 4.4974 n**	646450	8287
8	**40° 16.0493 e**	**0° 133979 n**	641050	24687
9	**40° 16.5613 e**	**0° 13.5676 n**	642000	25000
10	**40° 19.4717 e**	**0° 4.6672 n**	647400	8600
11	**40° 19.9838 e**	**0° 4.8369 n**	648349	8912
12	**40° 17.0734 e**	**0° 13.7373 n**	642949	25312
13	**40° 17.5854 e**	**0° 13.9069 n**	643899	25625
14	**40° 20.4958 e**	**0° 5.0066 n**	649299	9225
15	**40° 21.0078 e**	**0° 5.1763 n**	650249	9538
16	**40° 18.0974 e**	**0° 14.0766 n**	644849	25938
17	**40° 18.6095 e**	**0° 14.2463 n**	645799	26251
18	**40° 21.5198 e**	**0 ° 5.3460 n**	651199	9851

Fig. 5 : regional flight plan IFO-DAGAHALEY

2. Flight plans over IFO, HAGADERA, DAGAHALEY 1 meter resolution

One wishes to cover each camp to obtain a resolution lowers than the meter. Each track covers 600 m, with a lateral overlap between the tracks of 200 meters. The ellipsoid used is WGS 84, projection UTM (central meridian 39° east).

IFO : Nine 5.5 km length tracks for 600 m in width, 200 m of overlapping, central track : (649200,12300 N) to (643700,12300 N) (UTM)

N° point	Longitude (deg min)	Latitude (deg min)	X (UTM)	Y (UTM)
1	40° 20.4422 e	0° 7.5434 n	649200	13900
2	40° 17.4773 e	0° 7.5435 n	643700	13900
3	40° 17.4773 e	0° 7.3265 n	643700	13500
4	40° 20.4422 e	0° 7.3263 n	649200	13500
5	40° 20.4421 e	0° 7.1092 n	649200	13100
6	40° 17.4773 e	0° 7.1094 n	643700	13100
7	40° 17.4773 e	0° 6.8923 n	643700	12700
8	40° 20.4421 e	0° 6.8922 n	649200	12700
9	40° 20.4421 e	0° 6.6751 n	649200	12300
10	40° 17.4773 e	0° 6.6752 n	643700	12300
11	40° 17.4773 e	0° 6.4581 n	643700	11900
12	40° 20.4421 e	0° 6.4580 n	649200	11900
13	40° 20.4421 e	0° 6.2409 n	649200	11500
14	40° 17.4773 e	0° 6.2411 n	643700	11500
15	40° 17.4773 e	0° 6.0240 n	643700	11100
16	40° 20.4421 e	0° 6.0239 n	649200	11100
17	40° 20.4421 e	0° 5.8068 n	649200	10700
18	40° 17.4772 e	0° 5.8069 n	643700	10700

Fig. 6 : IFO's flight plan

HAGADERA : Nine 6.5 km length tracks for 600 m in width, 200 m of lateral overlapping, central track : (649300,100 n) to (655800,100 n)

N° point	Longitude (deg min)	Latitude (deg min)	X (UTM)	Y (UTM)
1	40° 20.4959 e	0° 0.8140 s	649300	9998500
2	40° 23.9997 e	0° 0.8140 s	655800	9998500
3	40° 23.9997 e	0° 0.5969 s	655800	9998900
4	40° 20.4959 e	0° 0.5970 s	649300	9998900
5	40° 20.4959 e	0° 0.3799 s	649300	9999300
6	40° 23.9997 e	0° 0.3799 s	655800	9999300
7	40° 23.9997 e	0° 0.1628 s	655800	9999700
8	40° 20.4959 e	0° 0.1628 s	649300	9999700
9	40° 20.4959 e	0° 0.0543 n	649300	100
10	40° 23.9997 e	0° 0.0543 n	655800	100
11	40° 23.9997 e	0° 0.2713 n	655800	500
12	40° 20.4959 e	0° 0.2713 n	649300	500
13	40° 20.4959 e	0° 0.4884 n	649300	900
14	40° 23.9997 e	0° 0.4884 n	655800	900
15	40° 23.9997 e	0° 0.7055 n	655800	1300
16	40° 20.4959 e	0° 0.7055 n	649300	1300
17	40° 20.4959 e	0° 0.9226 n	649300	1700
18	40° 23.9997 e	0° 0.9225 n	655800	1700

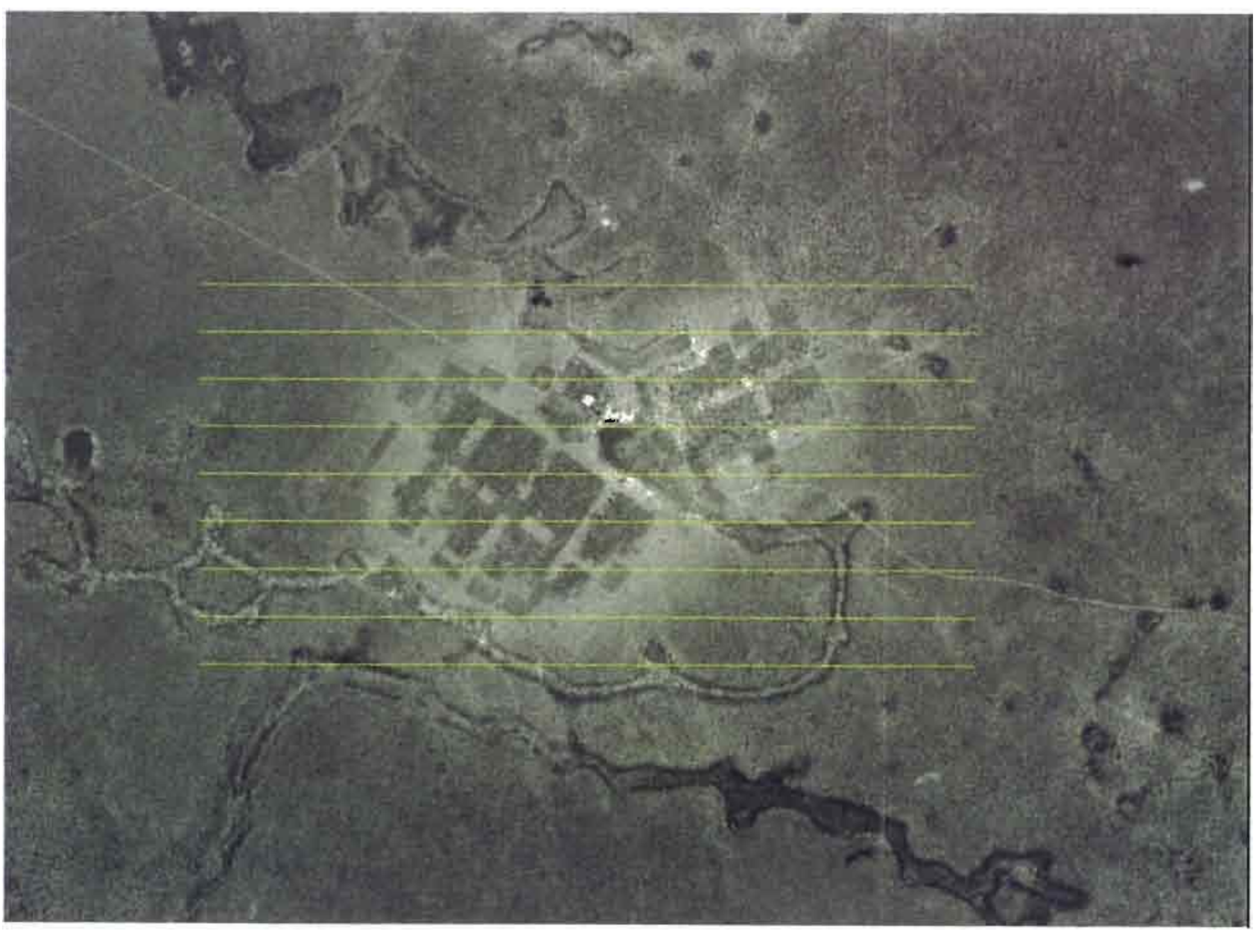


Fig.7 : HAGADERA's flight plan

DAGAHALEY : Nine 4.8 km length tracks for 600 m in width, 200 m of overlapping, central track : (641000,21200 n) to (645800,21200 n)

N° point	Longitude (deg min)	Latitude (deg min)	X (UTM)	Y (UTM)
1	40° 16.0220 e	0° 10.6370 n	641000	19600
2	40° 18.6095 e	0° 10.6368 n	645800	19600
3	40° 18.6096 e	0° 10.8539 n	645800	20000
4	40° 16.0220 e	0° 10.8541 n	641000	20000
5	40° 16.0220 e	0° 11.0712 n	641000	20400
6	40° 18.6096 e	0° 11.0710 n	645800	20400
7	40° 18.6096 e	0° 11.2881 n	645800	20800
8	40° 16.0221 e	0° 11.2883 n	641000	20800
9	40° 16.0221 e	0° 11.5053 n	641000	21200
10	40° 18.6096 e	0° 11.5052 n	645800	21200
11	40° 18.6096 e	0° 11.7222 n	645800	21600
12	40° 16.0221 e	0° 11.7224 n	641000	21600
13	40° 16.0221 e	0° 11.9395 n	641000	22000
14	40° 18.6096 e	0° 11.9393 n	645800	22000
15	40° 18.6097 e	0° 12.1564 n	645800	22400
16	40° 16.0221 e	0° 12.1566 n	641000	22400
17	40° 16.0221 e	0° 12.3737 n	641000	22800
18	40° 18.6097 e	0° 12.3735 n	645800	22800

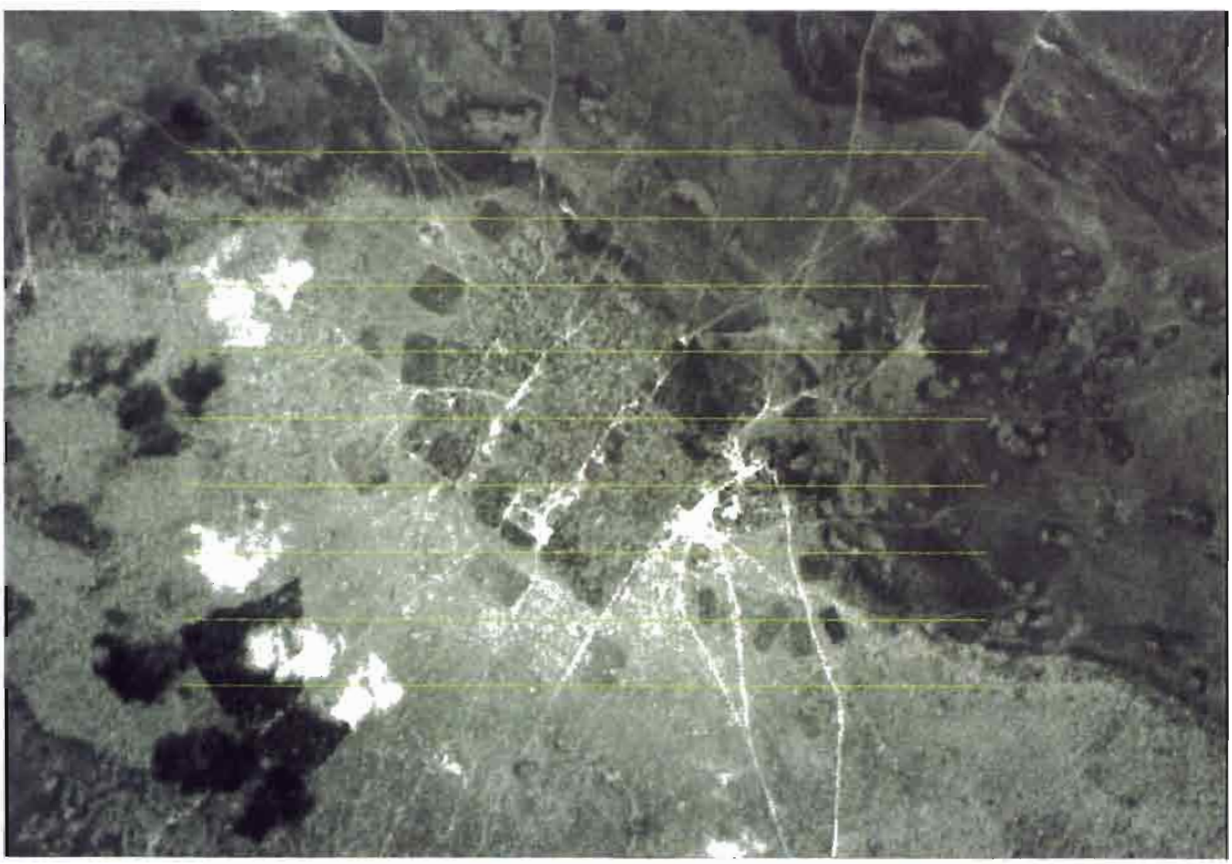


Fig. 8 : DAGAHALEY's flight plan

3. Kakuma's flight plan for a 1.2 meter resolution

One wishes to cover the camp to obtain a resolution of 1,2 meter. The ellipsoid used is WGS 84, projection UTM (meridian exchange 33° is).

KAKUMA : Twelve 1000 m width tracks, 10 km length with a 50% overlap (500 m) Cap 0°+ magnetic deviation (to the north) et 180 ° + magnetic deviation (to the south), central track : (704500,409000 n) to (704500,419000 n)

N° point	Longitude (d m)	Latitude (d m)	X (UTM)	Y (UTM)
1	34° 48.8568 e	3° 41.9062 n	701500	409000
2	34° 48.8680 e	3° 47.3317 n	701500	419000
3	34° 49.1381 e	3° 47.3311 n	702000	419000
4	34° 49.1269 e	3° 41.9057 n	702000	409000
5	34° 49.3969 e	3° 41.9051 n	702500	409000
6	34° 49.4081 e	3° 47.3305 n	702500	419000
7	34° 49.6782 e	3° 47.3300 n	703000	419000
8	34° 49.6669 e	3° 41.9046 n	703000	409000
9	34° 49.9369 e	3° 41.9040 n	703500	409000
10	34° 49.9482 e	3° 47.3294 n	703500	419000
11	34° 50.2183 e	3° 47.3288 n	704000	419000
12	34° 50.2070 e	3° 41.9035 n	704000	409000
13	34° 50.4770 e	3° 41.9029 n	704500	409000
14	34° 50.4883 e	3° 47.3282 n	704500	419000
15	34° 50.7584 e	3° 47.3277 n	705000	419000
16	34° 50.7470 e	3° 41.9023 n	705000	409000
17	34° 51.0170 e	3° 41.9018 n	705500	409000
18	34° 51.0284 e	3° 47.3271 n	705500	419000
19	34° 51.2985 e	3° 47.3265 n	706000	419000
20	34° 51.2870 e	3° 41.9012 n	706000	409000
21	34° 51.5571 e	3° 41.9006 n	706500	409000
22	34° 51.5685 e	3° 47.3259 n	706500	419000
23	34° 51.8386 e	3° 47.3253 n	707000	419000
24	34° 51.8271 e	3° 41.9001 n	707000	409000
25	34° 52.0971 e	3° 41.8995 n	707500	409000
26	34° 52.1086 e	3° 47.3247 n	707500	419000

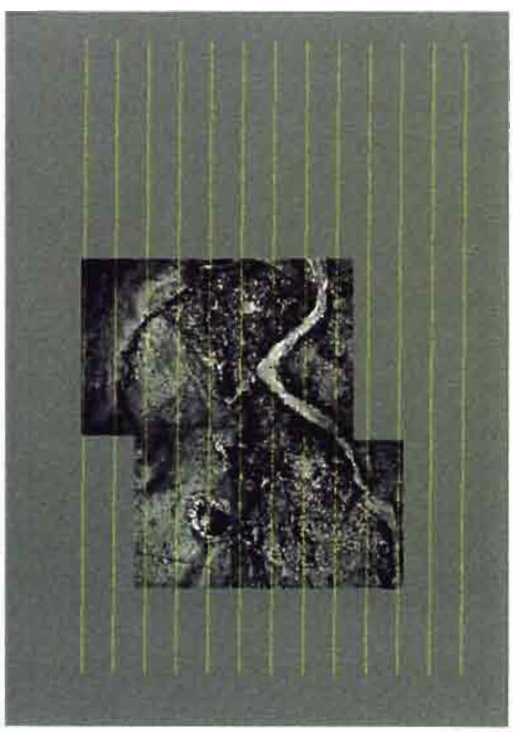


Fig. 9 : Kakuma's flight plan

Chapter 4

Aerial Filming : Flying over

Types of light aircraft's : Characteristics

Every light aircraft, which can be equipped with a camera, is suitable. With the equipment, which is presently in use, it is necessary to remove one door in order to fix the camera outside the aircraft and therefore have an easy sight of the ground (high wing). CESSNA aircraft's meet these conditions. The mounting requires the seat slides and it is perpendicularly fixed to the longitudinal axis of the aircraft enabling the camera to pass out of the plane. This rustic style of mounting is supposed to be adapted to most of the aircraft's available in the aero-club.

Our move is guided by simplicity : as far as the flights are concerned, it is necessary to accommodate oneself to the local conditions and to the flight availability. Our efforts are made in this way : we want to make the mounting of the camera very simple (fixation with a sucker, mounting on universal joint, fixation under the aircraft without removing a door).

The aircraft used in Kenya is a Caravan CESSNA, turbo propelled, 16 seats and equipped with many navigation extras. The rear lower half door has been easily removed and replaced by a deflector made for that purpose (the pilot and his co-pilot are in charge of that exercise).

Fig. 10 : CESSNA Caravan aircraft from BOSCOVIC Air Charter company

Preparing the equipment

Before flying over, the following equipment should be brought on the tarmac :

- The video camera and its accessories : a UV filter, cassettes, screws for fixing, an internal charged battery, an external microphone, a white surface to balance the blanks,
- A 12 V camera charger (lighter type) together with its connection cable
- A 12V 7VAH battery (minimum) which should be dry, charged, with its connection cable to the charger
- Fixation of the aircraft camera equipped with nuts and tools for its fixation (spanners, screw drivers, square)
- An adjustment instrument for the focal distance (for cameras with different focal distance that does not show the actual focal distance).
- A small 12 V monitor (optional) with a video connection, a cable connecting the output of the video camera and the input of the monitor, a 12 V cable for the monitor, a 12 V 3VAH (minimum) charged battery
- An adhesive tape, scissors, plastic safety bindings for electric wires. Large rubber tapes (tube type)
- A GPS to monitor the recording of the flying over
- Clothes, which are compatible with the meteorological conditions of a flight with an open door, ear plugs.

The camera can be connected to its internal battery but such kind of batteries short live (less than an hour) and they are sensitive to cold (cold significantly reduces the duration of battery charging). To cope with problems related to connection duration, we found it preferable to connect an external 12V camera enabling many hour lasting autonomy.

It is useful to have a monitor during the flight in order to make sure everything goes right (it is impossible to look in the viewfinder of the camera during the flight).

Preparing the aircraft

The lateral door should be removed and be replaced with a deflector who avoids contact with the camera wind and too much turbulence in the cockpit. This exercise can be simple (two pins) or complex (piano hinge) depending on the aircraft type.

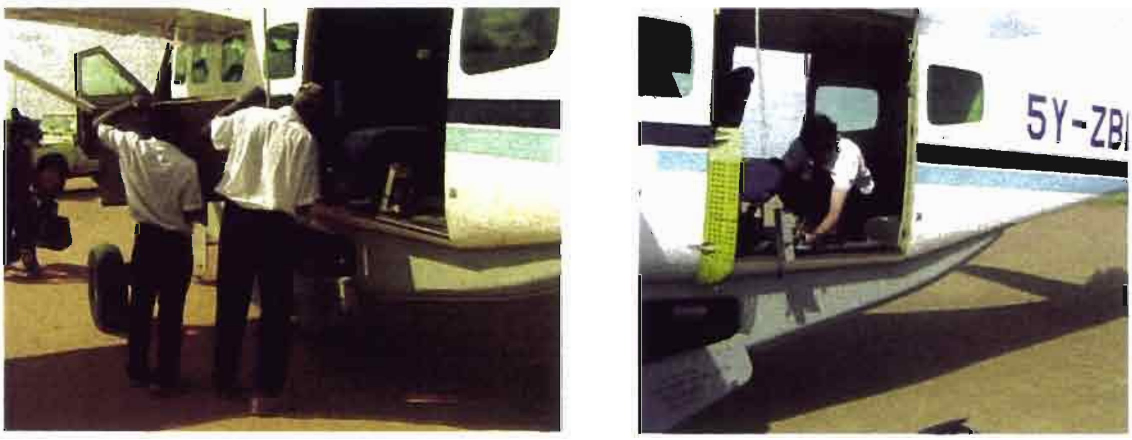


Fig. 11 : preparing the plane (lateral door, deflector)

Fixing the camera

The camera-fixing device is fixed itself on the floor of the plane with appropriate nuts. To adjust the position, we use a square in order to make it perpendicular to the longitudinal axis of the plane

This fixation also enables to connect the 12V battery and its subsequent connection to the camera. All the mobile components and all the connections should done with the adhesive tape.

Fig. 12 : fixing the camera on the plane

The camera is mounted to its stand with an appropriate screw and some plastic fasteners (which can only be used once)

The camera should be connected to its power supply, the external microphone and to the monitor.

GPS on board

To record the position of the plane during the flight, it is necessary to have two receiving sets, which will enable the GPS mobile differential positioning (see following pages). One of the GPS should be mounted at a known place, the other GPS will be put on board at a place enabling good visibility of the sky in order to make sure there is good reception of the satellites. One only has to start the GPS reception at the beginning of the flight.

Checking the camera

We have established a checklist of the necessary exercises to be done to adjust and check the camera just before the flight.

Adjusting the blanks

This exercise should be done just before the flight in order to be assured of the quality of the colours and their contrasts. It is therefore necessary to have a big blank sheet of paper which will preferably stuck on a carton paper (most often, there is wind on the tarmac).

The blanks should be adjusted before adjusting the focal distance, and if possible before mounting the camera to its stand.

Standardising the zoom

It is necessary to adjust the camera zoom factor to the focal distance done for that flight. The camera we used (SONY DCR-VX1000E) does not have any indication of the used focal distance, which can range from 40 mm to 400 mm (equivalent to 24*36). We have to set the zoom with an adjustment equipment we set for that purpose and which can only be used before mounting the camera on its stand. To do without that adjustment (a delicate but important exercise), it is necessary to have a flight plan with the shortest focal distance.

Obturation speed and priority speed

In order to have clear raster, the obturation speed should be high. If the camera has an automatic mode (speed and diaphragm), the speed remains too poor. It is therefore necessary to set the speed by setting the camera in the manual or semi-automatic modes (priority speed). During our flights, we set the obturation speed at 1/1000s. The camera we used could not obstruct both the speed and the diaphragm.

Focussing on infinity

Focussing on infinity enables to avoid problems related to auto-focus and the corresponding loss of energy.

Battery, cassette

Checking connection, switching on. Checking the presence of a cassette in the camera. Checking the registration on the ground (10 seconds). Checking the microphone. The presence of an external battery does not mean that the internal battery is no longer necessary, the latter should be fully charged.

Positioning and orienting the camera

Just before the flight, it is necessary to check and adjust the position of the camera using the standards set for the set for that purpose.

During the flight

During the flight, it is useful to have two technicians, the first to deal with the camera, the other to deal with monitoring the course of the flight plan and to communicate with the pilots. As the door is open, the working conditions are precarious : noise, wind, cold, and turbulence, which make the intervention possibilities very limited.

The camera technician plays a limited role as far as the monitoring of the camera is concerned. His main concern will be to make sure the camera stand is properly adjusted, to turn on the camera at the beginning of filming and to turn it off at the end (in order to save the effective time of filming), to make sure the camera is working properly (battery, tape).

The flight monitoring technician deals with the overall monitoring of the flight and the communication with the pilot. When the pilot has to follow a flight plan, it is necessary to check the progress of the flight in order to repeat the tracks, which were not properly followed. If the pilot is visually flying, the flight-monitoring technician will permanently be in touch with the pilot to indicate the progress of the flight vis-à-vis the objectives set.

Monitoring the flight

By taking a GPS on board, one can record the position (in 3D) of the plane during the flight time in order to compare it with the flight plan once the flight is over. In order to get enough precision , one must use the GPS mobile differential techniques or have radio access to the GPS data of a fixed and recognised station.

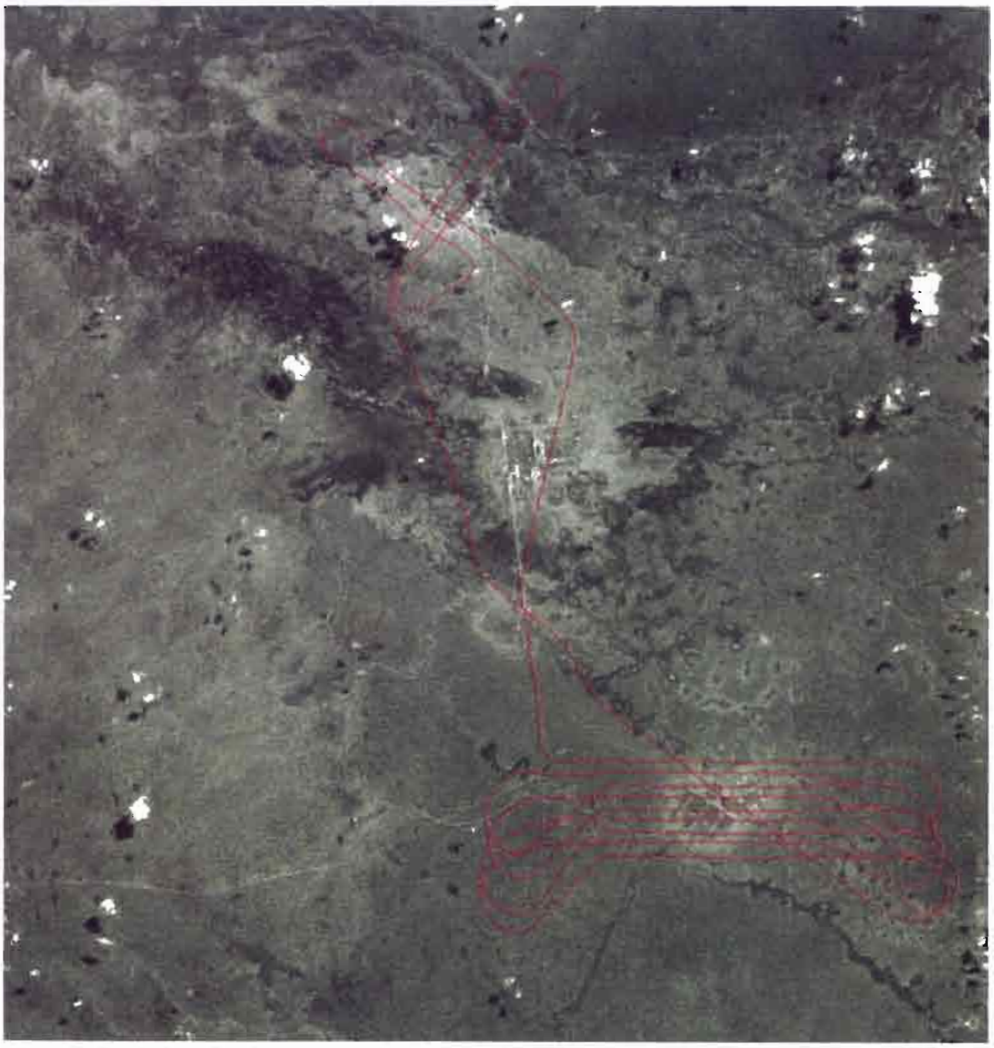


Fig. 13 : Dadaab flight plan GPS survey

Example : the follow-up of the HAGADERA Camp by the GPS mobile differential

We had two GPS MAGELLAN PROMARK X-CM. One GPS was set on the tarmac and the other one put on board in the cockpit dashboard. The GPS was equipped with a professional antennae while the one on board had only its original one. Both GPS record the points in mobile differential mode, at the rate of one point per second during the entire flight. The position of the fixed GPS had been calculated earlier using fixed differential measurements (see next chapter).

After the flight, the two files were downloaded from the laptop and processed using the MSTAR programme for GPS thus enabling us to obtain a positions file indicating the details of every point (in the three dimensions), the capturing moment, the validity of the point (PDOP). The points were then visualised with the SAVAMER module of the SAVANE system, then integrated into the database. We were thus able to compare the flight with the flight plan earlier drawn and ensure that the flight was going on as planned : the gaps between the flight and the flight plan were 50 meters maximum, despite a strong lateral wind. The inflows and outflows of the tracks were more precise : the average gap could not go beyond some meters.

This experience equally enabled us to verify the precision of the GPS in mobile differential mode. This accuracy is excellent : the uncertainty is less than 20 cm.

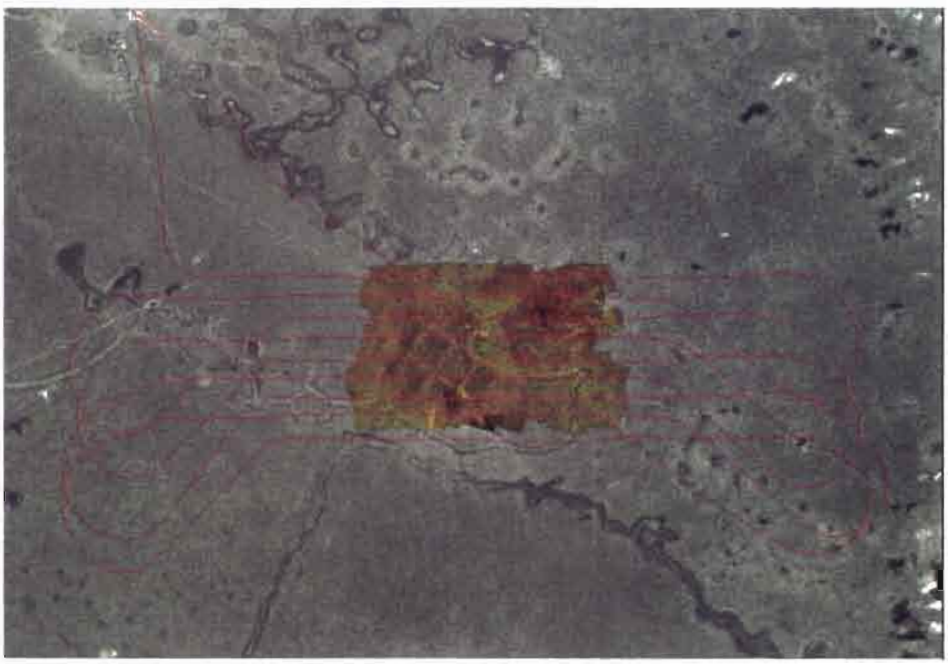


Fig. 14 : Hagadera flight plan GPS survey

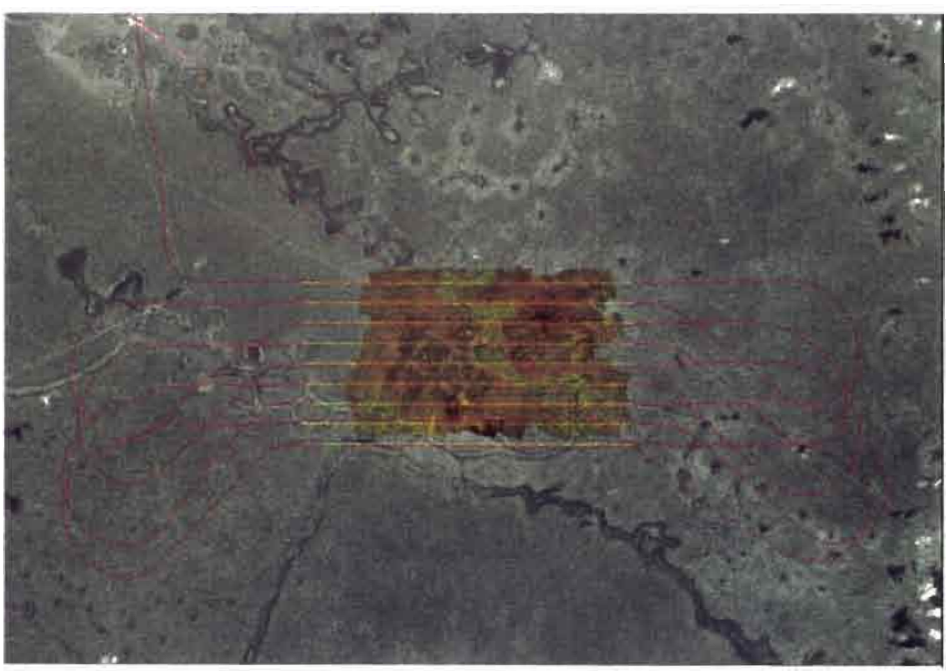
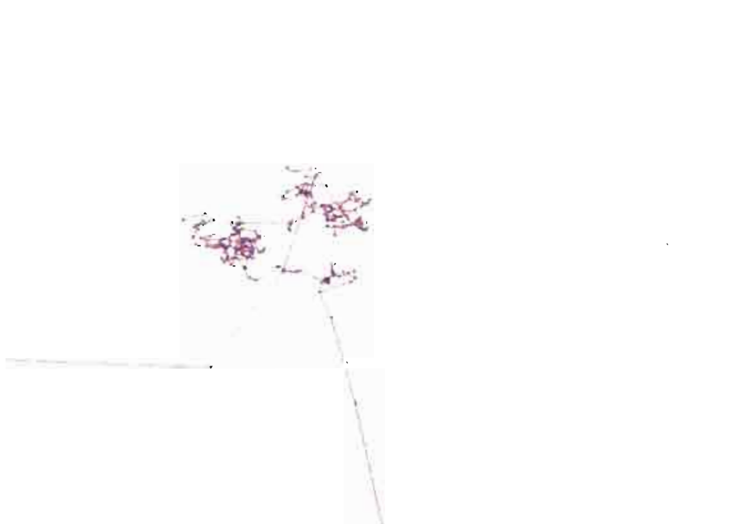


Fig. 15 : Comparison between the flight plan and the effective survey

DGPS Precision

Dadaab's airstrip (1 cm = 100 m)

Positions recorded before the take off (1 cm = 1 m)



Details of the positions recorded before the take off (1 cm = 10 cm)

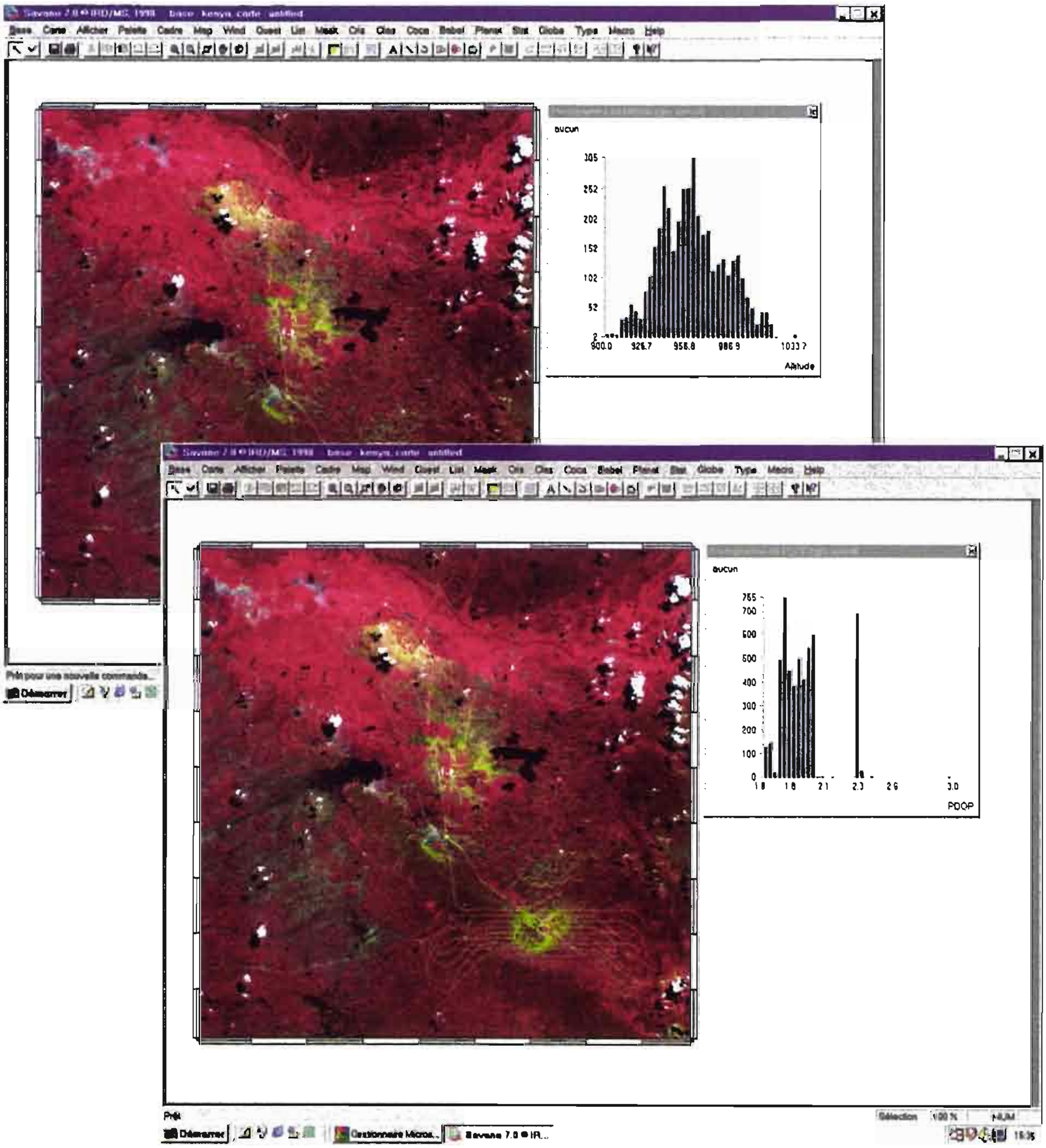


Fig. 16 : Flight altitude and PDOP variation during Hagadera's survey

Chapter 5

Taking positions on the field by differential GPS

Objectives

Images will be extracted from the video film. These images do not reflect the reality (movement of the flight, optical distortion, refraction, etc.) : they have to be straightened to conform to the geometry of the real surface. These should also be positioned by locating them on the surface of the globe. These two exercises are what are called " straightening ". To make this straightening, one must have the reference points on the ground, whose real position is known (in longitude-latitude) and their placement in the image. These couple of points are called the landmark. In case of unavailability of aerial photographs or maps precise enough to create these couples of points, it is necessary to go to the field preferably with printed images in order to point out the position of the visible objects both as seen in the images and on the ground. The number of points to be picked out depends on the estimated deformation of images, but the more the landmark points available, the easier the straightening of the images.

Thanks to the satellite of the GPS system, it is now possible to pick out the positions of points on the earth's surface with more precision. This chapter describes this exercise.

Geodesy and Cartography

To express the position of a point on the Earth, a simple mathematical surface which best looks like the real shape of the earth is used. This surface has the shape of a revolution ellipsoid and enables to express the position of a point thanks to the spherical points : longitude, latitude, and altitude in relation to the surface of the ellipsoid. Practically, several shapes and positions of ellipsoid are used : it is necessary to pay attention to the parameters of the ellipsoid (the datum) when picking out points using GPS, since these points are expressed in relation to this ellipsoid.

In order to have the co-ordinates in the same referential in the world, a universal ellipsoid has been defined by the Department of Defence of the United States (DoD) : it is a WGS 84 (World Geodesic System 1984 : with (a big side) = 6378137 m, e2 (square eccentricity) = 0.006694377999013). Generally, it is the default ellipsoid used by the GPS receivers. We can however transform the co-ordinates from an ellipsoid to another, but one should be acquainted with the parameters of the positions related to both the ellipsoids in question (for most ellipsoids, these parameters are available in relation to WGS 84). The co-ordinates of the same point expressed in both two different data can vary from several seconds of arcs (many tens of meters after projection). The Globe program (SAVANE System) enables the transformation of data.

In order to represent a piece of the surface of the Earth on an even surface, a cartographic projection exercise is used. This one deforms the curvilinear surface and projects it in two dimensions on the even surface in an orthonormal landmark whose unit is still the meter : the co-ordinates X and Y in this marker are called co-ordinates of the projection. This exercise also uses the parameters of the ellipsoid whose references are the sphere co-ordinates expressed in longitude, latitude, and altitude. Finally, in order to reduce the obtained surface from the one of the sheet of paper or from the screen of a computer, the divided plane co-ordinates as obtained with a reduction factor (the scale). Nevertheless, the co-ordinates indicated on the map will always be the co-ordinates of projection, before the scale is set, or the spherical co-ordinates of the corresponding point of the ellipsoid.

GPS background

The GPS system (Global Positioning System) is a world navigation and positioning system using a constellation of 24 satellites. Its study, funding ad maintenance is totally done by the Pentagon.

The GPS satellites are 24. They work on round orbits at a distance of 20,200 km from the earth ; this distance corresponds to a rotation period of 12 hours. The GPS receivers enable to capture and to process the satellite signals.

The availability of the system depends on the observable number of satellites during the measurement and on their geometrical positioning which influences the quality of the result.

In case of directions for use whereby the GPS receiver supplies the co-ordinates instantly and in an autonomous way (absolute mode), the GPS enables the supply of the positioning of about 100 m. That very modest accuracy is the result of many factors :

• Errors of the space segment: error on the orbit parameters of satellites (20 m), error of the very clock of the satellite as compared to the GPS time (some meters).

• Error of propagation : the GPS signal is propagated from the satellite to the antenna of the radio. It goes through the whole earth atmosphere and it undergoes the influence of different lays. The ionosphere delays the signal depending on the solar activities and the geographic situation (the error ranges between 0 and 50 m). The troposphere influences the propagation of the signal through the refraction phenomena. This error is highly sensitive to the low rising of the satellite (error ranging between 2 and 5 m).

• Error of multi-path : the GPS signal can undergo a reflection which makes the already made optic path long when it comes closer to the surface which is near the radio antenna. That effect is known as multi-paths. To get rid of it, one must keep the antenna far from any close metallic surface and it should be equipped with a mass plan, which absorbs the signals reflected by the ground.

• Error due to accuracy of the radio clock : this error is more important than the one caused by the satellite clock since the quality of the clock is directly linked to the cost of the receiver (approximately 30m).

• Voluntary degradation of the DoD (50 to 100 m). This degradation should end by the year 2002.

As the accuracy in locating the absolute GPS is most of the time not enough (and this is our case here), it is possible to get round the problem and to make a relative localisation of a point by establishing its relationship to a known reference : two GPS receivers will have two simultaneous measurements on the same satellites in order to determine the difference of the co-ordinates between two stations : this is called differential GPS. To calculate the co-ordinates it is necessary to do the post-processing exercise after taking from the computer the measurements, which were recorded by both receivers.

Differential Positioning using GPS

This is relative positioning as related to a reference station located near a known point. Two receivers are necessary in order to have simultaneous measurements, one will be located at a point to be determined, and the other will be put at the reference station. The principle of differential consists in removing the systematic errors correlated between the reference station and the mobile station. In this case the assessment of errors will be minimised :

• The error of the satellite clock will cancel itself during the processing of simultaneous observations

• Errors due to the orbit are going to be residual or insignificant;

• Error of ionospheric propagation will also be decreased, especially if there is a major difference between meteorological conditions for each receiver (attention should be paid to significant differences of altitude),

• Conversely, multi-path errors go on increasing,

• The error due to the clock of the receiver will be the same as the one due to the absolute positioning, but using the methods of double difference can reduce it.

The accuracy of relative positioning varies between approximately 0.1 and 5 m, and essentially depends on the quality of the receivers and on the number of the measurements done on the point to be measured.

In case of post-processed GPS differential, the reference station will be equipped with a memory enabling to record the measurements achieved so far. These measurements will be collected afterwards by a user through a computer directly connected to it or through a modem. The mobile station also records the measurements related to each point. The software dealing with post-processing enables to process the measurements and to calculate the positions of the points with a reasonable accuracy. The more the number of measurements increases, the better will be the accuracy. It is necessary to have at least a hundred or so of measurements to enable the differential calculation.

If the position of the fixed station is not known, it can be determined either by calculating the average of a many measurements or by differential calculation using the reception data from a known station.

The equipment

We have two receivers Magellan ProMark X-CM type. They enable a centimetre accuracy in differential mode, by phase measurements. The receivers are equipped with small movable antennae, the latter have been replaced with autonomous antennae having a mass plan which enables to minimise the double paths. These antennae are self-connected by using a deck of six AA Batteries. The antennae are connected to the GPS with cables of some meters long. We also have a tripod of geodesy for one antenna.

The receivers are connected either to a deck of six AA batteries, to a 12 V external continuous connection (plug of a lighter size), or to a 220 V alternative connection.

Fig. 17 : GPS Magellan Promark X-CM with his antenna

Example : Taking the points in the field

The main point in Dadaab : the water tank of the UNHCR compound. This position was obtained with an average of four-hour measurement (standard deviation 30 cm).

Longitude : 40° 18′ 38.63 e
Latitude : 0° 3′ 1.18 n
Altitude : 131 m
All the other points have a precision of about 30-cm compared to the base.

GPS Ifo
ellipsoid WGS 84, UTM zone 7 east.

N° point	Longitude (deg min sec)	Latitude (deg min sec)	X (UTM)	Y (UTM)
1	**40° 18' 27.6714 e**	**0° 6' 7.6431 n**	645525.26	11290.63
2	**40° 18' 26.1742 e**	**0° 6' 27.0582 n**	645478.94	11886.88
3	**40° 18' 52.7683 e**	**0° 6' 30.2658 n**	646301.17	11985.43
4	**40° 19' 8.7038 e**	**0° 7' 0.1941 n**	646793.82	12904.57
5	**40° 19' 24.4021 e**	**0° 6' 33.0717 n**	647279.21	12071.64
6	**40° 19' 5.9935 e**	**0° 6' 21.3744 n**	646710.07	11712.38
7	**40° 18' 36.6978 e**	**0° 7' 7.4634 n**	645804.25	13127.77
8	**40° 18' 22.1578 e**	**0° 7' 5.9514 n**	645354.71	13081.32
9	**40° 18' 25.7425 e**	**0° 6' 13.7186 n**	645465.61	11477.21
10	**40° 18' 27.4598 e**	**0° 6' 13.8981 n**	645518.71	11482.73

GPS Hagadera
Ellipsoid WGS 84, UTM zone 7 east.

N° point	Longitude (deg min sec)	Latitude (deg min sec)	X (UTM)	Y (UTM)
1	**40° 22' 37.52711 e**	**0° 0' 27.46344 n**	653250.59	843.45
2	**40° 23' 4.83963 e**	**0° 0' 42.31480 n**	654095.06	1299.56
3	**40° 23' 23.67249 e**	**0° 0' 20.84403 n**	654677.35	640.16
4	**40° 22' 44.48576 e**	**0° 0' 12.91431 n**	653465.74	396.62
5	**40° 22' 5.74807 e**	**0° 0' 14.75908 n**	652268.02	453.28
6	**40° 22' 34.96175 e**	**0° 0' 7.15235 s**	653171.27	9999780.34
7	**40° 22' 13.40126 e**	**0° 0' 30.59070 s**	652504.65	9999060.51
8	**40° 21' 43.92631 e**	**0° 0' 20.24721 s**	651593.33	9999378.18
9	**40° 21' 57.37426 e**	**0° 0' 0.00412 n**	652009.12	0.13
10	**40° 21' 43.42893 e**	**0° 0' 8.46660 n**	651577.95	260.02
11	**40° 21' 3.85965 e**	**0° 0' 2.39329 n**	650354.53	73.50

GPS Dagahaley
Ellipsoid WGS 84, UTM zone 7 east

N° point	Longitude (deg min sec)	Latitude (deg min sec)	X (UTM)	Y (UTM)
1	**40° 17' 53.28873**	**0° 11' 21.13002**	644461.67	20918.00
2	**40° 17' 39.30619**	**0° 11' 12.79209**	644029.38	20661.90
3	**40° 17' 21.02936**	**0° 10' 51.44641**	643464.36	20006.32
4	**40° 17' 6.83882**	**0° 11' 3.11361**	643025.60	20364.60
5	**40° 16' 38.78768**	**0° 11' 25.77771**	642158.28	21060.56
6	**40° 16' 58.40260**	**0° 11' 41.12036**	642764.68	21531.79
7	**40° 17' 7.24282**	**0° 12' 9.97049**	643037.93	22417.81
8	**40° 17' 29.64553**	**0° 11' 52.66090**	643730.61	21886.28
9	**40° 17' 25.47761**	**0° 11' 31.71123**	643601.79	21242.89
10	**40° 17' 53.69498**	**0° 11' 37.61586**	644474.19	21424.29
11	**40° 17' 55.45202**	**0° 11' 23.22025**	644528.55	20982.20
12	**40° 18' 1.96056**	**0° 11' 28.33349**	644729.76	21139.24

Chapter 6

Capture of fixed images

The principle of the digital videography

The numerical videography makes it possible to obtain 50 (pal/Secam) or 60 (NTSC) images a second, the video signal corresponding to each image being coded in numerical form. Numerical coding makes it possible to preserve intact the quality of the video signal, contrary to analogical coding. It also makes it possible to recover in numerical form each image without loss of quality.

The images recorded by a video camera are called "frames", for when one visualises a video on a cathode ray tube, one sequentially displays the frames by interlacing them : first frame on the even lines, second frame on the odd lines, third frame on the even lines, etc. One thus obtains the illusion of 25 (pal/Secam) or 30 (NTSC) images a second, with a vertical resolution twice higher than the resolution of each frame, while ensuring a perfect fluidity of an image to another when the movement is important : the video privileges the quality of the movement to the quality of the image.

The miniDV format

The majority of the general public using numerical video camera uses the miniDV format. In Pal/Secam, it corresponds to a size of 768*550 pixels (720*560 in NTSC) for each screen. The cassettes available last one hour or thirty-minute.

Capture of fixed images

One uses two successive frames to obtain a fixed image coming from the video signal. The program of capture carries out an average between the two frames to obtain a vertical resolution identical to the horizontal resolution. When the movement is important, the differences between two consecutive frames are important: in this case, one uses only one frame with an interpolation between two lines to supplement the vertical resolution.

The fixed capture of image is a very simple operation. The objective being to gather the images by mosaïquing them, it is only necessary to take care to preserve a sufficient zone of overlap between two after-images (approximately 30 % of the image). We use a monitor of control to visualise video film at the time of the capture of the images. As far as possible, it is necessary to avoid capturing images whose verticality is poor. At the time of the capture, the side movements of the plane are easily perceptible, and it is advisable to choose images if possible corresponding to a satisfactory position of the plane.

Examples : images seized coming from video film carried out on the camp of Hagadera (a complete track), images on Nairobi, images on Kakuma.

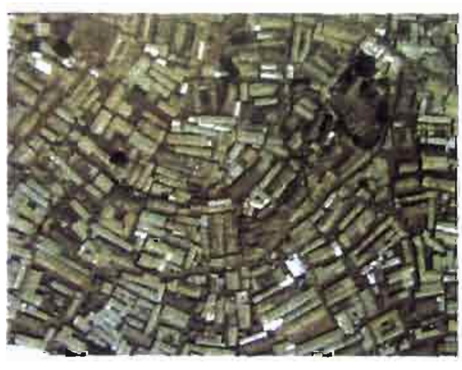


Fig. 18 : Two Nairobi's urban landscapes downloaded from video camera

Fig. 19 : Images downloaded from Kakuma's survey

Fig. 20 : Images downloaded from Hagadera's survey (central track)

Chapter 7

Adjustment, correction and mosaic

The images captured from videotaping do not have geo-reference : they have some global or local distortions and therefore must be corrected in order to better be conform to the geographical realities and to be used in a geographical information system. In this chapter, we are going to describe all the operations, which are necessary to achieve a geo-referenced image in the overall area, covered by the aerial video-filming exercise.

Distortions and adjustments

The images captured from videotaping do not correspond to the geographical realities. They have global and local distortions; they are not positioned in the space; they do not correspond to selected geographical projection (UTM, Mercator, Lambert ...). Many types of distortions happen :

- Distortions due to the passage of rays of light and the optics of the video camera;
- Distortions due to the positioning of the video camera: horizontally and altitude;
- Distortions due to the area relief;
- Mathematical distortions to adjust to a given geographical projection.

Distortions due to the camera optic can be modelled by using a focal adjustment instrument. Nevertheless, these distortions depend on the focal distance. The optic camera we have been using presents only very few distortions, even when the focal distance is short. Note that for this camera, the shortest focal distance represents an equivalent of 24*36 of about 40 mm which remains a quite long focal in the realm of aerial photography.

The distortions due to the passage of rays of light cannot be modelled because they depend upon the weather conditions. Those distortions are meaningless in case of these flight altitudes.

The most important distortions are due to the positioning of the camera as compared to the vertical. These distortions are of two types : horizontality and altitude. The video camera follows the movements of the plane since it is mounted on its stand. Such a mounting enables only to approximately adjust the azimuth. Assuming that the filmed area is flat, the rectangular image obtained at the moment of filming corresponds indeed to a trapezium on the ground. This is a polynomial distortion whose degree is 1 and the coefficients may be obtained by knowing the equation of the plan of the camera. As the position of the camera is not known at the time the filming is done, the equation of the plan as related to the plan of the projection can be calculated thanks to four landmarks. The polynomial distortion also corrects the differences between the actual altitude of the camera and the theoretical altitude of the flight plan.

The distortion due to the relief should, if possible, be taken into account. In fact, the previous distortion does not take into account the altitude of the points in the image : the points are projected in the plan as if they were all at the zero altitude, whereas the projection must follow the vertical but not a ray of light from an altitude assumed to be the point. In order to take into account that distortion, it is necessary to know the relief in all points and therefore have a digital model of the field.

The image filmed by the camera corresponds to the curvilinear surface of the ground, whereas the result should be given in a plan by using a geographical projection from positions expressed on the ellipsoid of reference. That mathematical distortion is known, that is the geographical projection.

The correction of the image will therefore attempt to remove all those distortions in order to have an geo-referenced image in a plan of projection and corresponding as better is possible to the geographic reality.

As altitude is in general not known, we will use to simplify a polynomial of degree one deformation, global or local, to simulate the projective deformation.

Re-sampling

Correction is done together with re-sampling : the pixels in the original images do not necessarily have the same size as the pixels in the final stage images. actually, the pixels never have the same size since they are altered by a series of correction exercises. Therefore the process goes the other way round: the size and the position of the pixel in the final image is determined, then the calculation of its (radiometric) value is done by trying to find the corresponding pixel(s) in the original image, after all the reversed distortions. Therefore, the re-sampling exercise consists in choosing the size of the pixel in the final image and in choosing the function in calculating the value of the radiometry from the corresponding pixel in the original image (very close to bilinear function, bi-cubic function, etc.). This exercise is essential : it enables to pass from an estimated value to a fixed value regarding the pixel in a given projection.

In fact, the resolution of an image corresponds to the size of its pixels and to the objects which can be defined and noticed in the image together with that pixel size (for example, with a one meter pixel, one can notice cars). The accuracy of an image corresponds to the absolute accuracy of localisation. Even if the image does not have any geo-reference, it has an estimated resolution, which is also evaluated most of the time in meter per size of a pixel.

The adjusting exercise

The adjusting methods are numerous : they essentially depend upon the type of distortion where the image to be straightened is related, to the possibilities of the filming of the landmark points, to the availability of a digital model in the field.

One can use :

• a translation : in this case, the image is already in conformity with the geographical projection, the size of the pixel is known, the translation is used only to locate the image but does not carry out any transformation on the pixels. Only one point of reference is necessary to carry out a translation.

• a translation and a rotation : it is the simplest transformation, to use if the image is geographically correct but must undergo a translation and a rotation to be in conformity with the reference mark of projection. The distances in the image are not modified. Two landmarks are necessary to carry out this transformation.

• a similarity : it is a translation and a rotation followed by a homothety (put on the scale). The similarity is to be used when, to be put in conformity with a geographical projection, the image must undergo a translation, a rotation, then a scaling. The scaling is identical on the whole of the image, the deformation is identical whatever the direction (it is a isometry). Two landmarks are necessary for this transformation.

• a polynomial deformation of degree 1 : this deformation is identical to the similarity, except that the scaling is not identical some is the direction. Three landmarks are necessary to carry out this transformation.

• a projective deformation (or homography) : it is a classical projection of a plan on a plan starting from a point. It is the natural deformation obtained on a photograph, when the ground photographed corresponds to a plan. This transformation must be combined with a deformation taking into account altitude, if not the scale obtained is not correct. Four points are necessary to fix the coefficients of this transformation, which amounts gauging the position of the camera compared to the plan of projection.

• A deformation by triangulation : this deformation combines a first global transformation (rotation, similarity, polynomial of degree 1, homography), with a local deformation of degree 1 in each triangle resulting from a triangulation starting from the seized points of land-marks. This transformation is most effective when one does not have a digital model of ground making it possible to know altitude in each point. Indeed it established a model of polynomial deformation of degree in each triangle. The deformation corresponds to a space division in plane facets, and if network of points of landmark is dense and

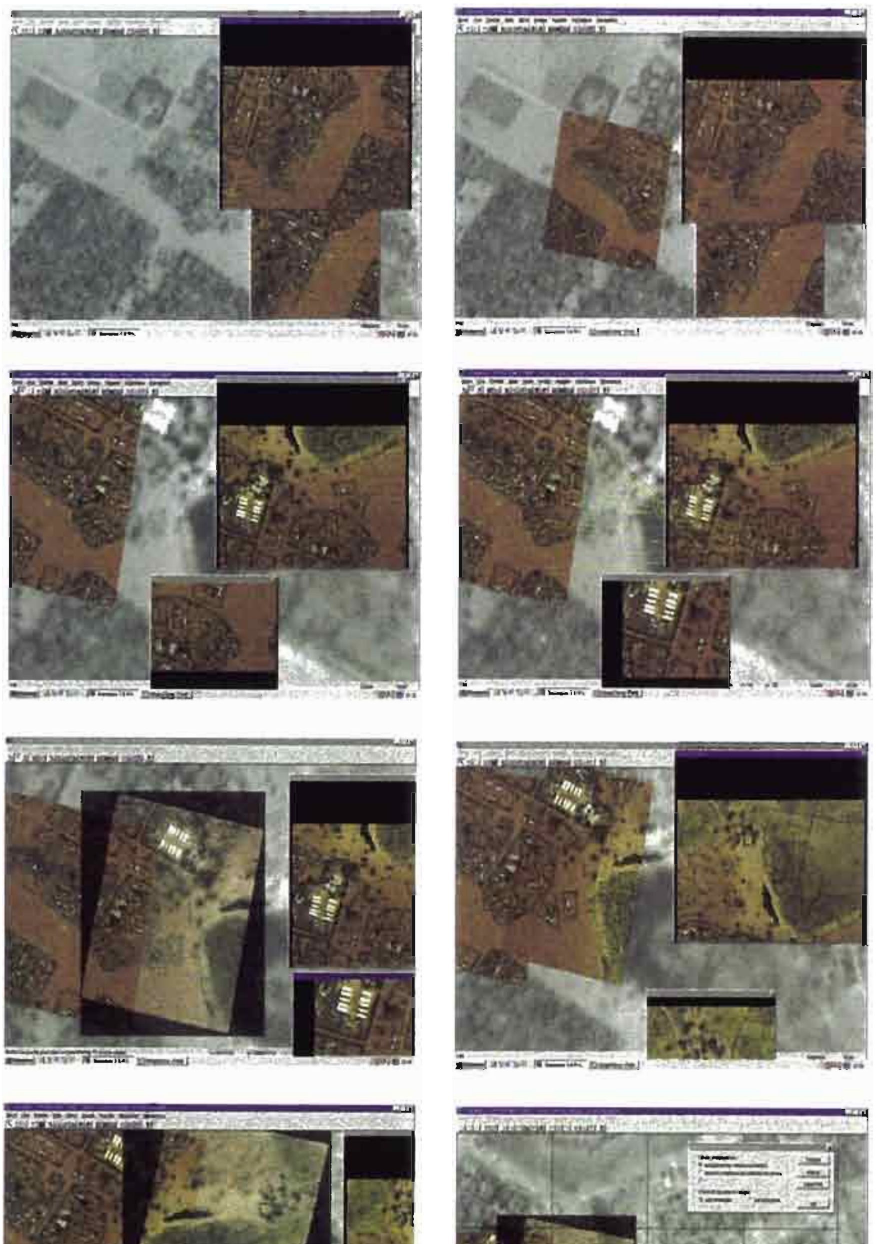


Fig. 21 : Geometrical images correction and mosaic (Hagadera)

homogeneous (and all the denser that the differences in altitude are large), the rectification makes it possible to directly obtain an image in conformity with selected geographical projection. This type of deformation also makes it possible to ensure a perfect joint between various images : once a rectified image, it is enough to seize points of landmarks between the rectified image and the image to readjust to make coincide the two images. The initial transformation makes it possible to fix the image coarsely to be rectified : it must correspond as well as possible to the type of deformation to which this image is subjected. The polynomial rectification of degree 1 or by homography (if one knows the altitude of the points of landmarks) is often most adequate.

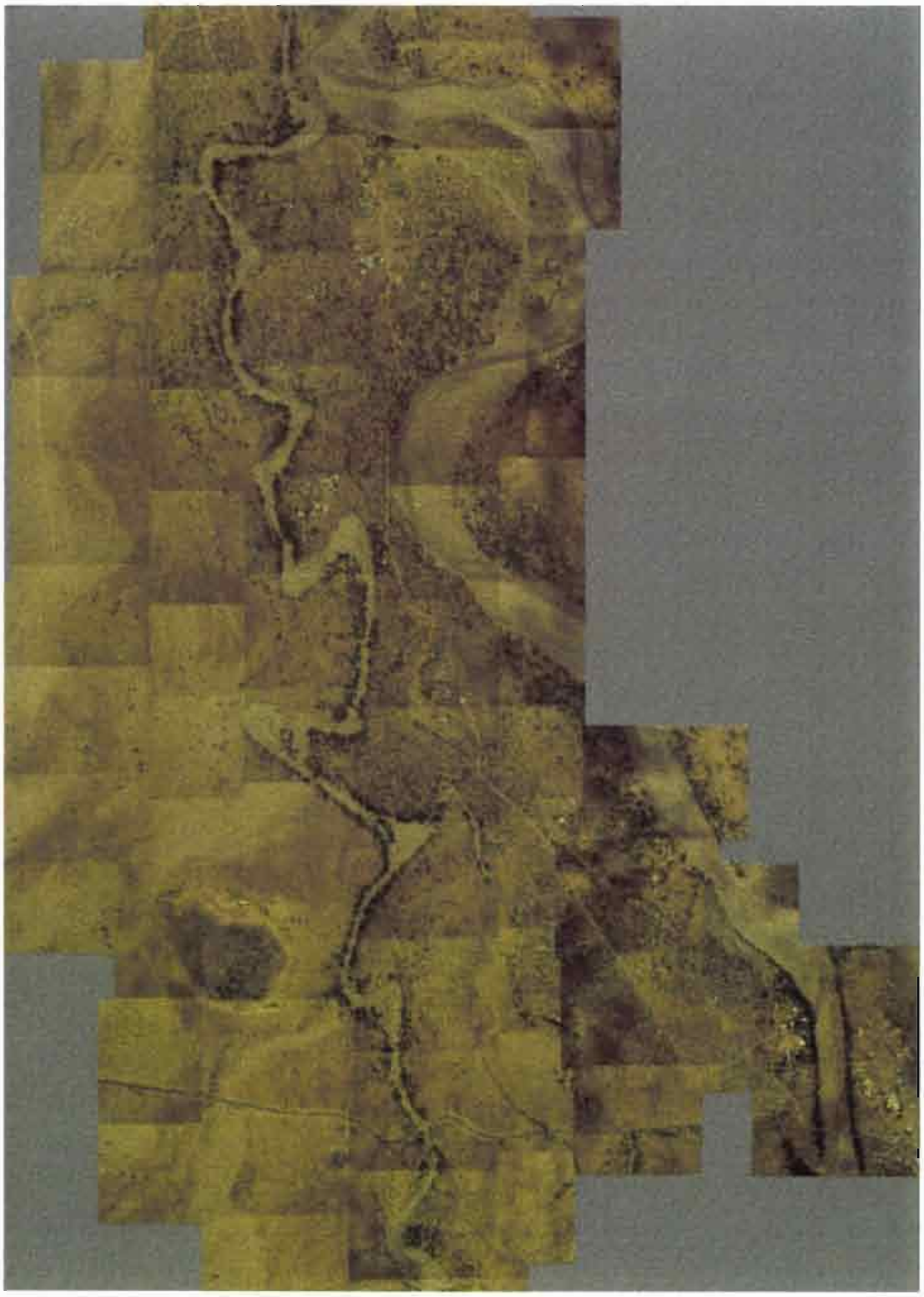
The deformations of the images taken by videography come primarily from the (lack of) horizontality of the plane and the relief. The optical deformations are negligible, just like the deformations due to the transport of the luminous rays. The best rectification is thus carried out thanks to a polynomial transformation of degree 1, or a projective transformation (if one knows the altitude of the points of land-marks), followed by a transformation by triangulation. If the network of point of landmarks is sufficiently dense, all the deformations are corrected and the rectified image is geographically correct (the local scales are exact). The principal difficulty thus lies in the availability of this network of points of land-marks, points which can be obtained either starting from an existing cartography, or starting from images satellite (but with a less precision, and provided that the satellite image is itself correctly rectified and geo-referenced), or starting from points GPS taken directly on the ground.

Introduction of the mosaic in a GIS

Once rectified, an image can be integrated in a unit so as to constitute a orthophotoplan. This operation is called " mosaïquing ". The mosaic thus made up is geo-referenced and is managed and used in a geographical information system. The many images coming from the videography disappear to leave room to only one image directly managed by the information system. The geographical information system SAVANNA was used for all the operations of rectification and mosaïquing presented in this document.

Fig. 22 : Three refugee camps mosaics overlapped on the Spot panchromatic image

Kakuma camp



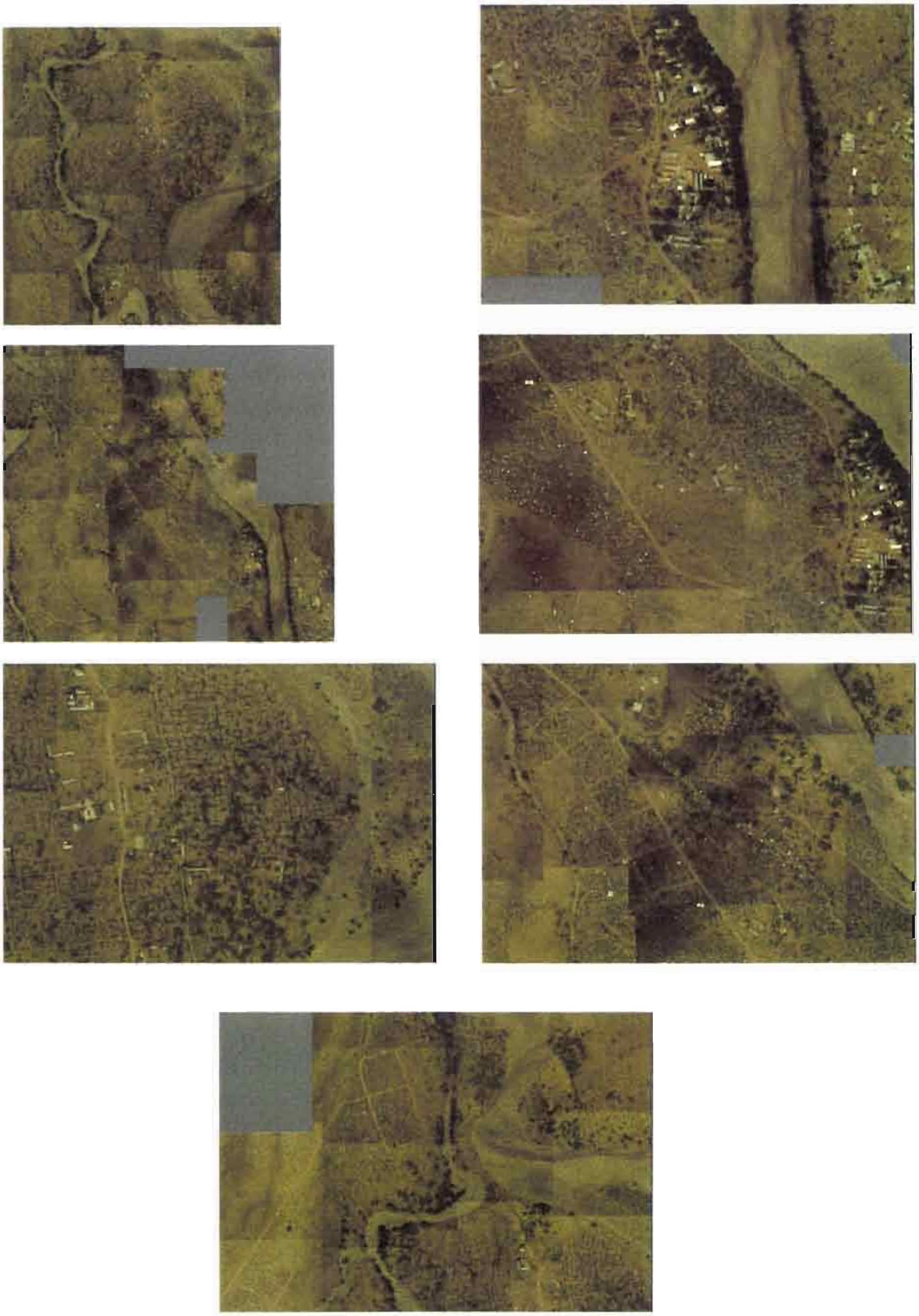


Fig. 23 : Kakuma camp mosaic details (resolution 1,2 m)

Dagahaley camp

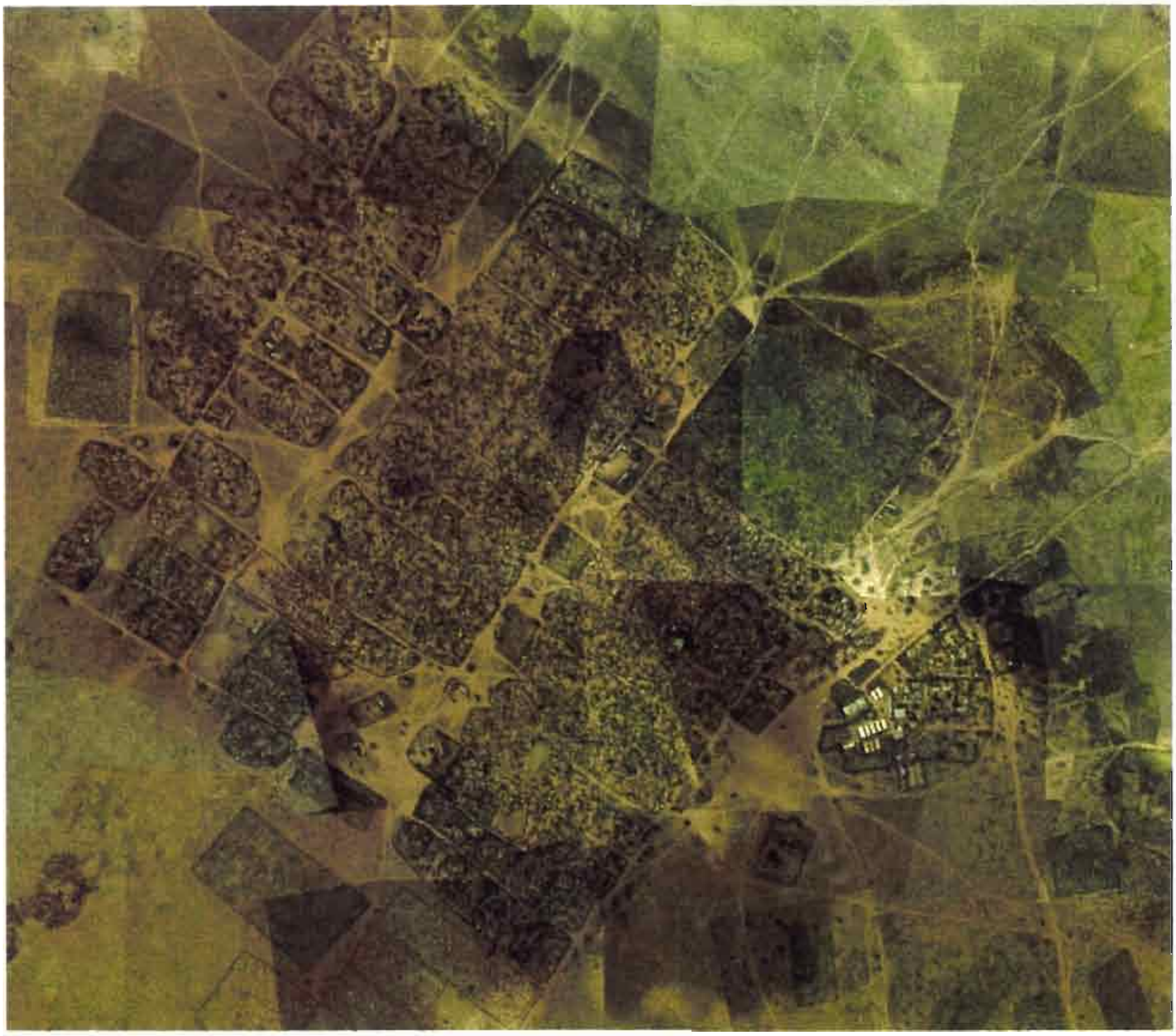


Fig. 24 : Dagahaley camp mosaic details (resolution = 1 m)

Hagadera camp

Fig. 25 : Hagadera camp mosaic (resolution = 1 m)

Ifo camp

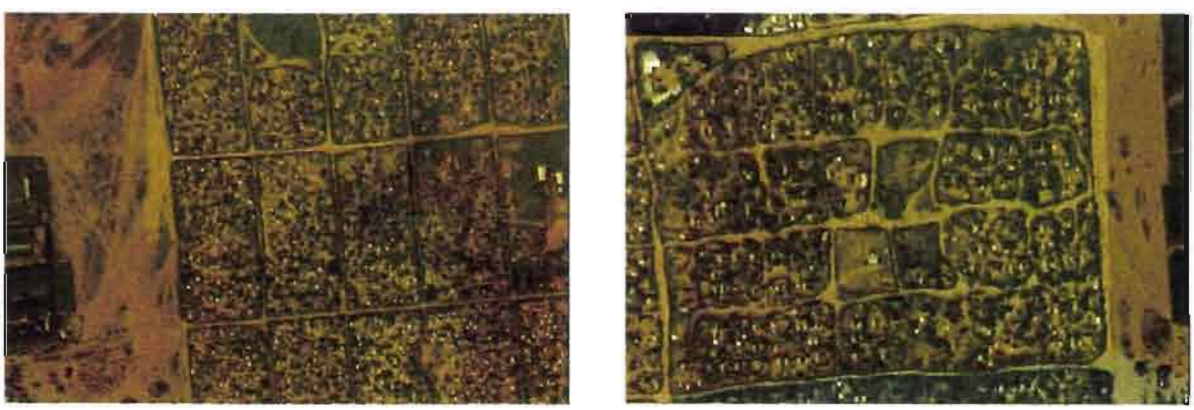


Fig. 26 : Ifo camp mosaic details (resolution = 1 m)

Chapter 8

Using mosaic in a geographical information system

Geographical Information Systems background

The geographical information systems are data management systems with two or three dimensions (x,y,z). They make it possible to manage and process the localisation in the space of the preserved objects, which model reality. These objects are zones, lines, points, or pixels of images. Each object is described by " attributes " : the objects described by the same attributes are gathered in collections (or layers). These collections are connected with the relations of a classical relational data base management system.

All the geographical data present in a GIS can be compared the ones with the others by using their localisation in space, to analyse and process them or chart them. It is thus very important to manage this localisation in space well, and to control all the aspects of them : precision, validity, space of reference, etc. If the recovery of the video images is well carried out, the mosaic answers these criteria and can be used in a GIS and can be put in relation with other localised objects.

Mosaics management

Among the objects managed by a GIS, the mosaics of images often hold a place separately. In the SAVANNA system, these objects are integrated in the base of data as well as the other types of geographical data. The mosaics can thus be used without particular effort. Once integrated in the base of data, the system takes care with all the management of these mosaics, which often represent great volumes of information.

Digitization on the mosaic

Once integrated in the data base, a mosaic can be used as reference to seize other objects : one can directly digitize these objects on a screen of computer by using the mosaic like a reference.

Fig. 27 : Blocks and shelters digitization in Hagadera

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Generalities

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