AGH
Akademia Górniczo-Hutnicza
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ALS Airborne laser scanning – backgrounds

AGENDA

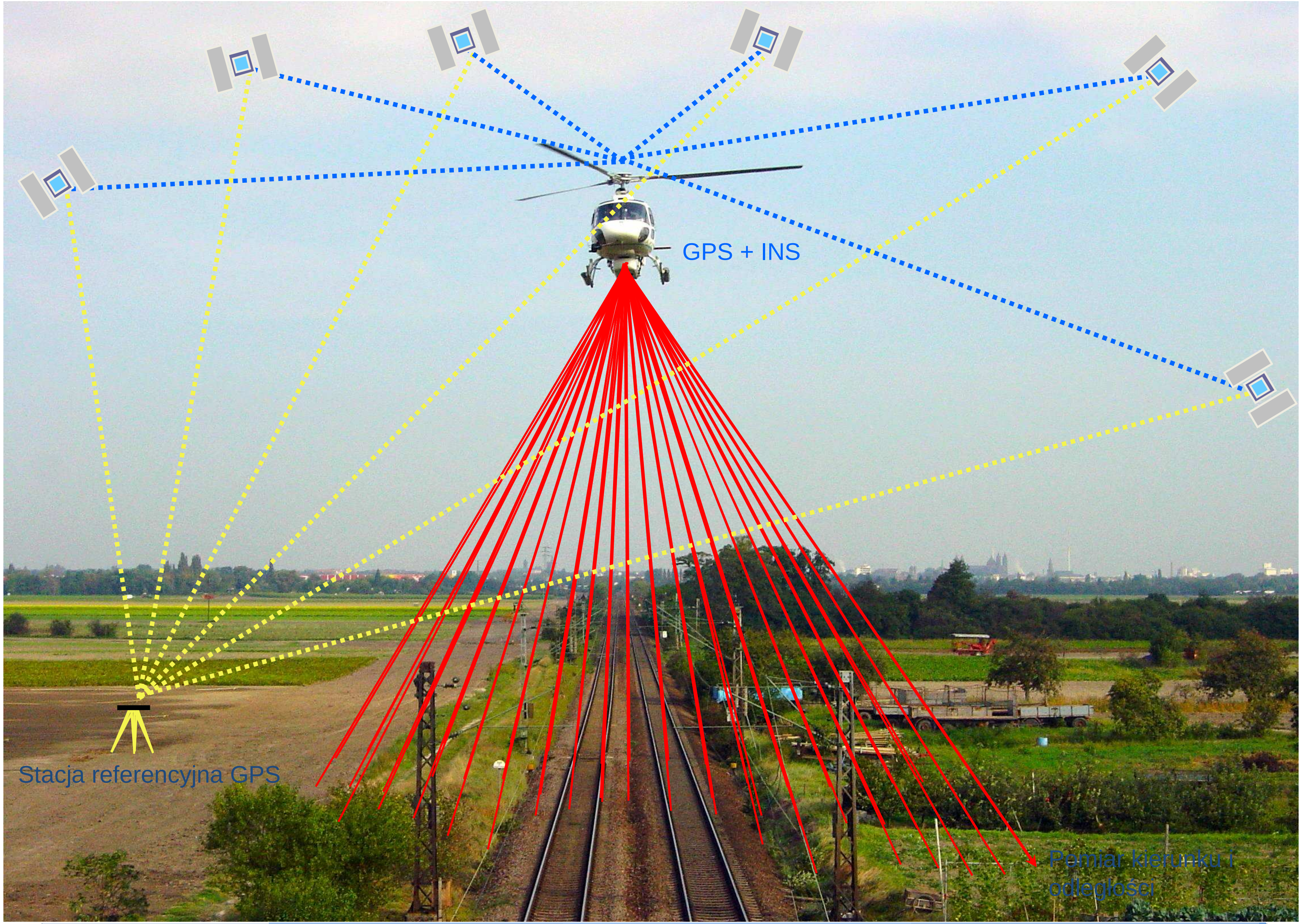
- Function basis
- Construction of scanning system
- Basic scanning parameters
- Commercial scanners
- Advantages and disadvantages
- Efficiency and costs
- Source of errors and accuracy
- Applications
- Steps on the project realization
- Basic ALS products

FUNCTION BASIS

• Laser beam is emitted perpendicular to the flight trajectory. Direction and distance is measured.

• To position determination GPS and INS is applied

• Combinning of the data from laser rangefinde and GPS/INS allows for points cloud generation of spatial coordinates: X,Y,Z


GPS + INS
Stacja referencyjna GPS
Pomiar kierunku i
odległości

ALS data

CONSTRUCTION OF ALS

Airborne part

- distance measurements system:
  - Laser rangefinde
  - receiver
- postioning system GPS
- navigation system INS
- photogrammetric camera (video)
- planning and managment system

Terrestrial part

- terrestrial, refernce GPS station
- workstation for laser data processing

LASER RANGEFINDE

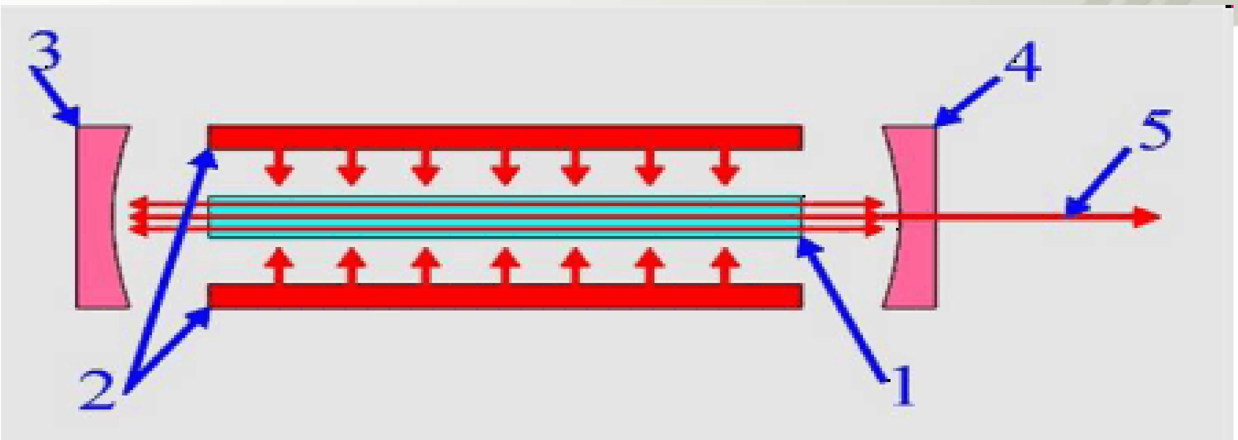
Laser *Light Amplification by Stimulated Emission of Radiation* (light enhancement by forced radiation emition).

Laser not only enhance the light but also emitt it

FEATURES OF LASER LIGHT

- Very high rate of monochromacy, width of the line of Δν tenths of Hertz rzędu dziesięciu herców
- Big focusing of the light, limited only by difraction effect on the laser outside window
- Large intensity of radiation, in impuls activity can be $10^{12} - 10^{13}$ *W*
- Possibility of the generation of very short light impulses (till 10^{-14}*s*)

ELEMENTS OF LASER



- *Active medium*, soils, gas or fluid (1)
- *Optical system* – laser is closed by to mirrors from both sides, one of them is usually permeable (3,4)
- *Pomp system* – external energy supplying is necessary for funtionality of the laser (2)

ACTIVE MEDIUM

Forced emition:

As it is known, emitted photon as a result of forced emmition has the same polarisation and frequency as photon forcing photon. For the laser action initialisation forcing photon must have proper energy equal the forcing medium energy. It also known the atoms in basic state absorb forcing photons. So for the laser acitivity process of forced emmition must dominante the process of phoptons absorbtion.

Inverstion of energetic levels location
Inwersja obsadzeń poziomów energetycznych:

It takes place when there are in medium more photons in forced state then in basic one. Main features of laser parameters depends on active medium what decides about the wavelenght, intensity, way of pomping and possible applications.

POMPING SYSTEM

The main task of the pomping system is to move as many as possible photons in active medium to the forced state. The system must be so efficient to create inversion of location in the active medium. Pomping, i.e. delivering the energy to the laser , can be performed on dirrerent ways, depending on the active substance in laser.

The most famous:

-Pomping by flash of flash lamp,

- Pomping by flash of other laser,

- popmping by electric current in gas,

- Pomping by chemical reaction,

- Pomping by atoms collision,

OPTICAL SYSTEM

Active medium is treated as electromagnetic wave generator. Optical system play feedback role, i.e. interaction output signal on input signal, for chosen frequencies, so the generated light has unique frequency.

Optical system is composed usually of two mirrors, one partly permeable
Precisely made and properly insatlled mirrors become the resonator of determined frequency and movement direction.
Therefore only the photons for them optic system is a resonator are runnig many times in active medium, causing emition of the other coincident with them photons. Other photons disappear.

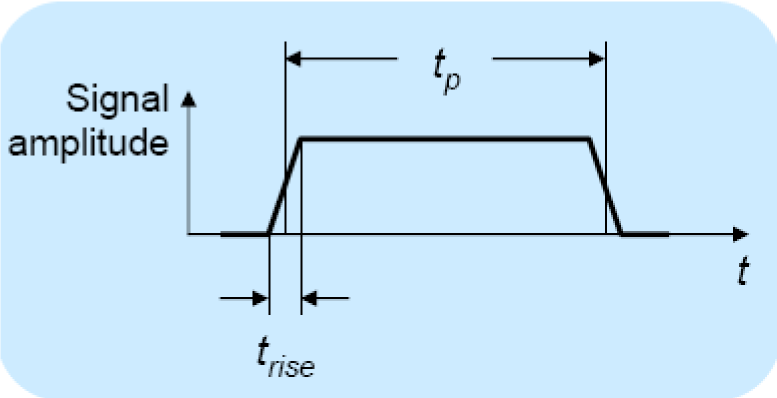
LASER ARE CLASSIFIED ACCORDING THE ACTIVE MEDIUM

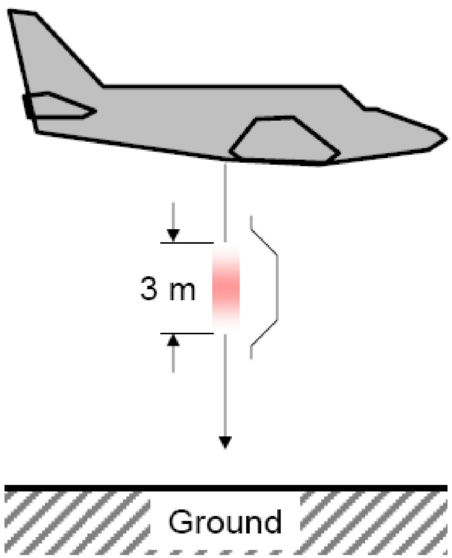
- Gas laser(*He – Ne* hel - neon, *Ar* argon (jon), on Co_2, CO
- Soil laser Lasery (rubinowy, neodymowy na szkle,- neodymowy na YAG-u (granat itrowo – aluminiowy - *Nd* : *YAG*) - erbowy na YAG-u, tulowy na YAG-u,holmowy na YAG–u, tytanowy na szafirze)
- Fluid laser – pigmental, active medium are pigments dissolved in non active transparent medium
- Semiconductive laser
  - linked – on volume metarial, onwell quantum, on quantum dots
  - No linked – quantum cascade laser

AIRBORNE LASER RANGEFINDE

- semicoductive lasers or lasers on solid (neodymowy na YAG-u – Nd:YAG)
- najczęściej występuje neodymowy Nd:YAG (*ang. Yttrium Aluminum Garnet*) – granat itrowo – aluminiowy
- most oftern in NIR (1064 nm)
- bathymetric lasers in VIS (523 nm – green)
- others: 810 nm (ScaLARS), 900 nm (FLI-MAP), 1540 nm (TopoSys)
- kind: impuls or continuos laser (CW – ang. continuous wave)
- Main features: large beam coherence, large intensity

IMPULS LASER





[Brenner 2006]

Impuls width:

t_p = 10 ns (→ 3 m)

Power:

P_{peak} = 2 000 W

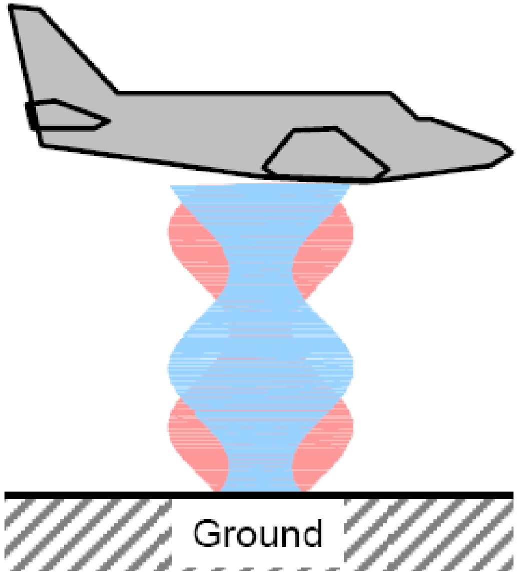
Impuls energy:

$E = P_{peak} t_p = 20\ \mu J$

Mean power: (dla F=10kHz)

$$P_{av} = E \cdot F = 0.2W$$

CW LASER



[Brenner 2006]

Characteristic (ScaLARS):

- two frequencies:

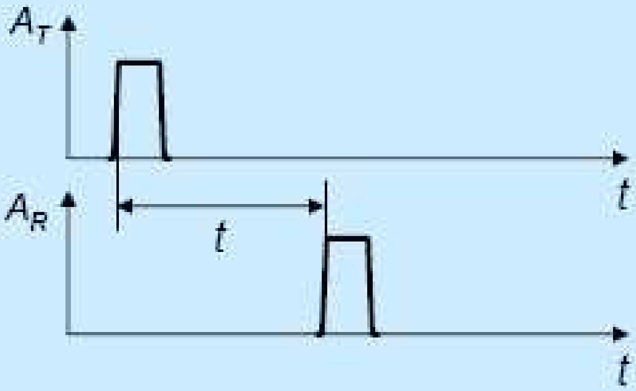
f_{high} = 10 MHz, f_{low} = 1 MHz

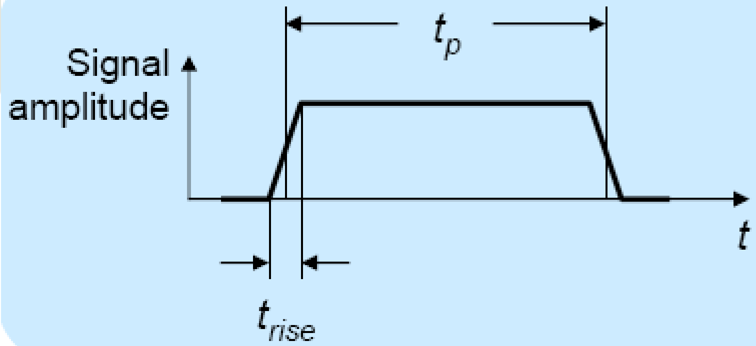
λ_{short} = 30 m, λ_{long} = 300 m

- mean power:

$$P_{av} = 0.26\ W$$

IMPULS LASER





- Range — Distance between sensor and object

$$R = \frac{c}{2} \cdot t$$

- Range resolution — Resolution od distance determination

$$\Delta R = \frac{c}{2} \cdot \Delta t$$

- Range accuracy — Accuracy od distance determination

$$\sigma_R \quad \propto \quad \frac{c}{2} t_{rise} \cdot \frac{1}{\sqrt{S/N}}$$

Symbols:

c – light speed

t – time of the single impuls

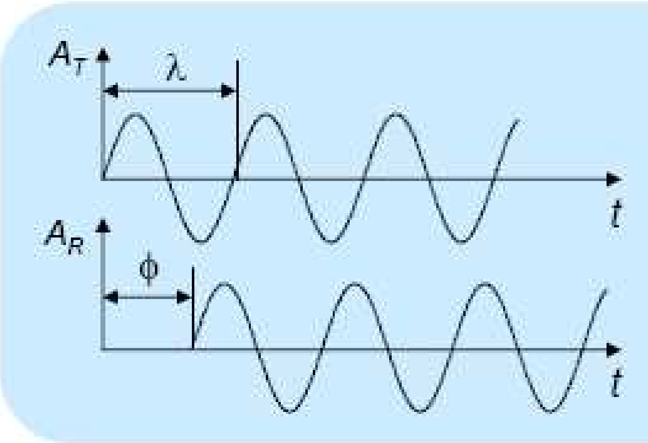
Δt – time resolution of measurements

t_{rise} – time of impuls increasing from 10% to 90%

S/N – signal to noice ratio

[Brenner 2006]

CW LASER



- Range

$$R = \frac{1}{2} \cdot \frac{\phi}{2\pi} \cdot \lambda_{\text{short}}$$

- Range resolution

$$\Delta R = \frac{\lambda_{\text{short}}}{4\pi} \cdot \Delta\phi = \frac{c}{4\pi} \cdot \frac{1}{f_{\text{high}}} \cdot \Delta\phi$$

- Range accuracy

$$\sigma_R \quad \propto \quad \frac{\lambda_{\text{short}}}{4\pi} \cdot \frac{1}{\sqrt{S / N}}$$

symbols:

Λ_{short} – short wave lenght

Λ_{long} – long wave lenght

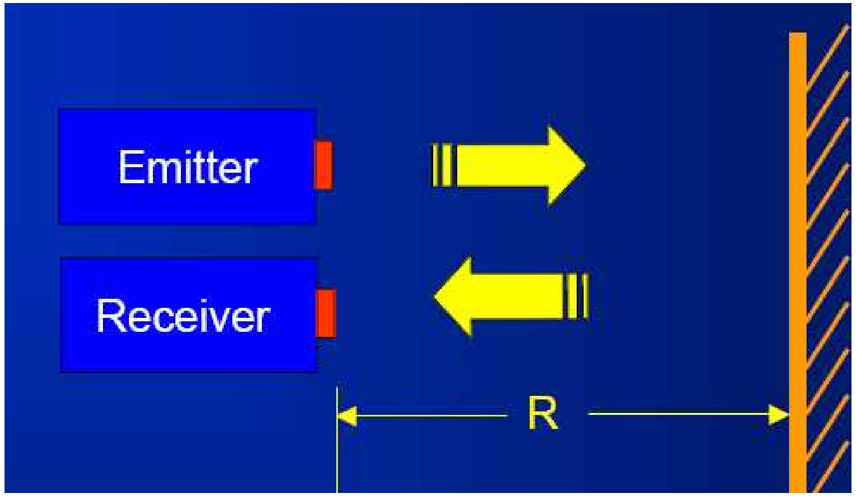
Φ – phase difference between signal sent and received
Δ Φ – phase resolution

[Brenner 2006]

IMPULS LASER – CHARACTERISTIC

Time of simgle impuls :

$$t_{travel} = \frac{2R}{c}$$



Example:

R = 1000m → t_{travel} = 6.7μs

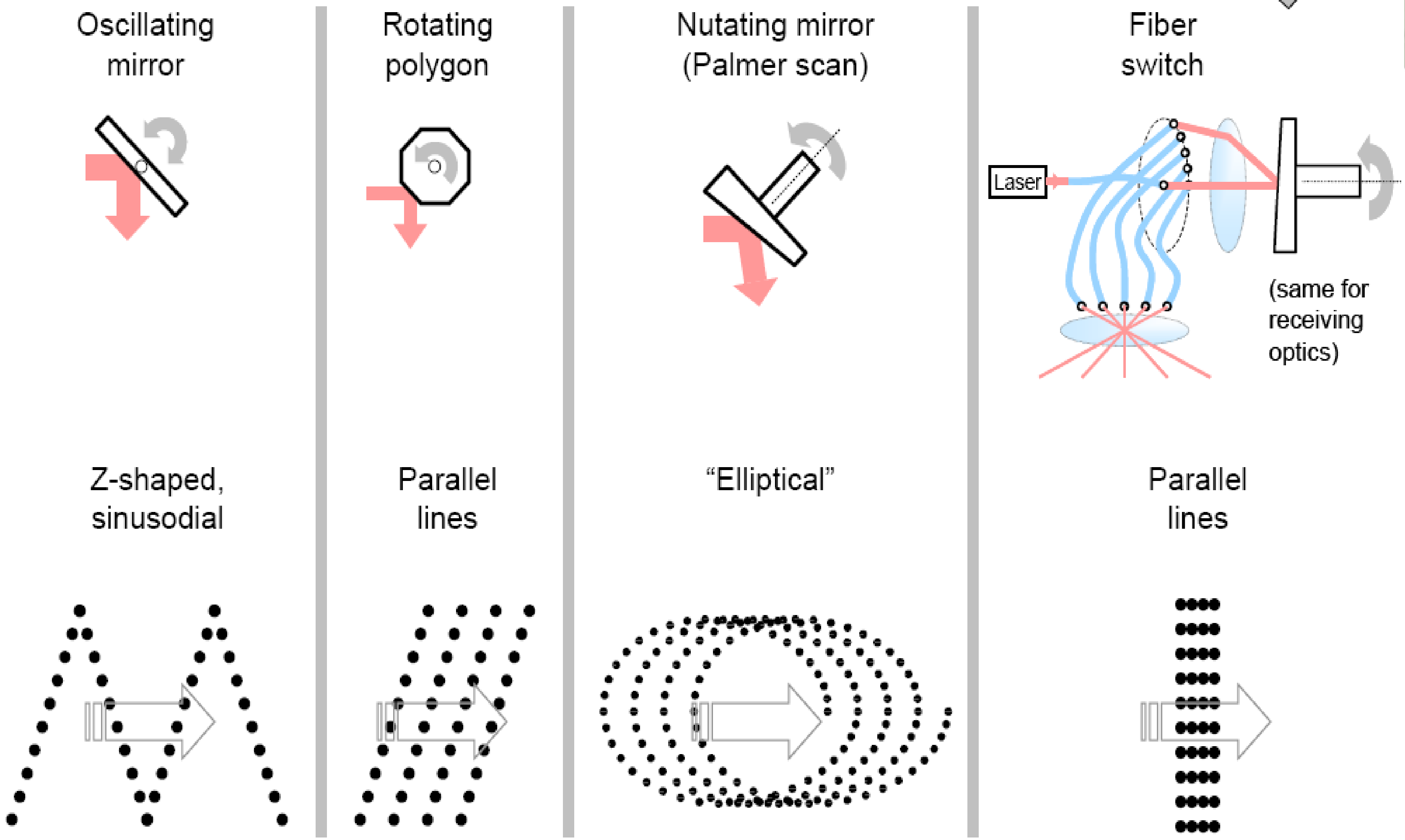
Maximal impuls frequency:

$$f_{\max} = \frac{1}{t_{travel}} = \frac{c}{2R}$$

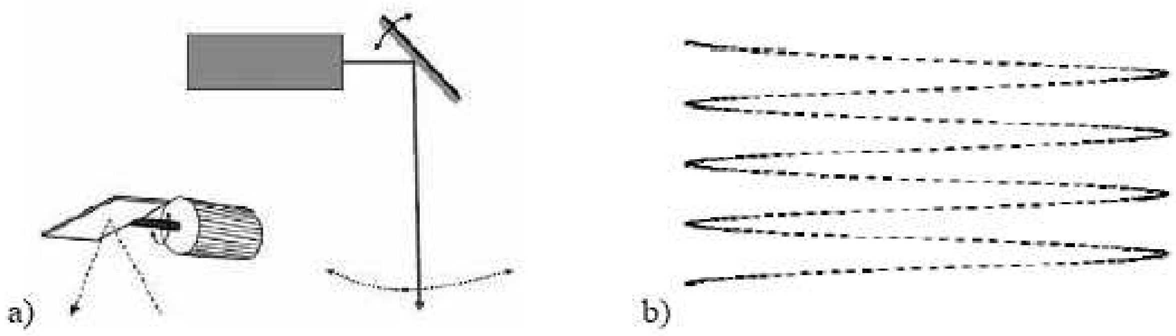
Example:

R = 1000m → f_{max} = 150kHz

SCANNING MECHANIZM

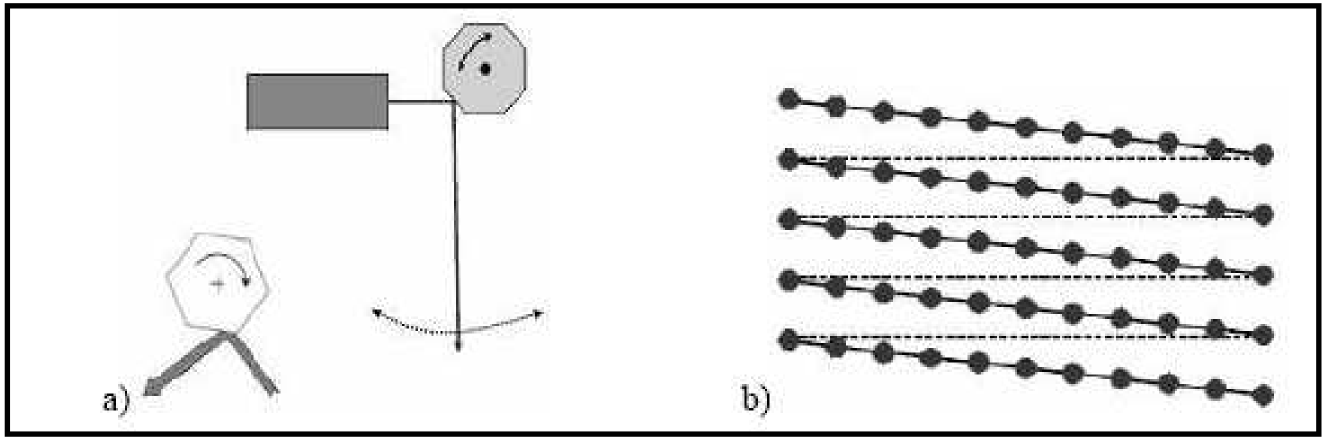


Mechanism of pendulum mirror



Beams are projected by mirror moving around its symetric axis. Inclination grade decides on reflection beam. This scanning way is flexible from angle change and scanning speed, but also non homogenic if we are talking about the laser beam dispersion in scanning line. When the maximum mirror inclination is reached rotation speed decerease, what cases more density of measurements points.

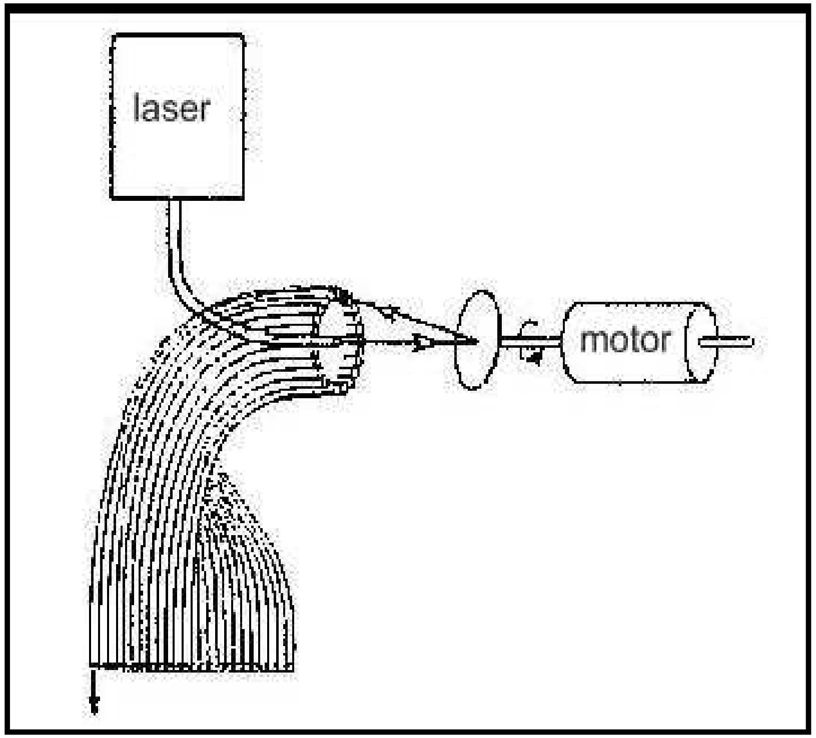
Mechanizm of rotating polygon



Beams are projected by polygon spahe mirror moving around its symetric axis. Mirror makes monotonus movement, without direction changing, what eliminates non homogeneous points distribution.

Machanism using optic fibre

Beams are projected by polygon spahe mirror moving around its symetric axis. Mirror redirect them to waveguide copomposed from optic fibre placed in circle shape. At the end of the channel leading laser light – waveguide, optic fibres in the same plane, and the way of their pacement allows for possibility of proper incident beams' angles



POSITION SYSTEM BASED ON FLY TRAJECTORY APPLYING GPS

Flying directory is determined by GPS, using DGPS

It bases on the application of terrestrial station, aclled reference station standing above the point with known coordinates. Station calculates error vector describing difference between the known and calculated coordinates. This information are sent to the GPS on the aircraft what makes the correction of its position. Finaly scaner location on the aircraft can be determined with accuracy not worse then 10 cm.

INS inertial navigation system

INS determines location, speed, orientation and angle speeds scanning platform (aircraft, helicopter) measuring linear and angle of acceleration in 3 platform axises what is in movement. System is composed from very sensitive gyroscopes and accelerators determining state of the system. Gyroscopes determine inclination angles of the platform. Accelerators deteremine its speeds in each direction. Integration of the two equipments INS is able to determine trajectory of the aircraft with the error below then 2 cm and the angles of scanning equipment.

GPS INS INTEGRATION

GPS and INS is characterised by different and complementar error propagation causing advantages of two systems: stability of GPS and precision of INS.

INS delivers temporary data, what are corrected on the base on the data from GPS. It eliminates cummulative errors and causes accurace of flying trajectory about 2 cm.

PHOTOGRAMETRIC CAMERA OR/AND VIDEO

Photogrametric or/and video camera can be linked with the laser scanner. For data synchronization, each photo and video frame has registered the numer and accurate time of acquisition. Video images are usefull for land cover interpretation. Wheras airborne images are used in classification process and ortophoto generation.

TERRESTRIAL SEGMENT

- **Terrestrial reference GPS station**

- **Work station for data processing**

  Work station is composed of computer platfrom of a big computation power, necessary for large size of the data. It integrates all acquired in measurements information:

- Laser data
- Video tapes or photogrammetric images
- GPS data from moving reciver
- GPS data from reference terrestrial station

BASIC SCANNING PARAMETERS

SCANNING ANGLE

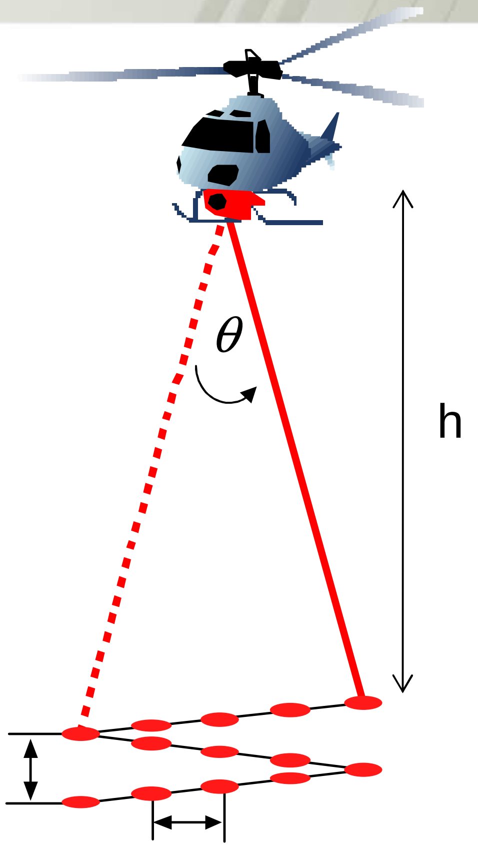
θ (FOV- Field of View)

Typical values 10° - 60° (max. 75°)

Small angles apllied for shadows elimination

Width of skaning strip

$$SW = 2h \cdot tg(\frac{\theta}{2})$$



FREQUENCY

Impuls frequency – F

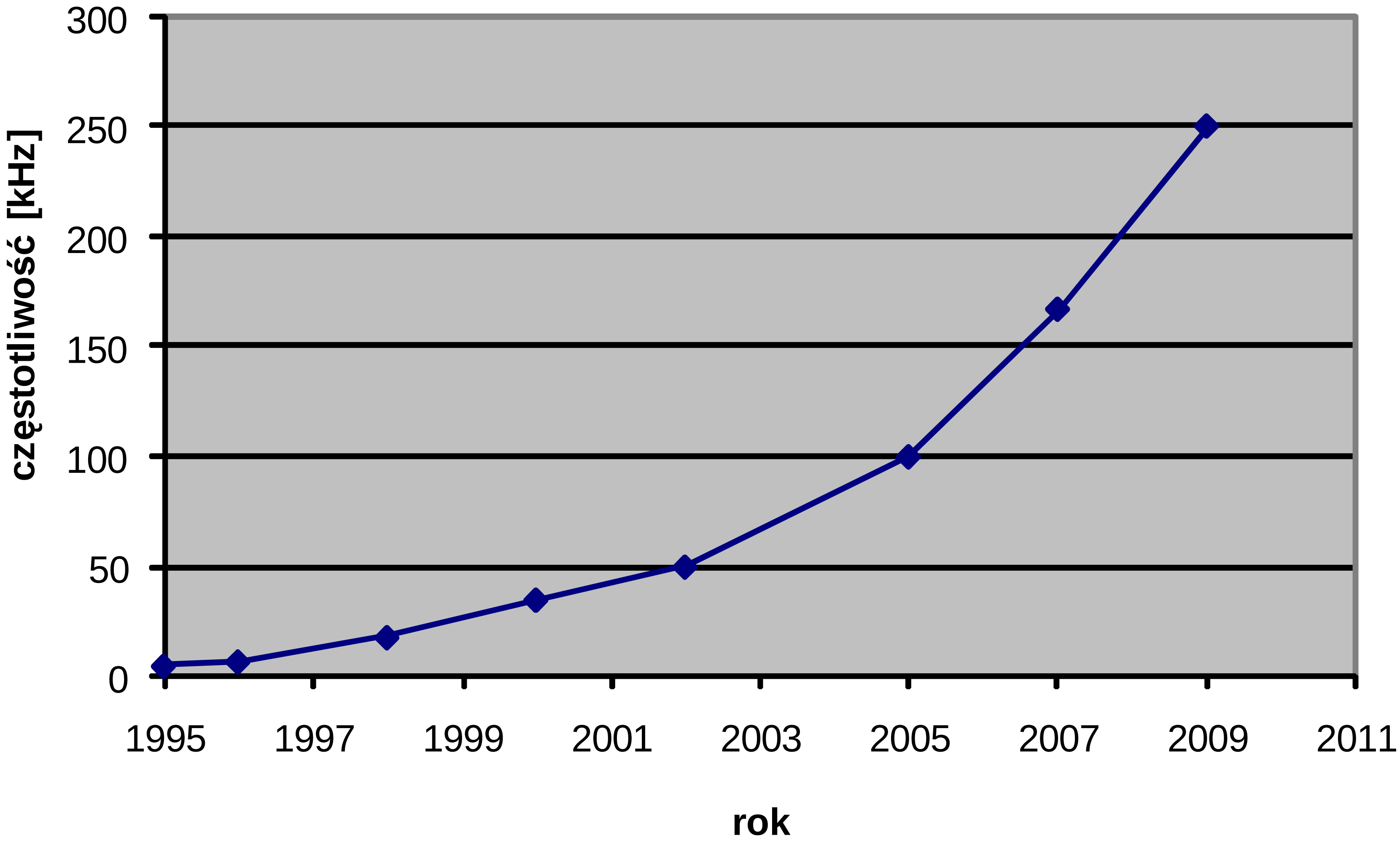
Typical values F= 100 -250 kHz

Scanning frequency - f_{sc}

Parameter determining amount of scannig lines obtained in 1 s:

Typical value f_{sc} = 600 Hz

FREQUENCY OF IMPULS CANNER



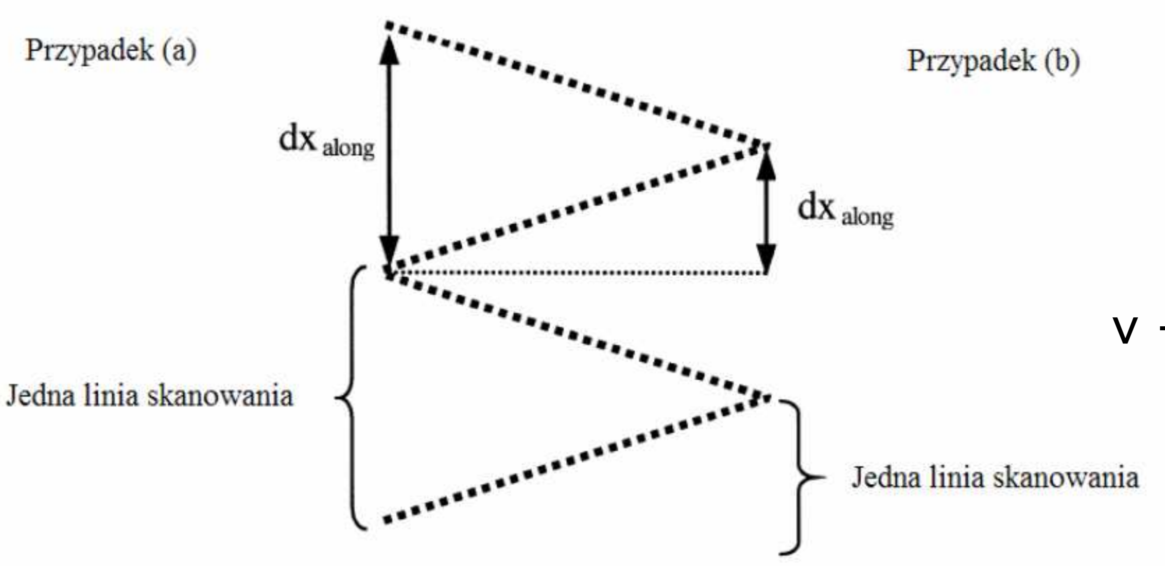
Number of points in scanning line

Is proportional to the frequency of laser impuls sending and inversely proportional to the number of scanned lines in 1 s.

$$N = \frac{F}{f_{sc}}$$

Mean distance between scanning lines elong flying direction – dx_{along}

The distance for scanns in zig-zag shape is measured between points registered in extreme laser beam inclination (case a) or between points measured in the same inclination (case b)



$$dx_{along} = \frac{v}{f_{sc}}$$

v – average fligh speed

[Baltsavias E.P., 1999]

Mean distance between scanning lines elong flying direction– dx_{across}

Assuming unique distance between next points in scanning line and flat tarrain the parameter is determined by:

$$dx_{across} = \frac{SW}{N}$$

Required numbers of rows - n

$$(n-1) \geq (W - SW)/[SW \cdot (1-q)/100]$$

W – the minimum dimention of rectangular area covered by measurements
q – lateral overlay (w %)

Density of points on unit area – d

Determined by average amounts of the points on unit area (m2).

It is depend from terrain denivelation and land cover (many reflectance registration).

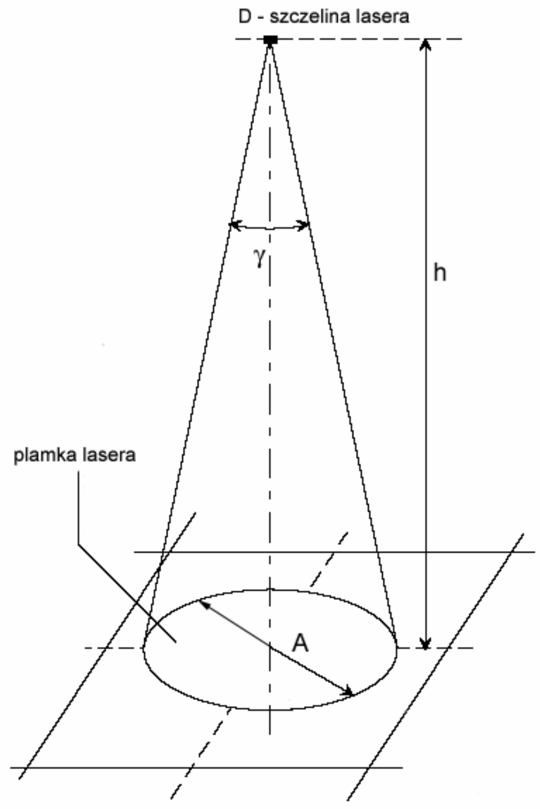
$$d = \frac{F \cdot n \cdot T_S}{A}$$

T_S – time net of measurement of one row (not including back platform movements).

DIVERGENCE OF LASER BEAM

$$IFOV = 2.44 \cdot \frac{\lambda}{D}$$

λ - wave lenght
D – laser slot



Example:

λ = 1064 nm; D = 10 cm → IFOV = 0.026 mrad

Typical values:

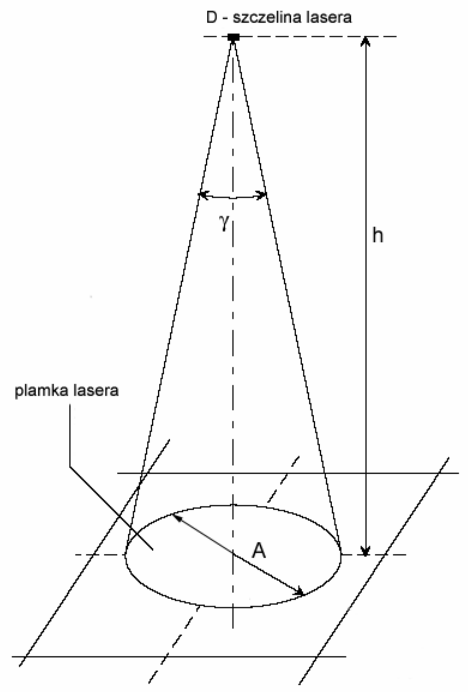
γ = 0.25 – 2 mrad

DIAMETER OF LASER DOT

$$A = D + 2h \cdot tg(\gamma / 2)$$

$$A \approx 2h \cdot tg(\gamma / 2)$$

$$A \approx h \cdot \gamma$$



Example:

h = 750 m; γ = 1mrad

A=0.75 m

POWER BALANCE

Received power:

$$P_r = \frac{A_r}{2\pi \cdot R^2} \cdot M^2 \cdot \rho \cdot P_t$$

where:
A_r – slot area
M – atmosphere transmition
R – distance
ρ– reflection cooficient
P_t – power sent

Example:

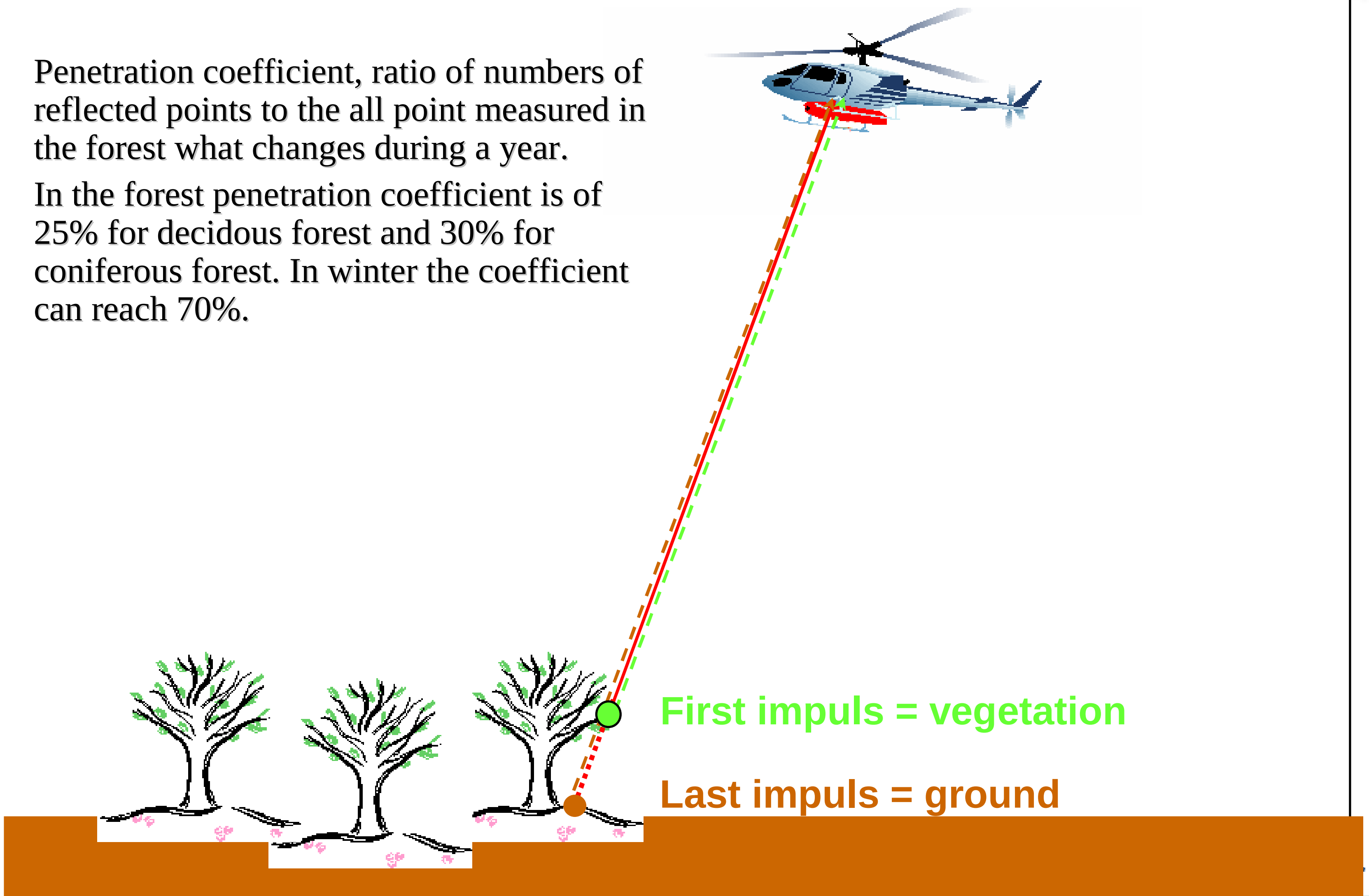
- P_T = 2000 W
- Atmospheric transmission M = 0.8
- A_r = 80 cm^2 (D_r = 10 cm)
- R = 1 km
- Reflectivity ρ = 0.5

→ $P_r = 4 \cdot 10^{-10}\, P_T$ = 800 nW

MULTI RECLECTION REGISTRATION OF SIMGLE IMPULS

Penetration coefficient, ratio of numbers of reflected points to the all point measured in the forest what changes during a year.

In the forest penetration coefficient is of 25% for decidous forest and 30% for coniferous forest. In winter the coefficient can reach 70%.



INTENSITY OF REFLECTED IMPULS

Laser scanner, besides X, Y, Z coordinate meausrements allows also for registration of the energy reflected from the object. Intensity image can be compared with airborne image (with enough amount of points)

Reflection intensity:

Rodzaj powierzchni obiektu	Odbicie [%]
Drewno sosnowe, czyste, suche	94
Śnieg	80 – 90
Białe konstrukcje z kamienia	85
Wapień, glina	do 75
Drzewa liściaste	zwykle 60
Drzewa iglaste	zwykle 30
Skała wapienna sucha	57
Skała wapienna mokra	41
Piasek pustynny, plaża	50
Beton	24
Asfalt	17
Lawa	8
Guma syntetyczna	5
Woda	5

$$I_r = \frac{P \cdot \rho}{A}$$

P – power of the impuls

ρ – reflection coefficient

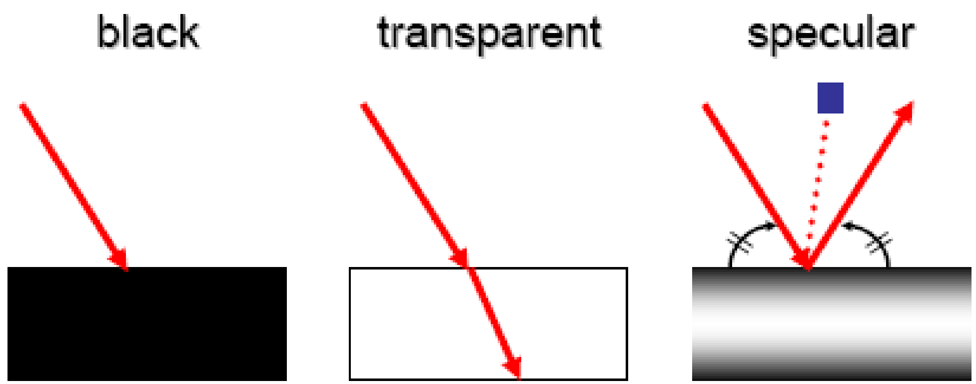
A – size of the area

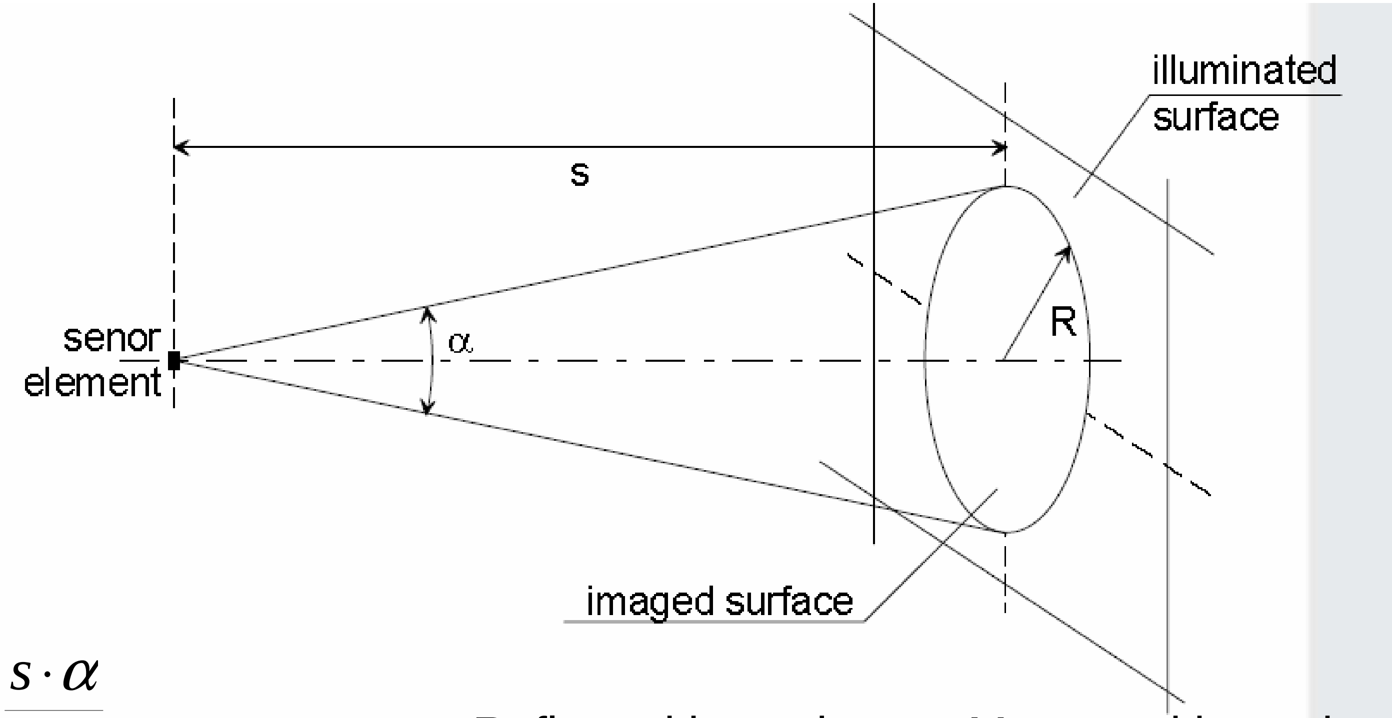
Detection is not possible if the area is:

black – highly absorbing

transparent – highly transmitting

mirror – highly reflecting





$$R = \frac{s \cdot \alpha}{2}$$

$$A = 2\pi \cdot R^2 \approx s^2 \cdot \hat{\alpha}$$

Reflected intensity :

$$I_r = \frac{P \cdot \rho}{A}$$

$$I_r = \frac{P \cdot \rho}{s^2 \cdot \hat{\alpha}}$$

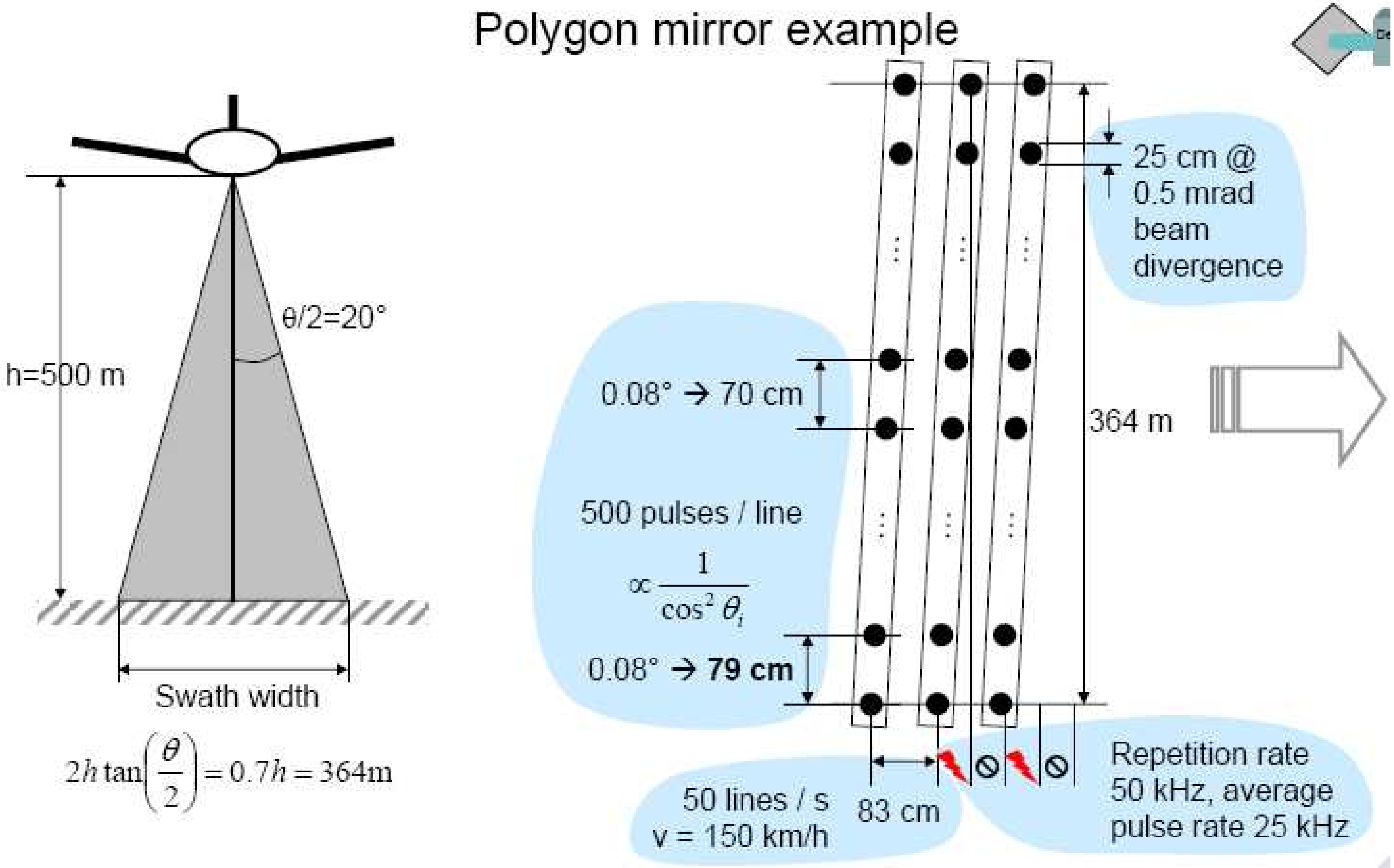
Measured intensity:

$$I_m \approx I_r \cdot \frac{R}{s}$$

$$I_m \approx I_r \cdot \hat{\alpha}$$

$$I_m \approx \frac{P \cdot \rho}{s^2}$$

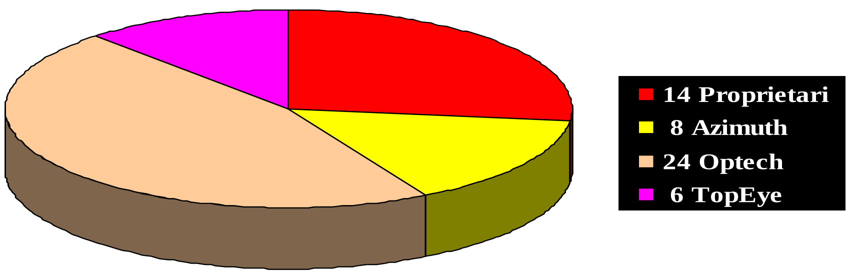
Polygon mirror example



[Brenner 2006]

Commertial laser scanners

- **ALTM** company **Optech Incorporation** (Canada)
- **ALS** company **Leica Geosystems GIS & Mapping** (USA)
- **TopEye** company **TopEye AB** (Sweden)
- **ALTMS** company **TerraPoint** (USA)
- **FALCON** company **TopoSys** (Germany)
- **FLI-MAP** company **Fugro-Inpark**
- **LiteMapper** company **IGI mbH** (Germany)
- **GeoMapper 3D** company **Laseroptronix** (Sweden)
- **LMS** company **Reigl** (Germany)



ALTM GEMINI 167 — FALCON III

Optech Inc. - Canada — Toposys – Germany

	ALTM GEMINI 167	FALCON III
Laser repetition rate	33 - 167 kHz	50 -125 kHz
Operating altitude	80 to 4,000 m (higher altitude optional)	30 to 2 500 m
Horizontal accuracy	1/11,000 x altitude; ±1-sigma*	< 0.20 m
Elevation accuracy	5 - 10 cm typical; ±1-sigma	< 0. 10 m
Range capture	Up to 4 range measurements for each pulse, including last	Up to nine per pulse
Intensity capture	4 intensity readings with 12-bit dynamic range for each measurement	12 bit dynamic range
Scan frequency	Variable to 100 Hz	165 Hz to 415 Hz
Scan angle	Variable from 0 to ±25°, in increments of ±1°	28^{O}
Spot distribution	Sawtooth, uniform spot spacing across 96% of scan	Swing mode

ADVANTAGES

Independence of illumination conditions

Laser rangefinde is an active system, so independent of illumination conditions

Dalmierz laserowy jest systemem aktywnym co czyni go całkowicie niezależnym od warunków oświetleniowych.

Significant independence of meteorological conditions

Registration is possible almot in any weather, only strong rain and fog (limiting laser penetration) can be an obstacle. It means in our climatological conditions almost half of a year is „flying”. It is significant alternative to the airborne images.

Cery high hight accuracy of measurements data

Basing on the experience error of the hight (understood as mean error) is :

mz = 0.15 – 0 .25 m.

Short time of the end product receiving and relative low costs

OPPORTUNITIES OF LASER SCANNING TECHNOLOGY IN COMPARE TO THE TRADITIONAL PHOTOGRAMMETRIC METHODS

- independence of weather
- possiblity of measurements during a day and night
- small amount of GCP
- high density of the points
- measurements of the tarrain covered by vegetation

DISADVANTAGES

- Laser impuls absorption by water, asphalt and pitch
- Laser impuls absorption by dense clouds and fog
- Large volume of the data

DISADVANTAGES OF LASER SCANNING TECHNOLOGY IN COMPARE TO THE TRADITIONAL PHOTOGRAMMETRIC METHODS

•control areas are necessary (on by one row)

•measurements of single hight points, information about the structures of topography is missing

•generation of DSM instead of DTM

•addition data are nacessarysą konieczne dodatkowe materiały (np. ortofotomapy)

•computers of large computing power are needed

•high cost data processing

EFFICIENCY AND COSTS

Proper for large area

- Compact area – > 5 km^2
- Corridor area – > 15 km

Data filtrtion – automatic in 90%

Costs of data processing – 60-80% of total costs

Price:

- Equipment – 0.8 – 2 mln USD
- DTM creation – 150-300 USD/km^2

Efficiency:

- till 100 km^2/ one hour flight
- Data edition time consuming

SOURCES OF THE ERRORS

Laser rangefinder

S/N, laser beam divergence, inclination of detector axis

GPS

Satelliet distribution and number of satellites, reference station location

INS

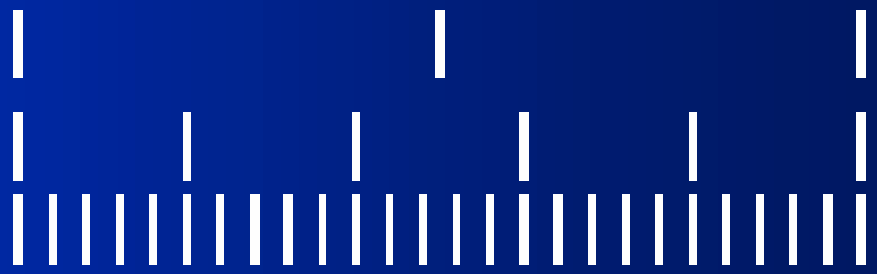
Drift error (decrease of accuracy of angle measurements in time)

Laser equipment GNS/INS common axis missing

Time synhronisation

Typical measurement rates:

GPS	1 Hz	...2 Hz
IMU	50 Hz	...200 Hz
ALS	5000Hz	...25000 Hz



GPS and INS data interpolation is needed

TYPES OF ERRORS

Random errors:

- Divergence of the laser beam
- Atmosphere transmitance
- Land cove type

Systematic errors:

- Inclination of the laser detector axis
- Lack of common axis instruments
- INS drift
- Data integration (synchronization, transformation between sensors, transformation into the local coordinate system)
- Slope of terrain

ERRORS ELIMINATION

- Maintance of the hight stabillity and high time synchronization
- Calibration of laser equipment, common axis GPS/INS
- Proper satellite distribution, optimal distance from reference station, small turbulence

SYSTEMATIC ERRORS STILL PRESENT

VALUES:

Distance measurements	5 cm
Error of angle measurement	$0.02^{o} - 0.03^{o}$
GPS i INS	3 cm / 0.01^{o}
dGPS error	10 cm
INS drift	0.01^{o}

DATA ADJUSTMENT NEEDED

SUMMARY:

Accuracy of laser equipment: **2 – 5 cm**

GPS accuracy (assuming proper reference station and satellites distribution) :
5 – 7 cm

Final hight accuracy depends on many factors (among others flight hight)
For the most systems are not worse then:

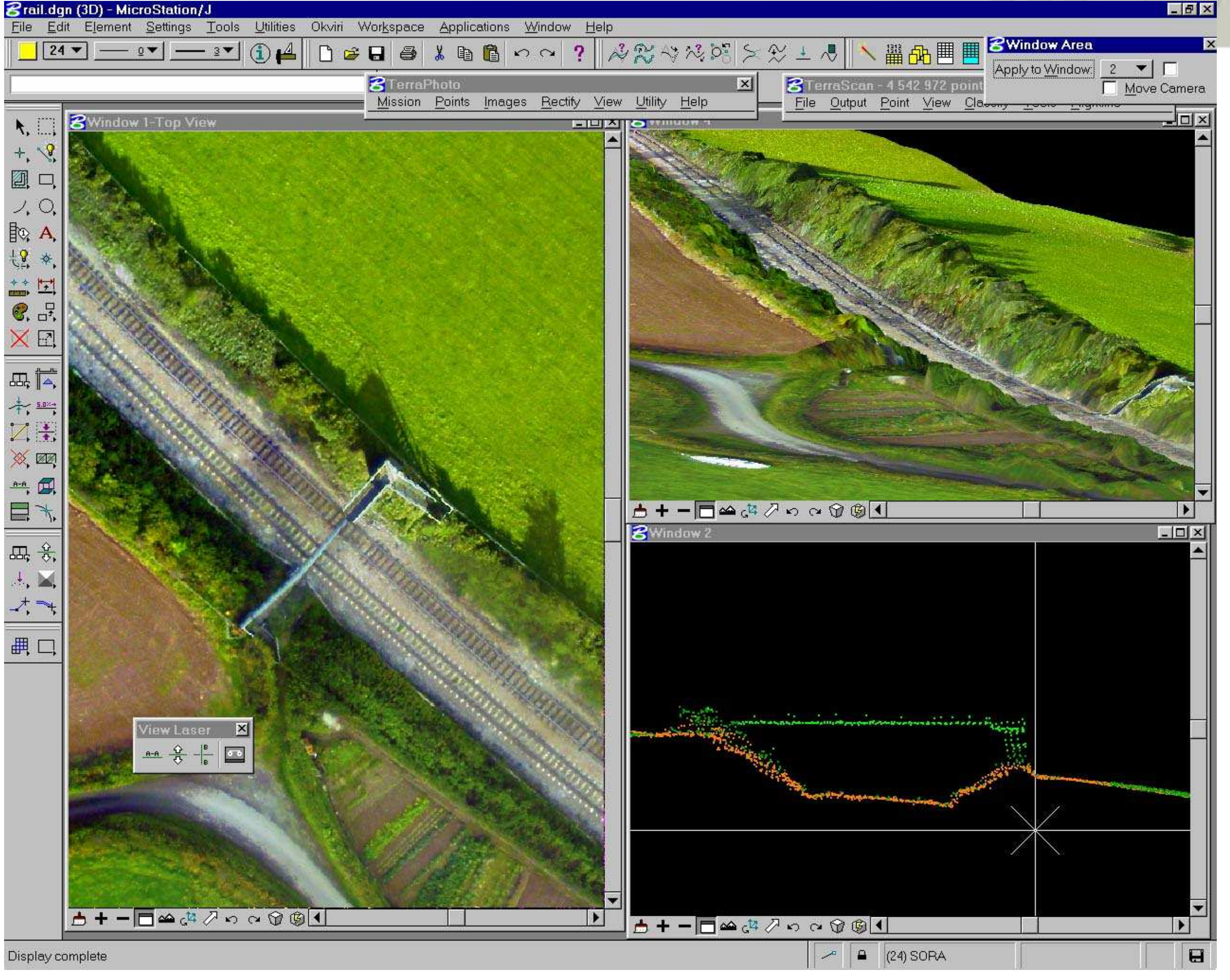
$\pm$ **15 cm**

$$W_{lotu} < 1000 \text{ m}$$

Final hight accuracy : 1/10000 W_{lotu}

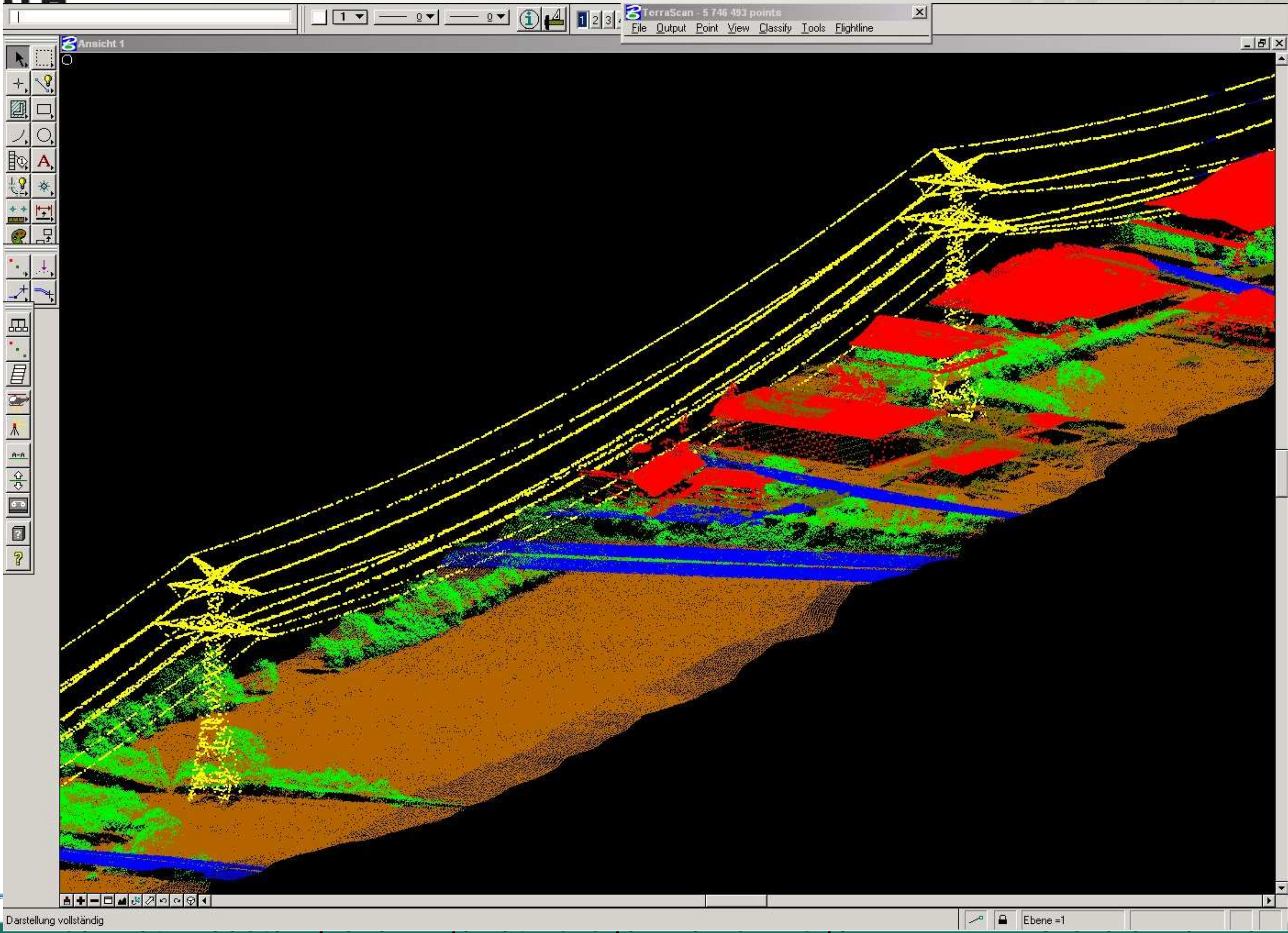
APPLICATION OF LASER SCANNING

ROADS, RAILWAYS, PIPELINES DESIGN



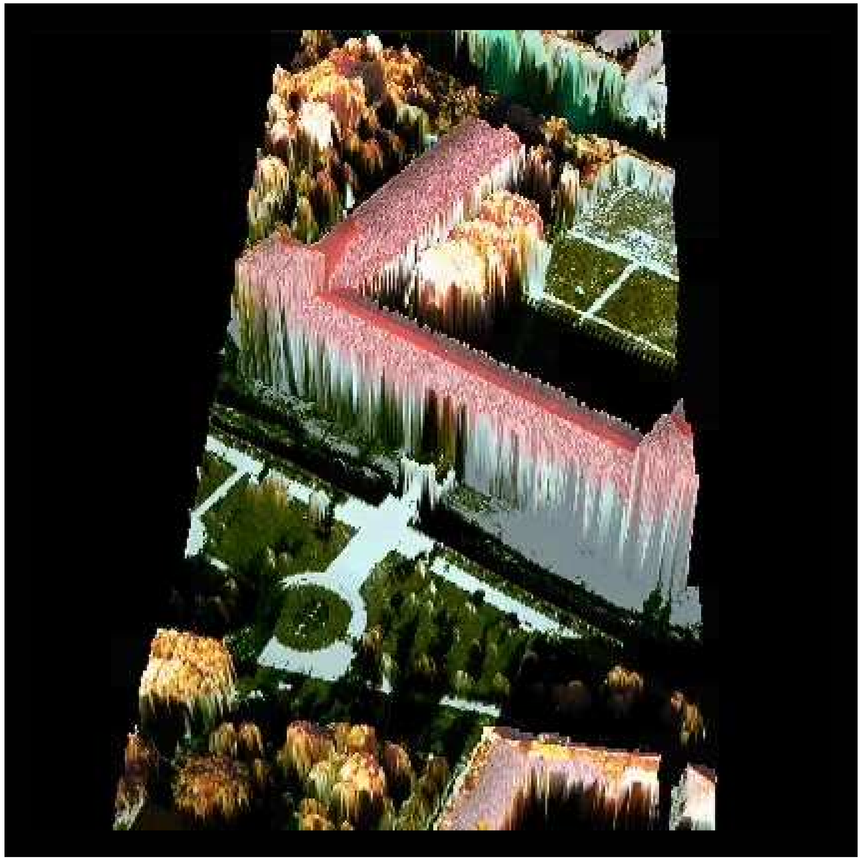
REJESTRAION OF HIGH TENSION LINES

Collision with trees



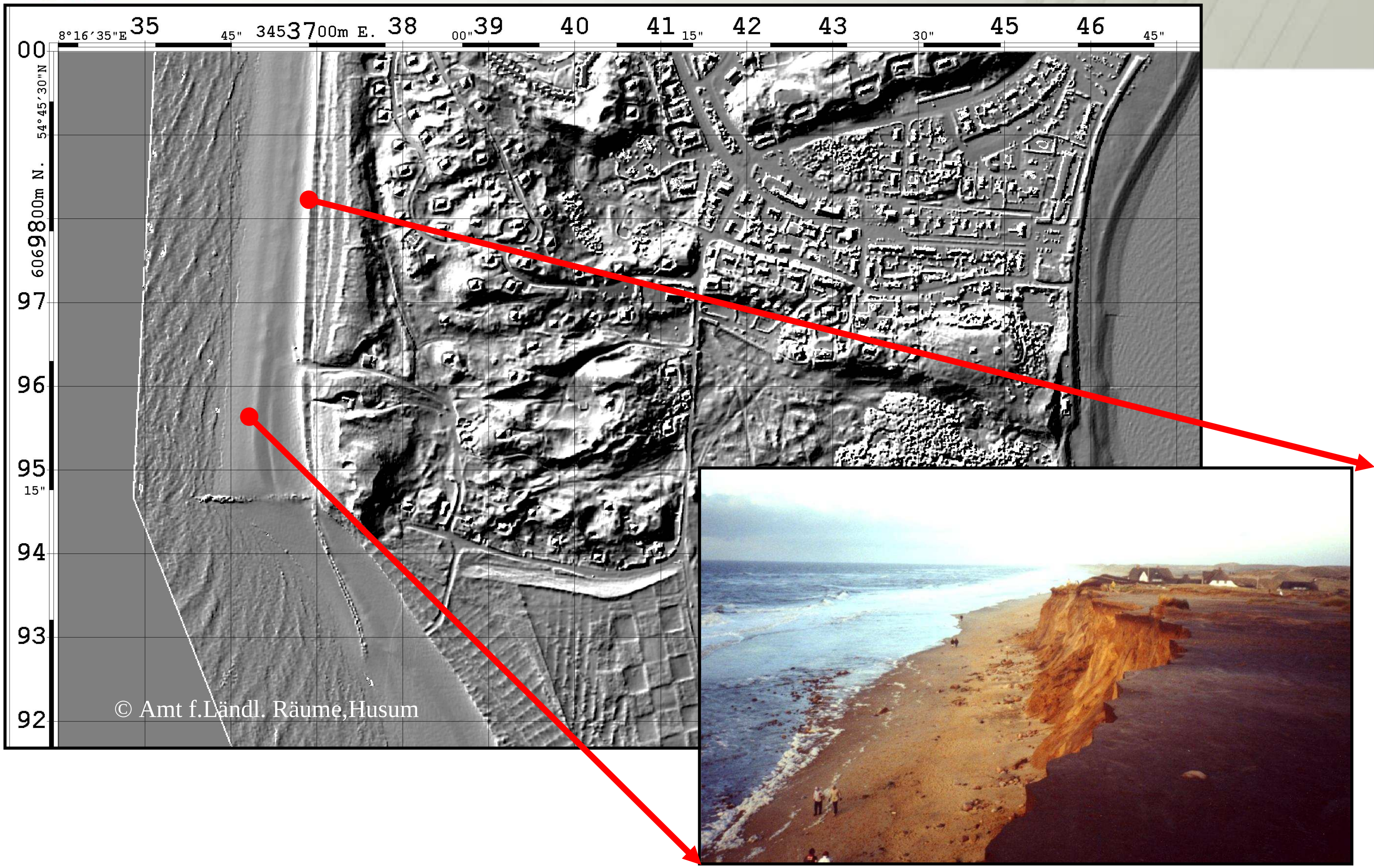
CITY 3 D

Antenna location, spatial planning, noise and pollution dispertion

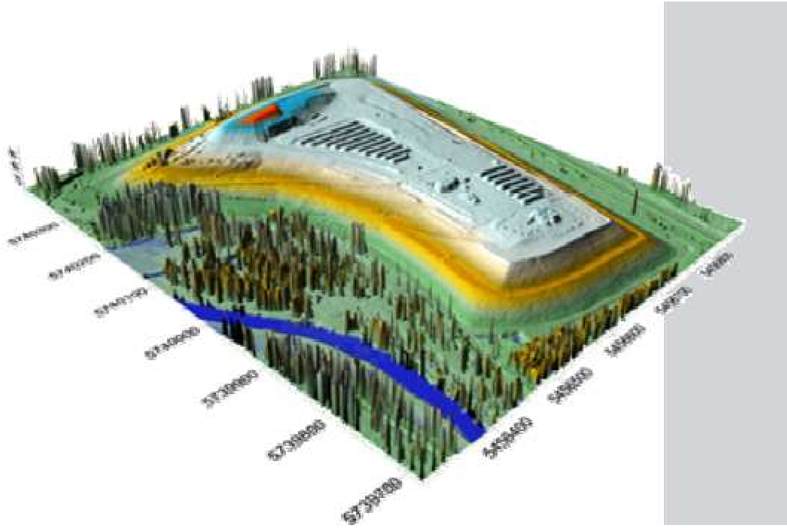


SEASHORE MEASUREMENTS

Change analysisi



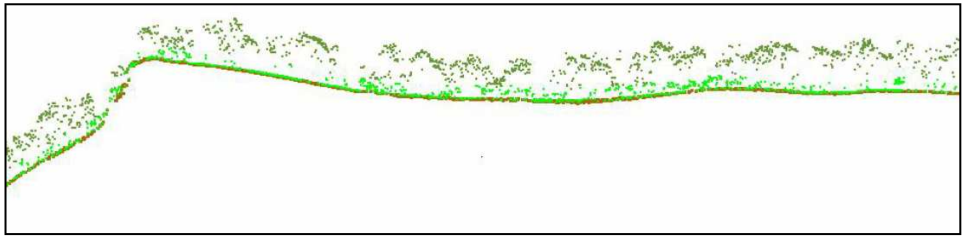
GROUND VOLUME DETERMINATION IN OPEN PIT MINE OR WASTE DAMP

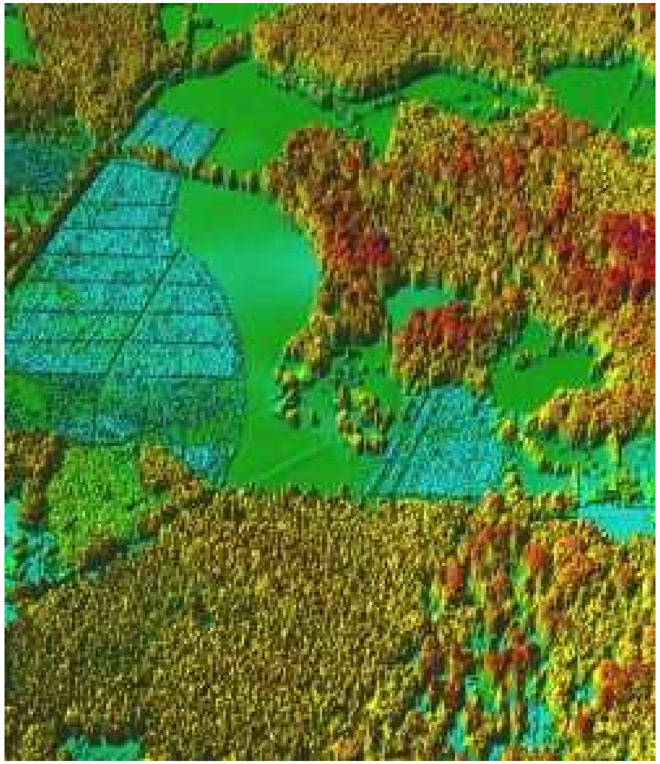


Open pit mine Janschwalde, Niemcy

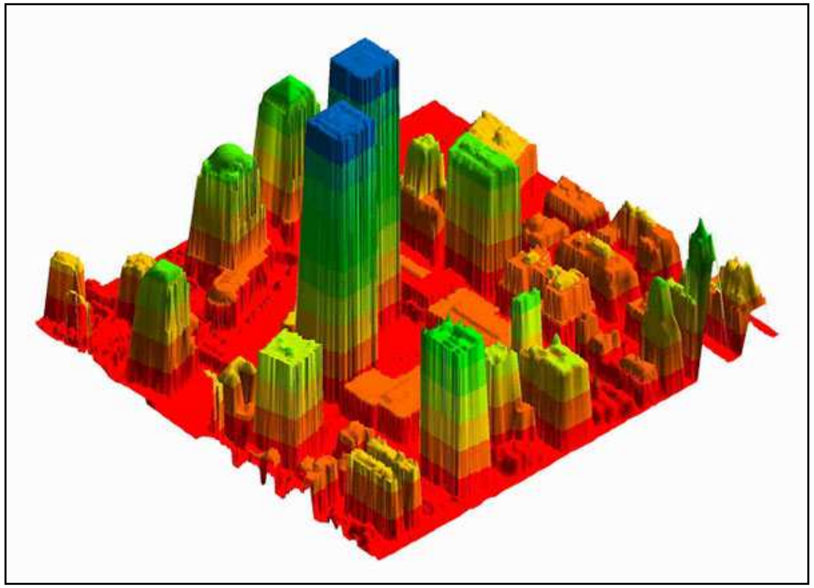
Vegetation analysis

Height of trees, crone diameter, forest density, biomass estimation

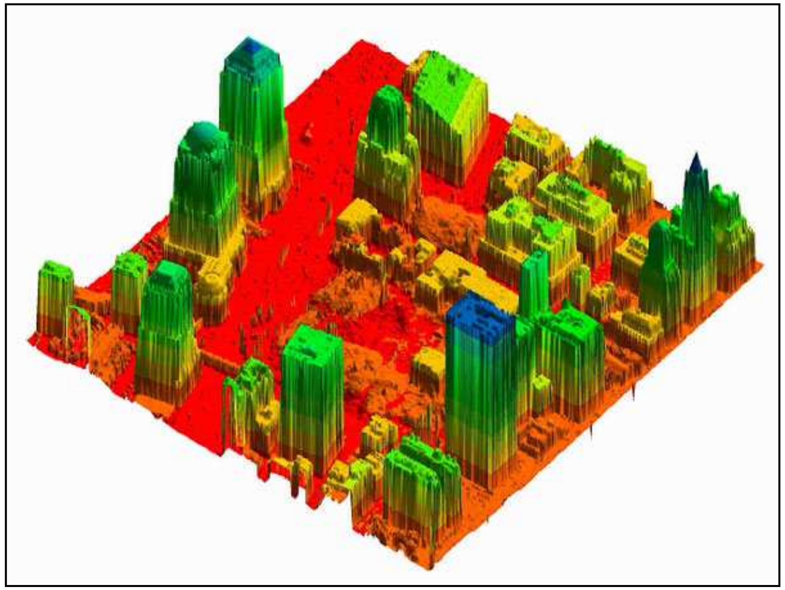




QUICK REJESTRATION – DISASTER

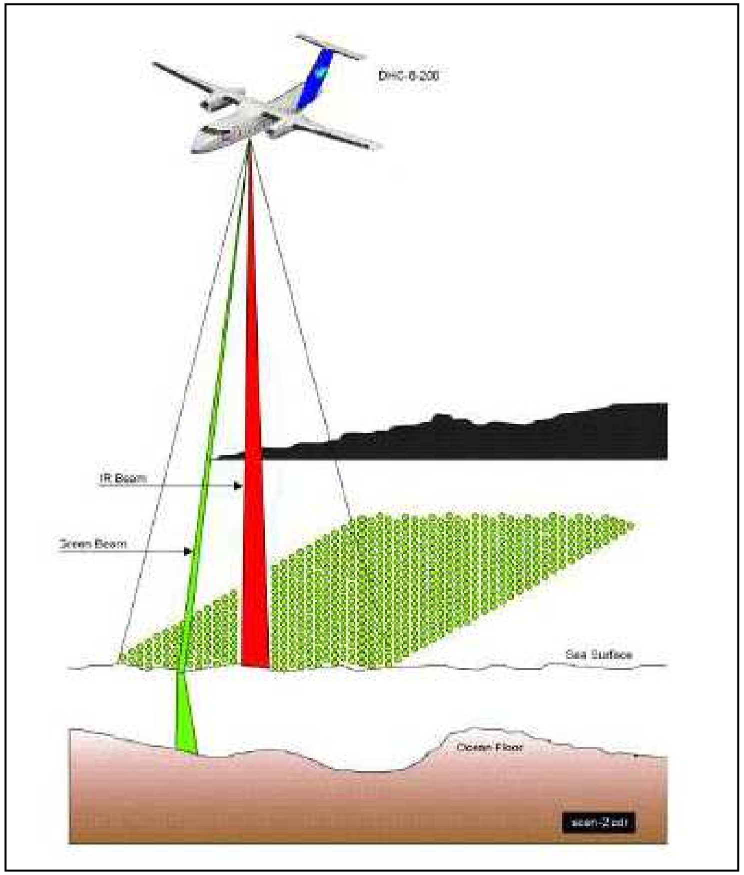


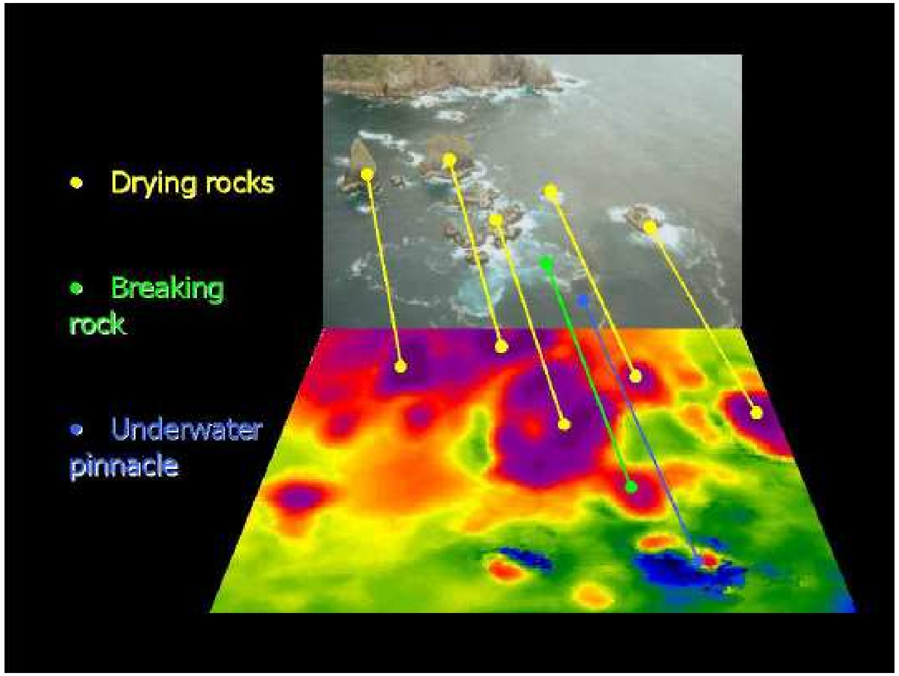
July 2001



15 September 2001

HDROGRAPHICAL MEASUREMENTS

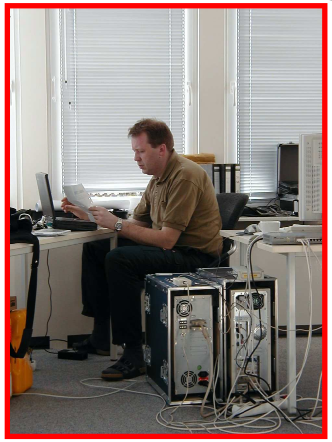




STEPS OF THE PROJECT

Data acquisation

Data processing

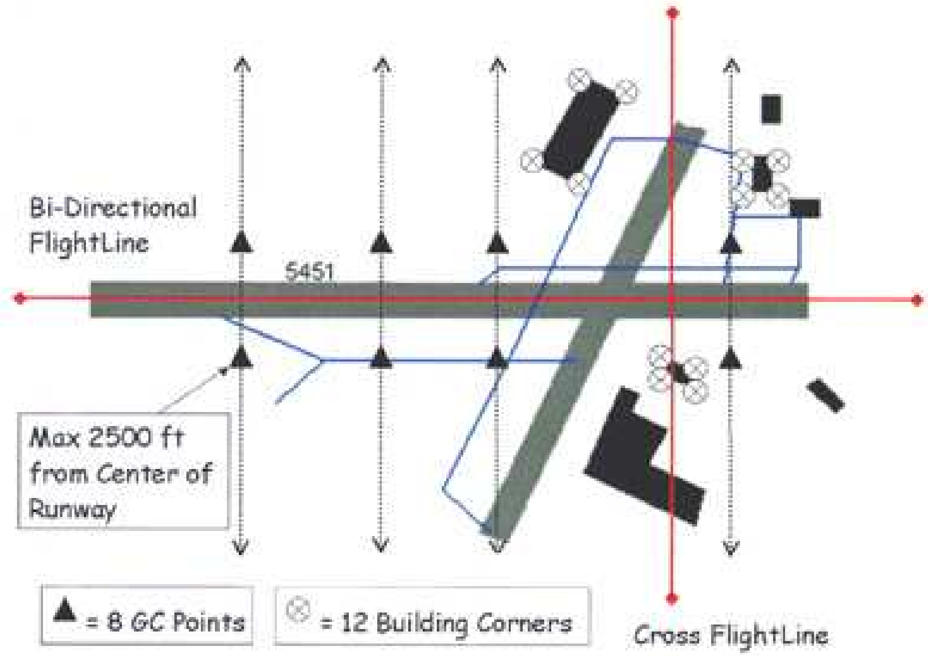


Fligh plan

Fligh planning and realization is simillar to the photogrammetric one.
In initial phase calibration of laser equipments, GPS and INS are performed.

- flight in two opposite directions
- additional perpendicular flight

Calibration. Źródło: EarthData International

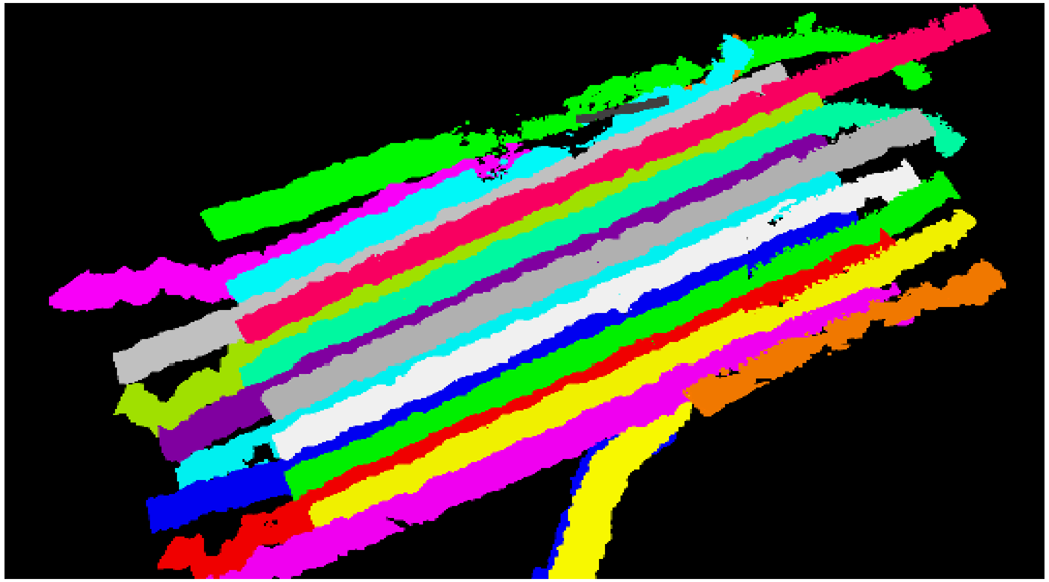


On the area on point or points of known coordinate – terrestrial, reference GPS station.

Optimal parameters determination :
Platform selection (ex. flight height and speed)
Laser equipment (i.e. frequency of laser impuls).

Elongated object (energetic line, river, pipeline) – one row

Surface object – parallel rows with lateral ovelap of 30%



DATA REGISTRATION

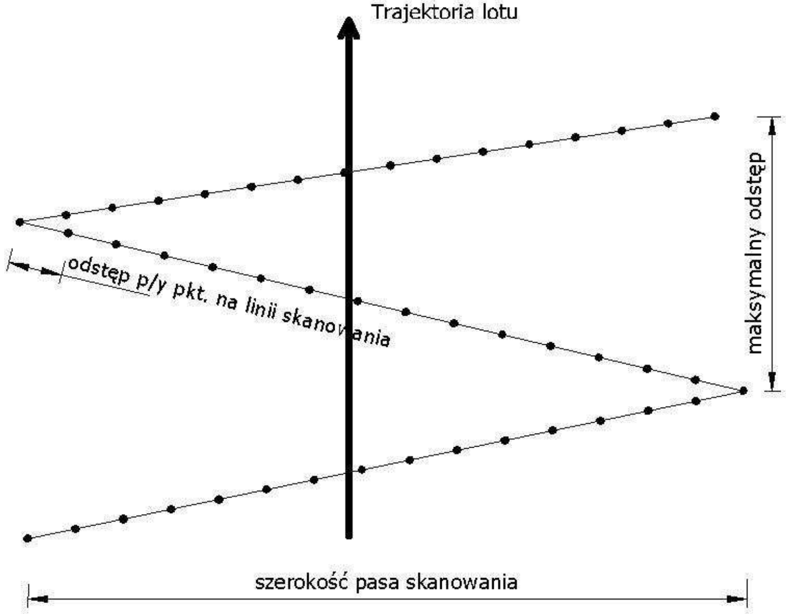
Data recorded in campaign:

- data from GPS refernce station,
- data about the flight parameters
- data of scanned area from alser scanning

Patter of data depends on scanner type

:

- zig - zak,
- parallel pattern,
- eliptical,
- sinusoidal.



BASIC PRODUCTS OF LASER SCANNING

- Numeryczny Model Pokrycia Terenu (NMPT)

  ang. DSM – Digital Surface Model

- Numeryczny Model Terenu (NMT)

  ang. DTM – Digital Terrain Model

FILTRATION

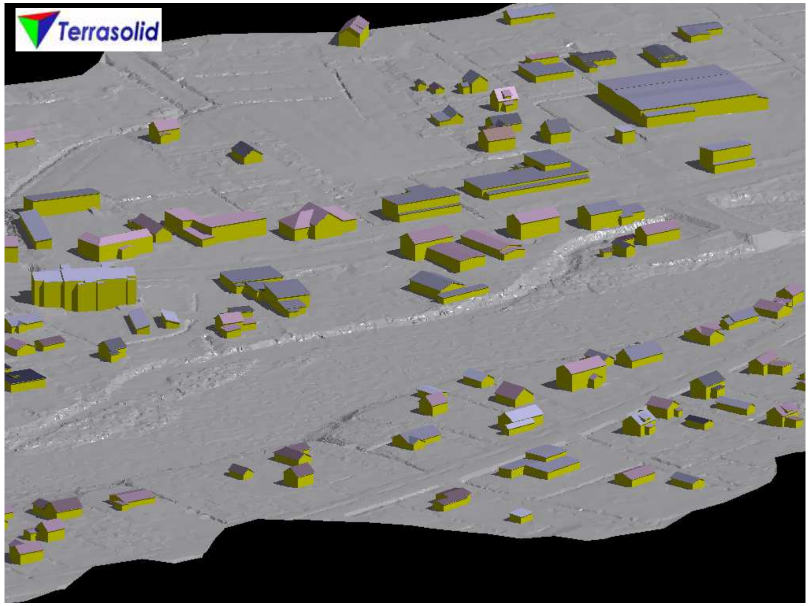
Laser measurements delivers information in „points cloud” about ground and land cover, building and trees as well. Extraction of DTM (ground surface is significant problem.

FILTRATION

DSM → **DTM**

MODELOWANIE

Wysoka częstotliwość skanowania, pozwala na określenie położenia budynków i ich wizualizację.



PODSUMOWANIE I PRZEWIDYWANIA NA PRZYSZŁOŚĆ

Rozwój technologii lidarowej w najbliższych latach przewidywany jest w pięciu głównych kierunkach:

- zwiększenie gęstości danych (zwiększenie częstotliwości impulsu lasera)

- rozwój oprogramowania do przetwarzania danych

- zwiększanie zakresu rejestrowanej fali

- laserowe pomiary wodne i podwodne

- rozwój platform satelitarnych

END