Federal Agency for
Cartography and Geodesy

Free Space Laser Safety System for Aircraft Camera Detection in the Infrared

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Passive Infrared Camera

Infrared Camera:

+ Infratec Variocam HD

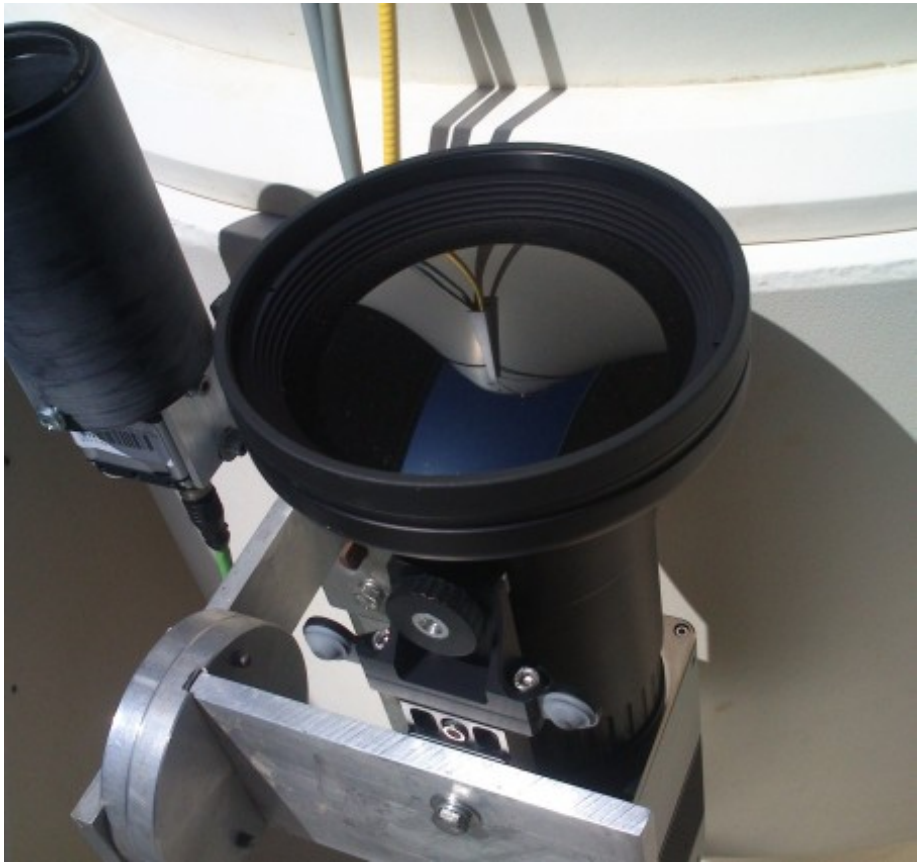
+ Sensor microbolometer array 1024 x 768

+ Spectral range 7,5 - 14 um

+ Framerate 30 / s

+ Lens 1.0 /120 mm

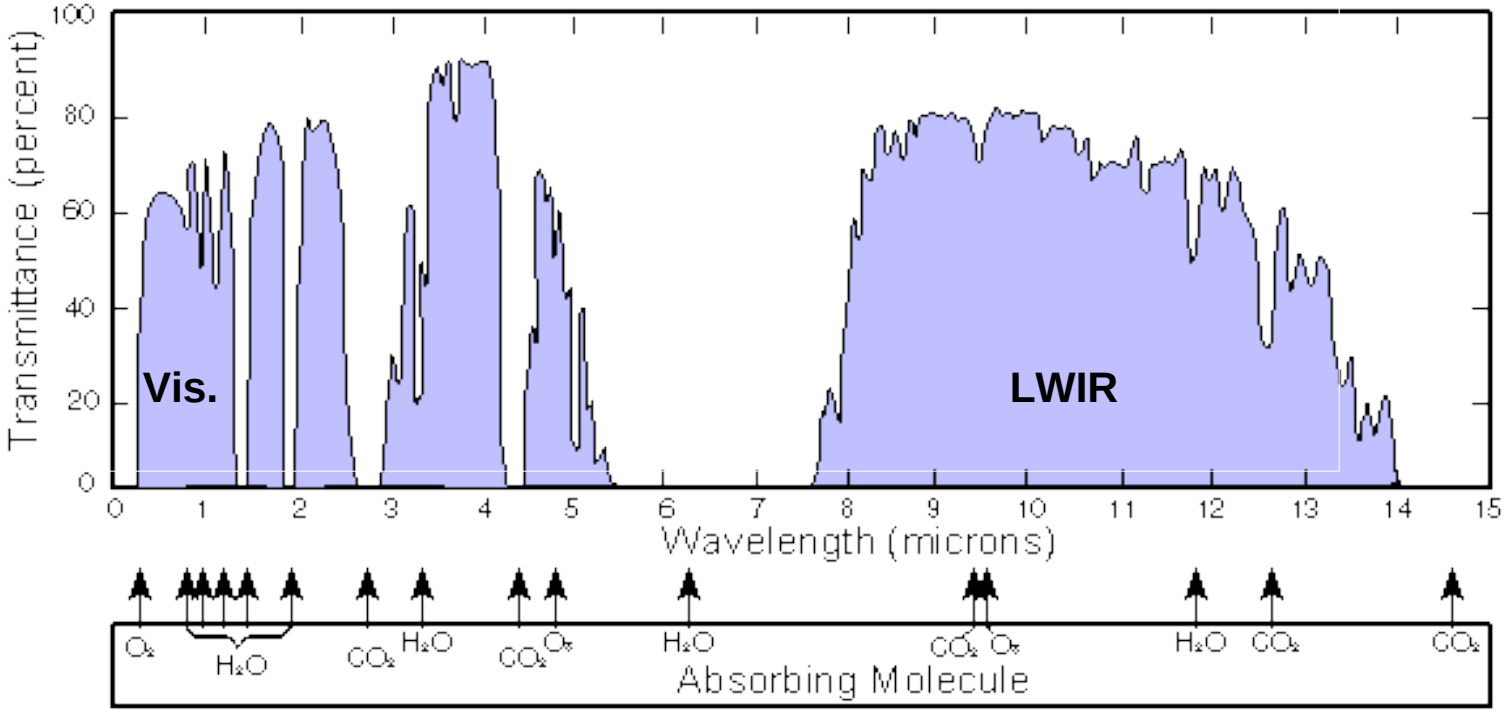
+ Field of view horizontal +- 4 ° , vertical +- 3 °



Passive Infrared

Why passive long wave infrared (7.5-14 um) ?

+ Higher transmission of atmosphere in LWIR than in the visible wavelength range



Passive Infrared

+ Airliner engines and fuselages will be prominent because of their own radiation

+ No sun induced glares on clouds

+ Visibility of objects independent from sun position

+ No interference with VLBI antennas

Motivation

Motivation for free space laser safety system:

+ The airspace around the geodetic observatory of Wettzell is crowded with airliners

+ Less frequently small airplanes or gliders are flying around

+ The restriction zone (ED-R 139) is quite small

+ A safety system that reliably detects all flight objects without interfering with our VLBI receivers is required

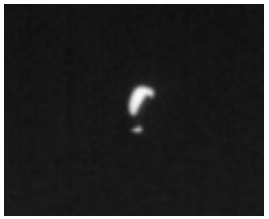
Requirements

Distance :

+ Flight objects in a distance between 900 m (ED-R 139 upper bound) and up to 40 km have to be detected.

Shape:

+ Varying shaped airplanes, helicopters, unmotorized gliders, paragliders or balloons have to be detected.



Requirements

Latency:

+ Laser shutter and electronics have a latency of 150 ms

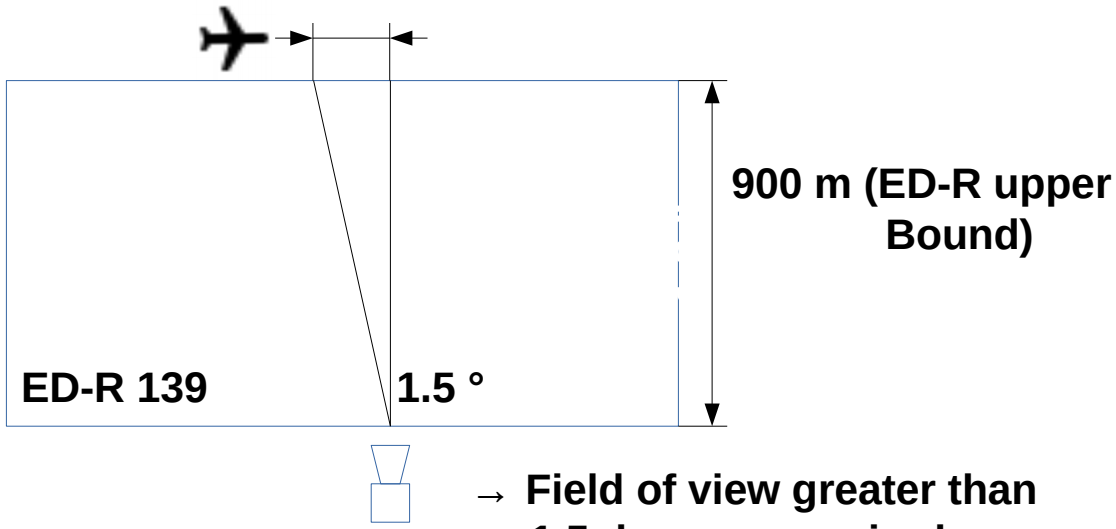
+ Image processing deadline is 50 ms

Requirements

Latency:

+ Worst case scenario:

Airplane moving with 250 kts at distance 900 m
→ 25 m in 200 ms.



→ Field of view greater than 1.5 degrees required

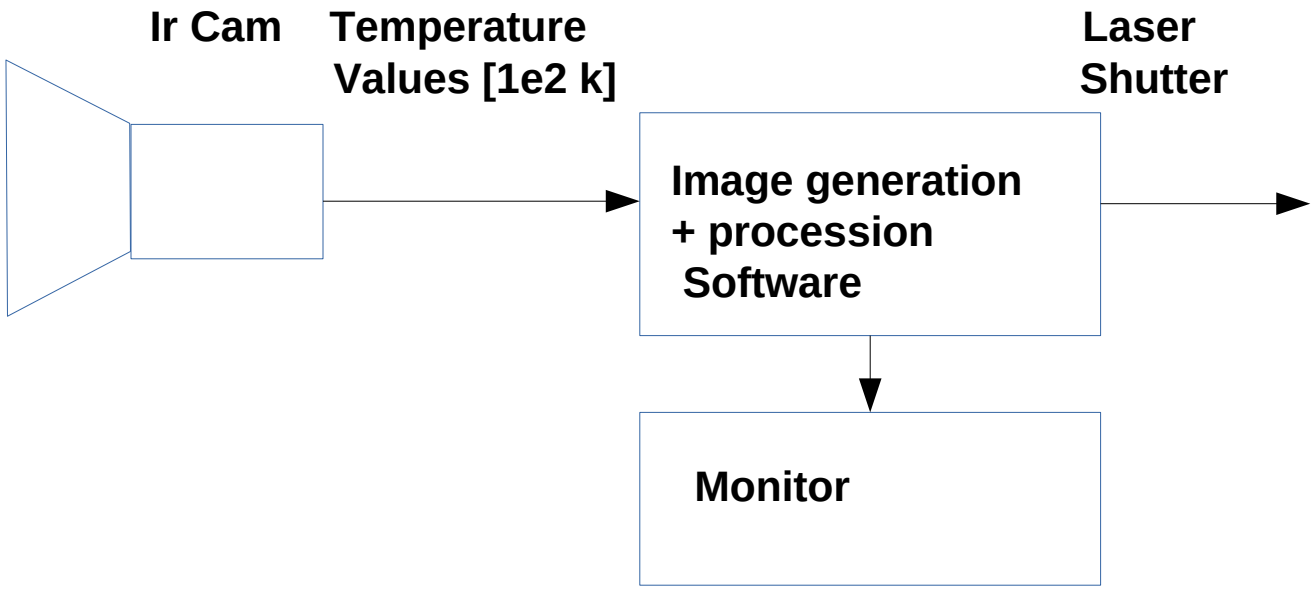
Hardware

Computer Hardware:

+ Xeon eight core image processing server

+ Linux operation system

Outline


Ir Cam
Temperature
Values [1e2 k]
Laser
Shutter
Image generation
+ procession
Software
Monitor

Software

Software

+ OpenCV image processing library

+ Open source license

+ Initiated by Intel

+ Efficient as it written in C++

+ Takes advantage of multi-core machines

Software

Image processing challenge

+ For low latency single image procession is required

+ How to find an airplane in an infrared image partly concealed by lower clouds ?

Software

Image processing steps

1. Step : noise reduction by median filter

+ Important as infrared camera images are noisy

+ Principle: move a sliding window over the image. Replace each pixel by the median of the neighboring entries.

+ High performance

+ Preserves edges (important for next step)

Software

Image processing steps

2. Step: extract local image areas with flight objects

+ Principle: flight objects use to have higher gradients in respect to clouds.

+ Considering the absolute magnitude will not perform in an image with low clouds and high flying airliners

Canny Algorithm

Canny algorithm (John F. Canny)

+ Finds the gradient of intensity and its direction in the image in multiple stages

+ Apply a pair of derivative masks in horizontal and vertical direction 'Sobel operator'

$$G_x = \begin{bmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix} \qquad G_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ +1 & +2 & +1 \end{bmatrix}$$

+ Calculate gradient magnitude and direction

$$G = \sqrt{G_x^2 + G_y^2}$$

$$\theta = \arctan\left(\frac{G_y}{G_x}\right)$$

Canny Algorithm

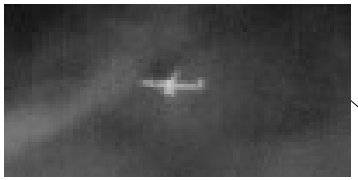
+ Round the direction to one of the angles: 0, 90, 45, 135

+ Remove pixels that are not part of an edge
  -> Only thin edges remain

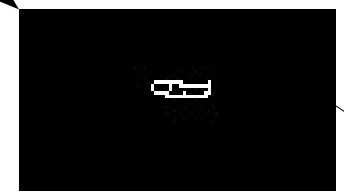
+ Apply hysteresis by double thresholding:
  Accept gradient higher than upper threshold
  Reject gradient below lower threshold
  If gradient is in between thresholds accept if connected to an established edge

Canny Algorithm

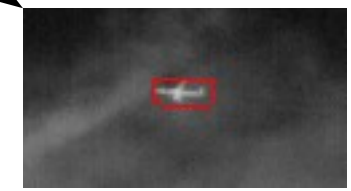
+ Canny generates binary images
  containing only edges



2. Step: canny algorithm



3. Step: vectorization by
   border following algorithm



+ Size of objects is used to reject
  seed artifacts or insects

Drawbacks

- Weakness at high temperatures in coincidence with low telescope elevation (< 25°)

- False alarms on birds (frequent but short)

- False alarms on clouds

Summary

+ Airplane detection rate in respect to ATC data for 2019 (overcast conditions excluded):

Distance [km]	Rate [%]
10	97
20	88
40	84

Thank you for your attention!