Photogrammetric Record, 16(91): 105–109 (April 1998)

DIGITAL ELEVATION MODELS BY LASER SCANNING

By U. LOHR

TopoSys Topographische Systemdaten GmbH, Ravensburg, Germany

(Paper read at a Technical Meeting of the Photogrammetric Society on 13th October, 1997)

Abstract

The TopoSys laser scanner system is designed to produce digital elevation models (DEMs) at a maximum accuracy of 0·5 m in x and y and 0·1 m in z. The regular scan pattern and the measurement frequency of 80 000 measurements per second (on average 5 measurements per m^2) form the basis for high quality DEMs.

The mainly automated data processing makes it possible to generate DEMs of large areas in a short production time. The DEMs produced come into common use as basic data for different applications, some of which are water resources management, shoreline control, planning of utility lines and urban planning (simulation of noise and pollution distributions). The performance of the system is illustrated with the help of DEM sections produced with the TopoSys system.

KEY WORDS: digital elevation models, laser scanning, data fusion

INTRODUCTION

LASERS are well know for their ability to measure distances with high accuracy. Laser scanners in aircraft can be used to scan the earth's surface in order to produce digital elevation models. Due to their measurement principle, laser scanners require entirely digital processing. Therefore, laser scanning is the appropriate choice for largely automatic digital elevation model (DEM) generation. Even without post-processing, the calculated raster DEMs can form a basic data set for a GIS used to perform monitoring and/or simulation tasks.

DESCRIPTION OF THE SYSTEM

The TopoSys system can be divided into flight and ground segments. The main elements on board the aircraft are the subsystems: navigation and positioning, laser scanner, video camera and data handling and recording (Fig. 1).

The design of the navigation and positioning system is based on the integration of differential GPS (dGPS) with a laser inertial navigation system (LINS) for position and attitude determination. GPS, LINS and laser scanner data are stored digitally on hard discs, while the video images are stored on a standard SVHS

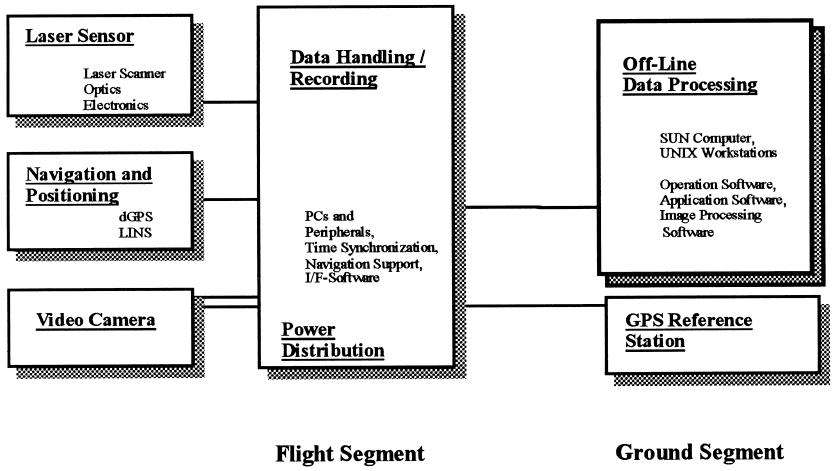

FIG. 1. TypoSys system components.

recorder. A time synchronization facility ensures the precise synchronization of these different data streams during the post-processing.

GPS data are registered with help of Novatel L1/L2 receivers at a data rate of 1 Hz, while the high precision LINS collects position and attitude data at a data rate of 64 Hz. So, after flight path restitution and merging of dGPS and LINS measurements, position and attitude data are available at 64 Hz. This means that (at a cruising speed of about 70 m sec^{-1}) the system's orientation is known each metre.

The laser scanner is the key element of the flight segment. The eye-safe sensor operates in the near infra-red region at 1·54 μm at a pulse rate of about 80 kHz.

This type of fibre optic line scanner has been under development for more than 10 years and it has proved its quality and reliability in various non-topographic applications. For DEM generation, the basic scanner has been slightly modified in order to meet the special requirement. So, for example, the scan angle was fixed at $\pm 7°$ in order to minimize shading effects at the borders of the scan. The small scan angle, in combination with the high measurement rate, forms the basis for reliable distance measurements and the high quality DEMs.

The offline processing system includes several UNIX workstations. The key software packages are those for flight path restitutions and the TopoSys package for DEM generation and elimination of vegetation cover. Further tools allow the fusion of digital data from various sensors and an image processing software package supports DEM visualization and quality control.

The primary output of the DEM production process is a 16 bit raster DEM, typically at a raster width of 1 m and with a height accuracy of about 0·1 m. The distribution of measurement points on the ground is shown in Fig. 2. As the distance between neighbouring scans is less than 0·15 m, the TopoSys scanner provides on average five measurements per m^2. In other words, about five elevation measurements are available to perform statistical and plausibility analyses when calculating a single DEM value for a 1 m grid. Depending on the customer, either this basic product or value added products are delivered in various co-ordinate systems and data output formats.

As the final accuracy of the DEMs is also determined by the precision of the

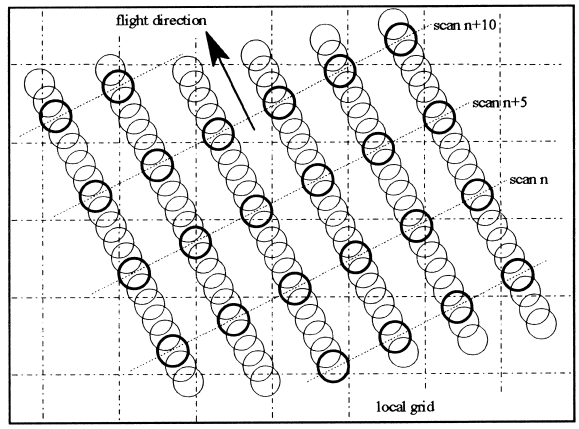

FIG. 2. Scan pattern on the ground.

position and attitude measurements during the survey flights, these components have been selected carefully. The TopoSys LINS allows a pointing accuracy of 0·2 m on the ground (from a survey altitude of 1000 m), while dGPS provides a maximum accuracy of 0·1 m for the position measurement. A summary of performance parameters is given in Table I.

DEMs FOR VARIOUS APPLICATIONS

TopoSys DEMs, geocoded and delivered at a raster width of 1 m to 3 m, are intended to be used as one layer in a GIS. Presently, such kinds of high resolution DEMs are used as basic data sets for:

water resources management and monitoring of coastal zones;
3D city models;
obstacle detection (for example, in approach tracks to airports);
DEM generation in forestry areas; and
monitoring of open pit mines.

Further applications are being developed in close contact with customers.

TABLE I. Performance parameters.

Sensor type	Pulse modulated laser radar
Range	$\approx$ 1000 m
Scanning principle	Fibre optic line scanner
Transmitter	Solid state at 1·5 μm
Measurement principle	Run time measurement
Laser pulse rate	80 000 Hz
Scan frequency	600 Hz
Field of view	$\pm 7°$
Number of pixels per scan	127
Swath width (at 1000 m flight height)	250 m
Resolution of a distance measurement	$<$ 0·06 m
Position accuracy of TopoSys DEMs	$<$ 1·0 m
Height accuracy of TopoSys DEMs	$<$ 0·15 m
Laser scanner classification	Class 1 by EN 60825 (eye-safe)

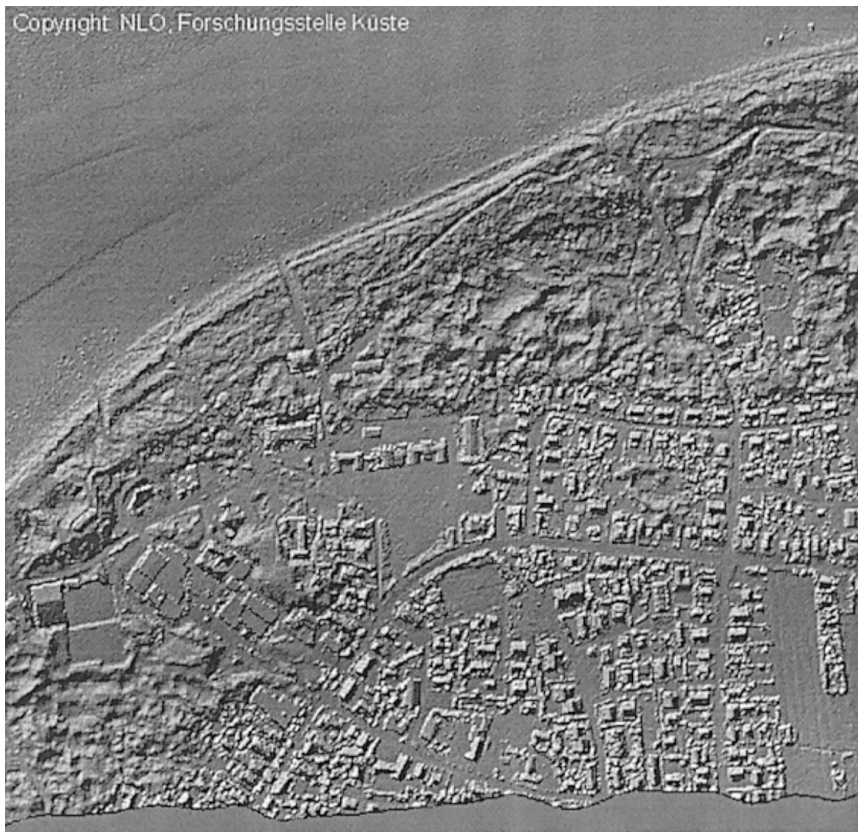

FIG. 3. Section of the DEM of the island of Langeoog, Germany.

DEM Example of the Coastal Zone

Fig. 3 shows a section of the DEM of the northern part of the North Sea island of Langeoog, in East Friesland. The image is a relief presentation of the raster 1 m DEM.

As the survey flight was performed at low tide, the DEM includes not only parts of the village of Langeoog, the dune area and beach, but also the mud sea bottom. Due to the different texture, even the land/water boundary can be identified in the digital data (the upper left corner in Fig. 3).

DEM in Urban Areas

Fig. 4 shows part of the 3D city model of Bonn, Germany. For the purpose of visualization, the TopoSys 1 m raster DEM has been overlaid with a scanned aerial photograph. In the centre of the DEM, Rathausplatz and the Friedrich Wilhelm University can be recognized.

Such high resolution DEMs may form the basic data set for city planning, flood risk assessment and antenna site planning for mobile communicaton companies.

FIG. 4. Section of the 3D city model of Bonn, Germany.

Résumé

Le système de scanneur à laser TopoSys est conçu pour produire des modèles numériques d'altitudes (MNA) avec une précision maximale de 0,5 m en x et y et 0,1 m en z. La régularité de la trame du balayage et la fréquence des mesures qui atteint 80 000 déterminations par seconde (soit en moyenne cinq par mètre carré), sont à la base des MNA de haute qualité. C'est essentiellement l'automatisation du traitement des données qui permet d'établir des MNA courant de vastes zones dans de courts temps de production. Les MNA ainsi produits sont d'un usage courant en tant que bases de données pour diverses applications telles que par exemple la gestion des ressources en eau, la surveillance du trait de côte, la planification des réseaux de distribution et l'urbanisme (simulation du bruit et répartition des pollutions).On a illustré les performances du système à l'aide de fragments de MNA issus de ce système TopoSys.

Zusammenfassung

Das TopoSys Laserscannersystem ist entwickelt worden, um digitale Höhenmodelle (DEM) mit einer maximalen Genauigheit von 0·5 m in der Lage und 0·1 m in der Höhe herzustellen. Das regelmäßige Abtastmuster am Boden, verbunden mit der hohen Meßrate von 80 000 Messungen pro Sekunde (im Mittel 5 Messungen pro m^2) bilden die Grundlage für Höhenmodelle von sehr hoher Qualität.

Die überwiegend automatisierte Datenverarbeitung ermöglicht es, DEMs größerer Gebiete in kurzer Zeit fertigzustellen. Die erzeugten DEMs werden in verschiedenen Gebieten eingesetzt, zur Zeit am häufigsten für Planungen in Küsten- und Flußbereichen, Planung von Versorgungsleitungen und als 3-D Stadtmodelle. Die Leistungsfähigkeit des Systems wird verdeutlicht mit Hilfe von Ausschnitten aus Höhenmodellen, die mit dem TopoSys System hergestellt wurden.