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ENVIRONMENTAL SURVEY BY A HELICOPTER-BORNE MULTISENSOR SYSTEM

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1. Abstract

The basis of the system is a helicopter Bell 206 III "Long Ranger" with special equipment for precise navigation, data recording and survey flight management. With an aerial survey camera the three-dimensionally interpretable photographs are produced for mapping or support of environmental analysis tasks.
A magnetic sensor detects invisible ferromagnetic objects in the ground and a VLF sensor detects non-ferromagnetic objects or structural discontinuities.
Thermal radiation images are used for climatological analysis and other environmental tasks.
During sensor flight some interesting operational and piloting problems have to be overcome.
The IABG helicopter-borne sensor system achieved lower costs and accelerated issue of results.

2. Introduction

Caused by a dramatically sharpened environmental awareness and the problems in the new Eastern Federal States the need for control and analysis increased dramatically in Germany.
Due to the unique properties and the versatility of the helicopter, IABG introduced a helicopterborne multisensor system. Helicopters are very versatile workhorses but nevertheless some interesting operational and piloting problems had to be overcome.
For more than 2 years the helicopter-borne survey system of the IABG, Ottobrunn, Gernmany has proved its aptitude for environmental survey, control and waste deposit reconnaissance.
By remote sensing one is able to get information about expected environmental problems. Furthermore one can get the basis for the production of geographical maps (if necessary) and thematical maps concerning the environment. By different remote sensor techniques it is possible to explore waste disposal sites or areas of suspected contamination with fast, wide-area coverage and cost effectively.
Aerial survey allows the exploration of an area within only a few hours. A ground team needs a whole week. Additionally some areas, e.g. sludge deposits or military sites with residual ammunition cannot be explored by ground teams at all.
The helicopter's special capabilities and flexibility for multi purpose operation are essential for a great part of the environmental analysis tasks (low altitude, low speed, external sling load capability). Even for tasks, done normally by aircraft, the helicopter has proved to be suitable.

The helicopter - based high resolution measuring techniques yield detailed but sometimes complementary results, so surface structures or subground anomalies can be distinguished only by their combination.
In the following the permanently installed survey flight management system is described.
Afterwards the mainly used sensors are presented including the results and operational conditions with respect to the helicopter. In the next part some results of the combined evaluation of different sensor data are described.
Some operational aspects of helicopter operation including high precision sensor flight guidance are discussed in the last part.

3. Sensor flight management

To gain the required precision of the navigation on some tasks the tracks flown are only 20 m apart, a geodetical GPS receiver with 9 channels and phase information is used in the helicopter. Together with the same type of receiver as the ground station and a radiolink to the helicopter the achieved precision in the online differential mode exceeds 1 m by far in all 3 dimensions. The position of the antenna on the vertical fin of the helicopter is precisely determined in relation to the sensor position to calculate the exact position of the sensor in all 3 directions. This accuracy of the DGPS allows to eliminate the artificially built in GPS inaccuracies (e.g. selective availability) and a most exact position recording as well as exact position calculation in the postflight mode (no radiolink). The exact position is calculated after the flight by correction of the recorded helicopter position by means of the recorded position of the ground station. Also integrated is a precision instrument to determine, record and display the height above ground at a precision of 0,1 m. The survey flight management system allows the sensor flight planning in the office on a PC or portable computer. During flight, it records the position and photo data on a data card device and allows, back on ground, the plotting of survey flight data for the client's diagrammatic photo-index when the aerial survey camera (see below) is used. The system operates (especially triggers) the camera according to the position data automatically. The required additional operation tasks (e.g. flight line on exposure selection) could even be done by the pilot. But for today we consider this workload too high and operate the helicopter always with at least a two men crew (pilot and camera / sensor operator).
Depending on the task, some functions could be changed to a more automatical mode. If the pilot is then assisted by an autopilot, this total system has the development potential for a real single crew operation.
In contrary to a pure navigational display, the pilot's monitor shows the planned track and actually flown true track together with the helicopter's heading. The pilot can compare the planned and flown flight path which helps him to maintain or correct back to the flight path because he has not to rely only on a deviation information (which nevertheless is available to show the gap limits where a photo is automatically fired).
This survey flight management system is used only for the sensor flight itself. All enroute navigation (ferry etc.) is done conventionally by a complete IFR equipment. Nevertheless we operate the helicopter strictly under visual flight rules by day and night.
For some tasks which do not require the high precision flying an off-the-shelf moving map display could be linked to the GPS, but for a ground track spacing of less then 100 m this is not useful.

4. Survey camera

With a latest state-of-the-art aerial survey camera (Zeiss RMK TOP) on a gyro-stabilized platform three dimensionally interpretable aerial photographs with films in different spectral bands are produced.
Aerial photographs can be the base for geodetical surveying (aero-triangulation) which requires the most exact navigation and position recording described above. Furthermore, these photographs can be used for a wide range of purposes in environmental analysis and biotopical assessments.
Last but not least, actual aerial photographs are the basis (even if exact maps exist) for the allocation and evaluation of every sensor result and combination of results.
The camera turned out to work well even beyond the limitations recommended by its manufacturer. Even during low flying at 150 feet above ground the lense produced sharp photographs (resolution in the region of millimeters, e.g. fence-wire). This is to be seen also in context with the vibration isolation of the helicopter type and the tuning of the vibration absorbers and the stabilizing function of the gyro platform in pitch / roll and yaw (drift angle).
Though helicopters in general are more sensitive than fixed wings to external disturbances around the vertical axis they proved to be less sensitive against turbulences causing roll and pitch attitude changes. This type proved to be sufficiently stable to gain results as good as fixed wings (this fact caused some clients overcome their prejudices). The gyro platform compensates the drift angle of the fuselage with reference to the planned ground track so that each photo is aligned. This fact is important for the coverage of the whole area.
Due to the typical rotor system, disturbances in pitch and roll are softer than in fixed wings and coped with by the gyro platform without problems.
The heavy and bulky survey camera (150 kg i.e. 330 lbs) together with the IABG built installation rig just fits into the rear compartment. Some sensor modifications on the platform were done by its manufacturer Zeiss to allow the simultaneous installation of the external cargo hook.
The camera requires a 37 cm diameter opening in the lower fuselage shell. According to the IABG delineation this opening was approved and built into the factory new helicopter by Bell. A second opening in the lower shell (10 cm diameter) allows e.g. the parallel usage of a video / IR - camera or a 6x6 camera for control purposes.
Both openings are used for the installation of other sensors (with a plexiglass inset the 37 cm one can be used also for visual observation of sling loads).
The ground surface imaging by aerial photographs in the visual and near IR spectrum (CIR) to detect subground anomalies is well known.

5. IR-scanner / IR-camera

Together with the partner company Spacetec we use a thermal scanner for the subground reconnaissance of waste deposits and climatological analysis.
Subground structures can disturb the surface temperature distribution and are thus detected on a thermal image. By flying 600 ft above ground level you achieve a ground resolution of about 50 cm and detect temperature differences of about 0,1 Kelvin. For climatological analyses of town areas we produce scanner images from great altitudes. The scanner is also mounted on a gyro platform to get the scantracks aligned to the planned groundtrack and to ease the distortion correction of the data.

The measuring campaigns with an IR-linescanner are done during nightflying in altitudes of more than 10.000 ft over the cities with high speeds. During these flights we cannot use published airways or routings between navigation facilities. The tracks are kept by our sensorflight management system based on GPS position data and air traffic coordination is done by the mostly very cooperative air traffic controllers on ground. This is done with transponder in stand by during the scanner's operation because the scanner is disturbed by the transponder's emission. The exact navigation is very helpful because the interpretation of the results is done by comparing images from beginning of the night to images from end of the night.
On the contrary, the exploration of waste deposits requires night flying at about 500 ft (or even less) above ground and speeds below 50 knots because of the peculiarities of a line scanner and the required resolution of less than 0,5 m. Furthermore the line scanner offers the possibility to use other regions of the spectrum. Modern IR multispectral cameras offer almost the same resolution as a scanner and were used for the same purpose. They offer the advantage of a direct visible sensor image in addition to the data record.

6. EM / MAG survey system

Another way to detect ferrous and nonferrous objects in the ground is the usage of a special "sensorbird" as sling load.
The vertical magnetic gradiometer is extremely sensitive to local concentrations of ferrous metals. For example, a single barrel can be detected at more than 10 m distance. An accumulation of several barrels can be detected at 20 m. A gradiometer is especially important in areas with strong cultural interference from electric trains and other DC or low-frequency electrical power usage, because the gradiometer's output is less sensitive to changes in the local background magnetic field. The three-component fluxgate magnetometer is generally used for bird orientation correction, but also useful in locating strongly magnetized objects near the surface.
The electromagnetic (EM) sensor is primarily sensitive to changes in ground conductivity, caused by trench or pit boundaries, buried road, railway or runway foundation beds, or clay caps/liners on pits. The EM sensor is also very useful in locating groundwater contamination plumes, particularly those involving electrolytic contamination such as those caused by salt, acids (e.g. mine drainage) or alkali spills. It is also useful in locating accumulations of non-ferrous (and therefore non-magnetic) metallic debris such as aluminium, stainless steel, copper and brass. The frequency range and coil orientation is negotiable, but should probably lie in the range of 8 kHz to 150 kHz. The horizontal coplanar coil orientation presently considered is included for excellent resolution of small, conductive discrete targets as well as lower-conductivity layered structures. Use of a higher top frequency will permit more detailed mapping of thin soil layers on relatively conductive bedrock.
The VLF and the magnetic sensor (together in one "bird") must be operated as external sling load on a 35 m long cable to minimize the electrical disturbances caused by the helicopter itself. Despite of this, the active radio emission can disturb the measurement equipment in some cases. To make the sensorbird move in about 3 - 5 m above ground requires an exact height measuring done by a LASER altimeter in the bird. The described navigation and display system including precise height information is sufficient for forward flight with up to 50 knots. Nevertheless this type of sensorflight requires the pilot's full concentration especially during flight over structured terrain and close to obstacles. Major improvements could be achieved by a special head-up-display and an obstacle warning device in the "sensor bird".

As physics dictate, the long suspension pendulum swings with low frequency but great amplitudes as soon as aerodynamic stabilisation is reduced during deceleration. This requires special attention during touch down of the slingload.
In addition to the helicopter GPS a second differential GPS is integrated into the bird because positions of aircraft and bird are not the same due to the long suspension allowing relative movements. For data interpretation, the exact position of the bird is decisive and therefore recorded for post flight calculations.
The following table shows some of the possible sensors and their purpose.

Possible Techniques for Airborne Data Acquisition

active EM/VLF	µm-Waves			Magnetic	Laserspectrography
	thermal IR	near IR	visuell		
anomalies in ground conductivity	surface temperature	moisture content and chlorophyll absorption of vegetation		magnetic anomalies in the ground	spectral response (fluorescence)
conductive objects in the ground (drums, pipelines), conductivity changes (disposal site)	structures below the surface, chemical/ biological reactions	state of health of vegetation (⇨ harmful substances in the ground)		ferromagnetic objects in the ground (pipelines, tanks, cars, drums,...)	various kinds of fuel, various kinds of plastic, vegetation examination

7. Installation of other sensors

Due to the permanently installed sensor flight management system and the navigational aids it is easily possible to integrate other types of sensors according to the special need of the customer. For instance laserscanner, radiometer, laserinterferometer and gaschromatographs. All interfaces are standardized as far as possible. For safety reasons the sensors and the flight management equipment are fully independent of the normal helicopter equipment. No disturbances of the helicopter systems by the measurement equipment have emerged until now.
The fuselage openings are very useful for sensors which must look down vertically. Thus you avoid to install sensors on the outside of the helicopter causing problems of

- mass and center of gravity
- aerodynamic behavior
- vibration and stabilisation
- erosion by wind, precipitation and sand

Even sensor mounts, which are able to be gimballed could be installed, if necessary as well as telescopic devices or small winch equipment.
The helicopter's special properties are essential for a lot of environmental control tasks (low altitude, low speed, external slingload). Even for tasks normally done by aircraft, the helicopter proved to be suitable.

8. Economic considerations / conclusions

By combining tasks even the economic side can be handeled although operating costs are higher than for a fixed wing aircraft. Additionally you must consider that on a multi sensor campaign flight hours are not the dominating factor.
If you look upon the overall advantage of this helicopter operation, you must consider that human working time is nowadays by far the most costly production factor .
Nevertheless the choice of a single engine type is on the one side an economical decision. But you must consider on the other that for this kind of work the helicopter is operated out of ground effect with very low speeds for a great part of the time, and loaded to its maximum take-off mass.
In this regime a light twin does not offer a real twin engine safety and medium twins are of very strong economic influence.
As a conclusion you can consider the IABG sensor helicopter a valuable system to reduce costs and to accelerate measuring or survey procedure.
A research program is started to further improve the results of the mainly used sensors. Parallel to this, efforts are on the way to look at the results of additional sensors and their integration into the system.