Performance characterization of advanced Electro-Optical and Infrared imaging systems

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Workshop 2023
ePicture This

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2020005 Mantis Vision
2021004 Imagination

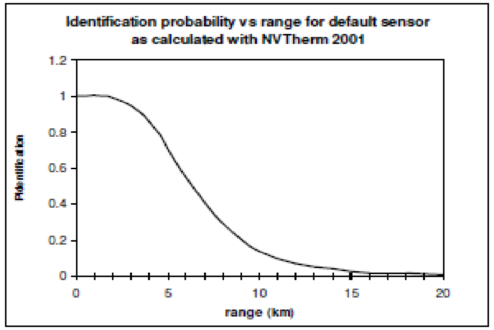
Outline

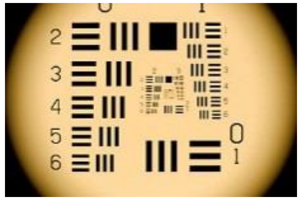
- History of modelling Target Acquisition performance
- TOD: Triangle Orientation Discrimination method
    - TOD test method
    - Analytical TOD model
    - DRI range model
    - Modelling the imaging chain
- Current operational models
- Calculation example

History

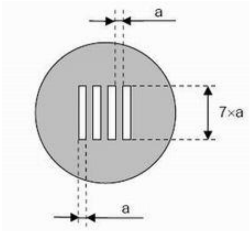
- Since Johnson in the 1950's, Target Acquisition (TA) performance prediction for imaging systems with the human-in-the-loop is dominated by the response on periodic test targets or edges
  - D: Detection (50%) = 1 lp on target (N_{50} = 1)
  - R: Recognition (50%) = 4 lp on target (N_{50} = 4)
  - I: Identification (50%) = 6.4 lp on target (N_{50} = 6.4)

- Many Target Acquisition models based on this principle
  - Measurement/prediction of the Minimum Resolvable Contrast (MRC) or Temperature Difference (MRTD)
  - Conversion of target size and range to number of cycles on target
  - Gives a probability of D, R and I as a function of range (including atmosphere)





USAF 1951

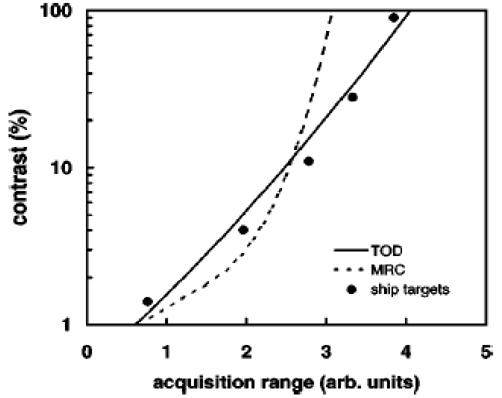


MRC/MRTD

Rotakin

History

- The approach is nice and intuitive, but has a variety of drawbacks:
  - MRC for well-sampled systems too steep compared to threshold for real objects
    - ! When tuned to DRI range for high contrasts, it will be too optimistic for lower contrast targets
  - MRC is not well defined for under-sampled imaging systems
    - ! What to do above the Nyquist frequency: cut-off the MRC (and favor low sensitivity sensors systems)?
    - ! MRC cannot be measured for moving targets (so the effect of motion on performance is not included)
    - ! Advanced signal processing often uses motion (so advanced systems are excluded in favor of simple systems)
  - Thresholds are measured with a Yes/No task
    - ! This introduces observer bias between (and within) human obervers
    - ! It is difficult to develop a simulation model of the human visual system performing this task



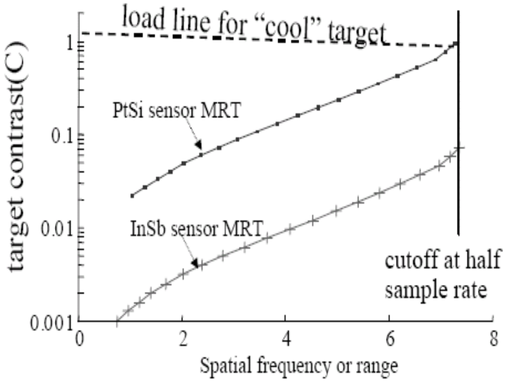
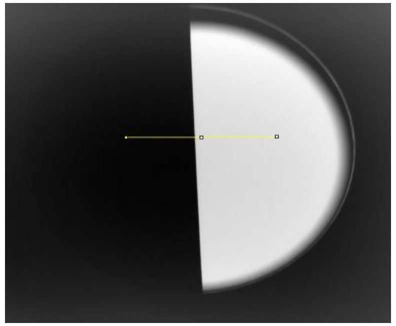
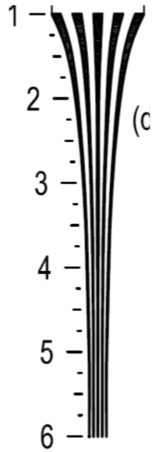


Figure 1. The Half –Sample Rate Limit of Performance.

History

- Some other standardized tests (e.g. edges and hyperbolic wedges, ISO 12233):
  - They are useful but characterize only part of the system response
    - Edge responses characterize the presample MTF of the system
    - Hyperbolic wedges measure the Nyquist (half the sampling) frequency of a system
  - They measure complementary system properties but are often considered as interchangeable
  - The human is hardly involved and they lack connection with human performance in operational conditions



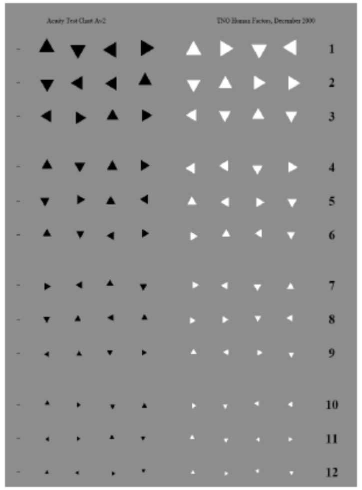


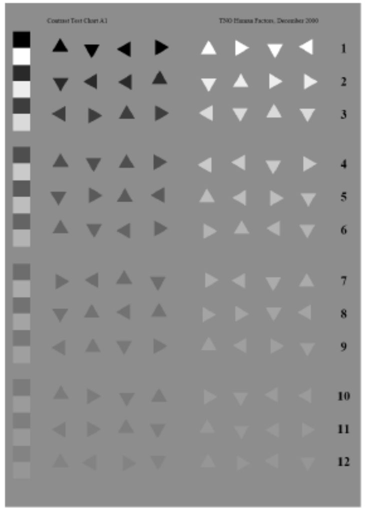
TOD (TNO development)

- TOD = Triangle Orientation Discrimination method
  - Non-periodic triangle test pattern represents target features
  - 4-alternative forced-choice task (Up, Down, Left, Right) allows
    - bias-free observer responses and
    - easy definition of automatic classification task

- Characterizes imaging systems performance with the human-in-the-loop:
  - describes the ability to discriminate between ▲▼▶◀
  - describes the ability to discriminate between real objects under practical circumstances (Target Acquisition)
  - Validated for a wide variety of imaging systems and operational conditions

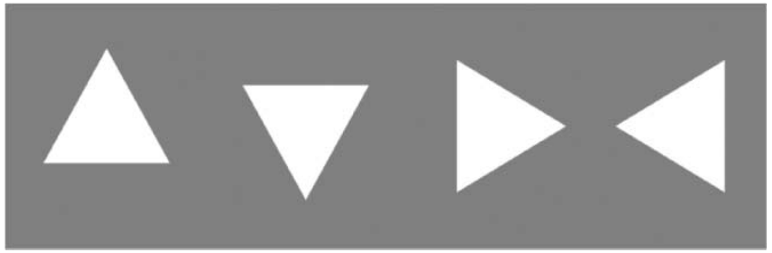
- Includes system test, analytical model, image-based model and DRI range model
  - Useful for procurement processes, acceptance testing, and system design



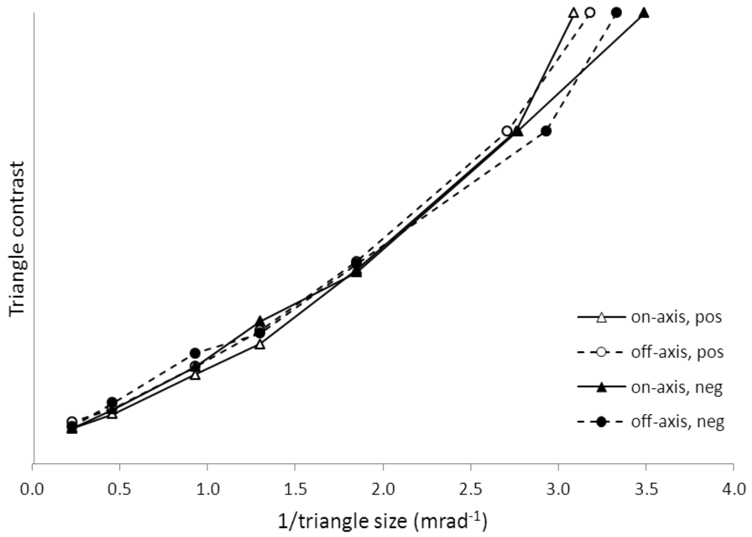


TOD Test method

- Simple spatial test pattern
  - Triangle Up, Down, Right, Left
- Simple observer task:
  - indicate triangle orientation
  - Bias-free
- Both contrast and size varied and presented several times
- Statistical analysis yields 75% correct contrast (+ σ) as function of size
- TOD curve: contrast threshold plotted against reciprocal angular size
- DRI ranges are directly related

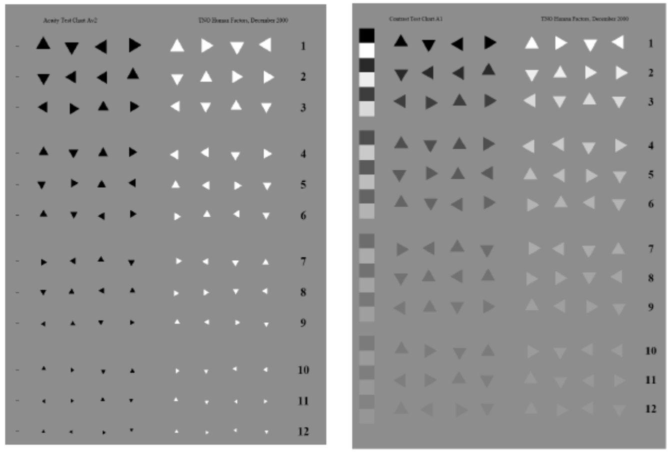


visual or thermal contrast ->

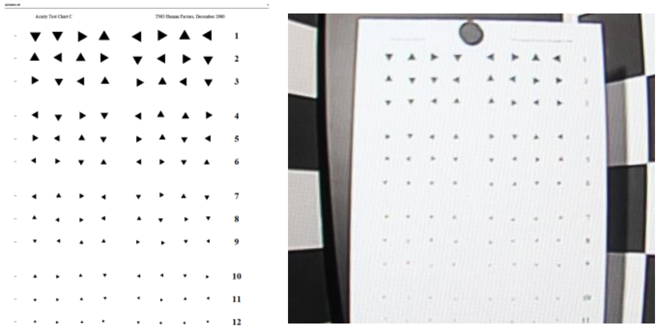


reciprocal triangle size S^{-1} (mrad^{-1}) ->

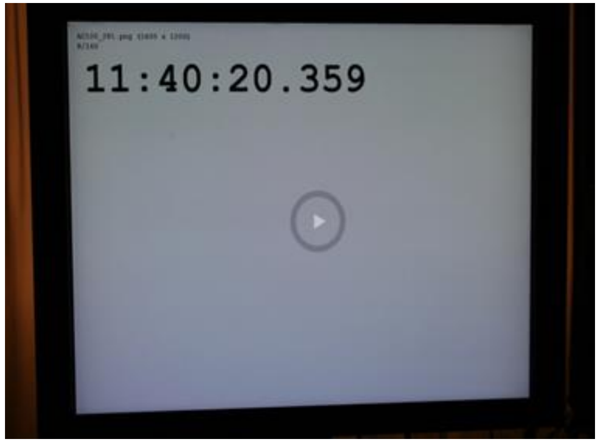
Test method and equipment



High Quality calibrated VIS/NIR test charts for in/outside use

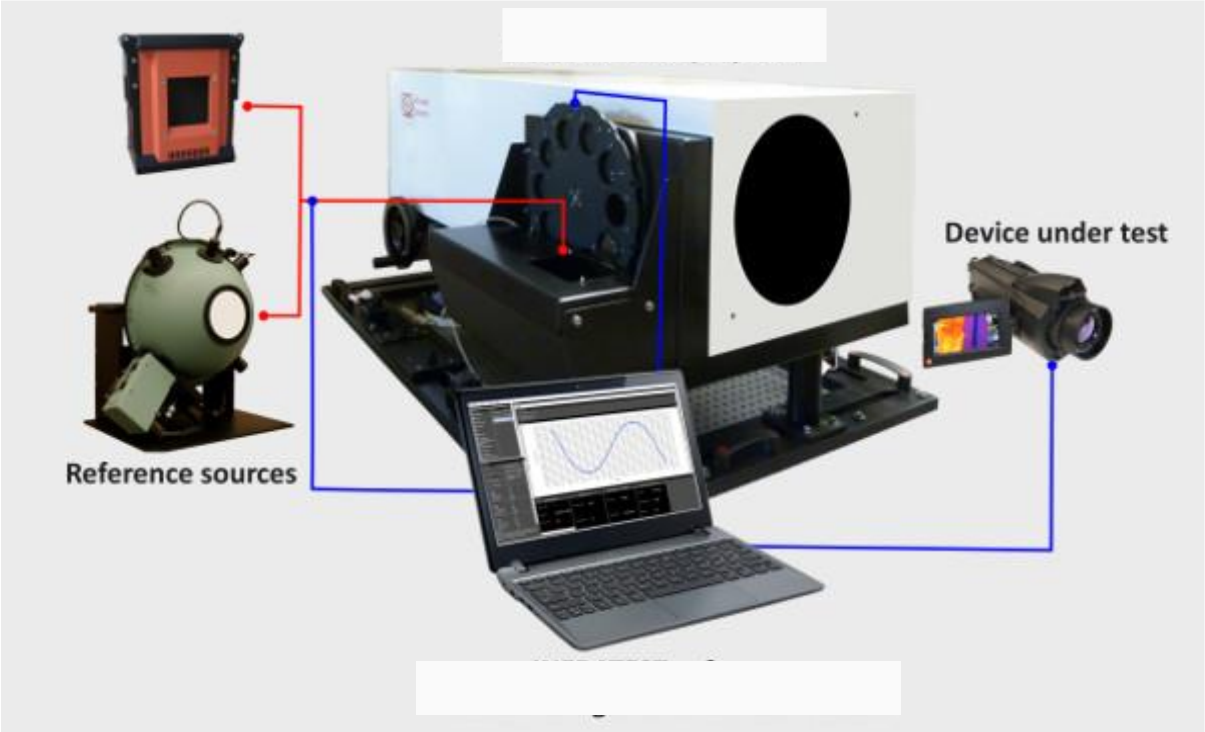


UN ECE-46 test chart for vehicle vision systems



Computer-controlled systems

Test method and equipment



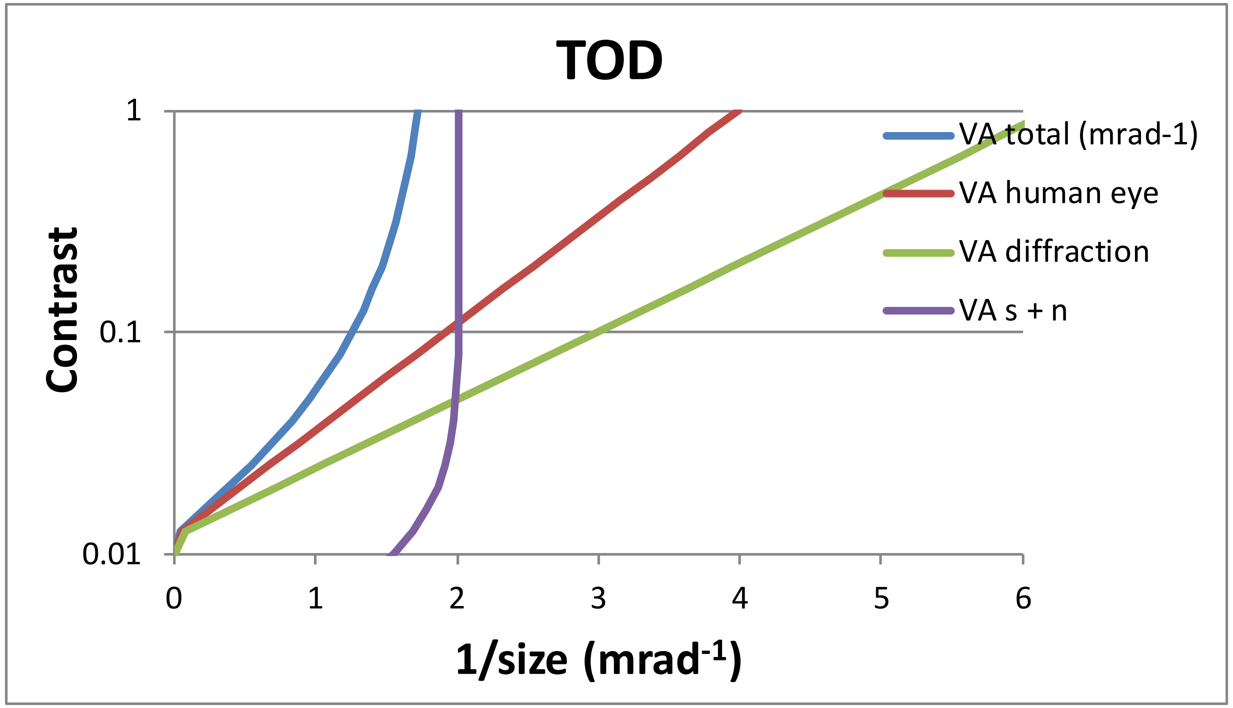
Commercial collimated IR test bench with TOD test

TNOs TCAT for in/outside use

Analytical TOD model

- Analytical TOD model: for quick estimates
- Based on four limiting components: optical blur, sampling, noise and human eye
- Total TOD is Pythagoran sum of component TODs

Contrast ->

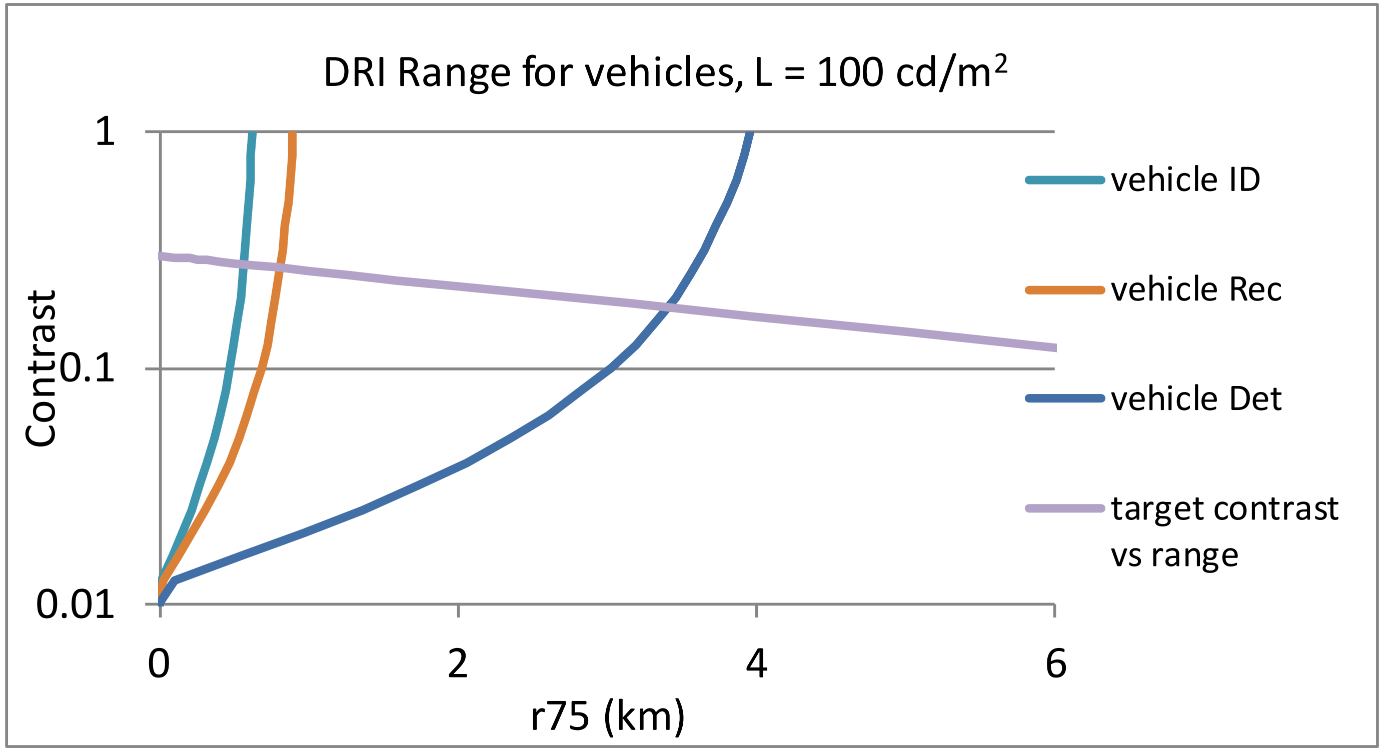


1/angular size ->

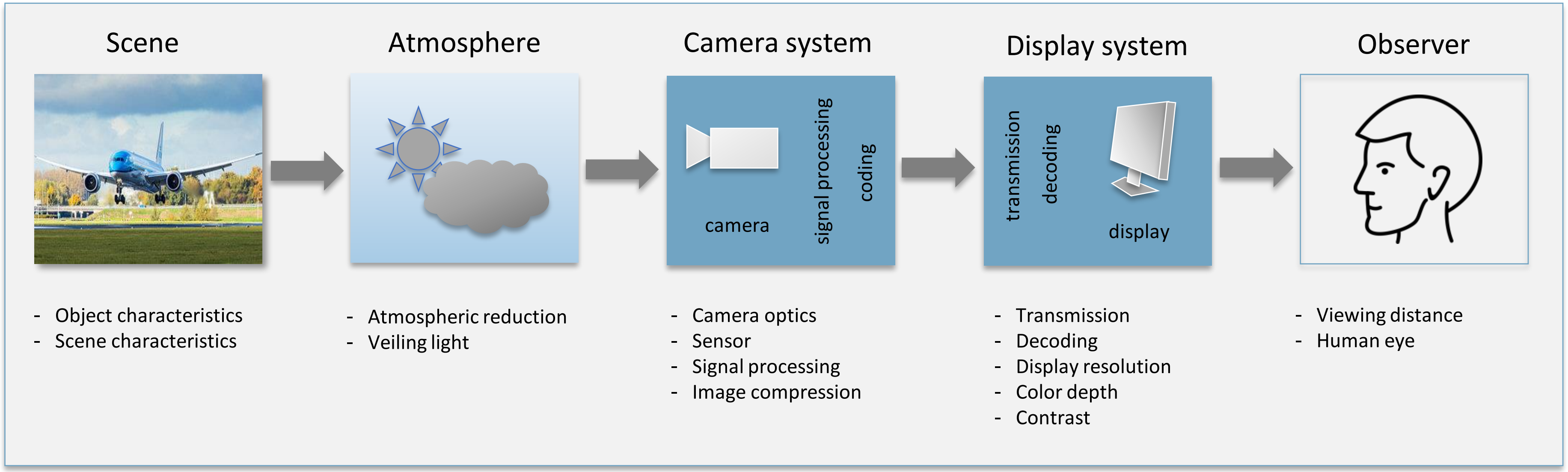
DRI range TOD model

- From the TOD acquisition ranges for target sets, e.g. tactical vehicles or humans, can be predicted:

Target	Task	Corresponding task from Table 7 or Table 8	Thermal Contrast	Characteristic dimension (m)	N_{50}	M_{75}
Tactical vehicles	I	12 tracked vehicles, I	4K	3.1	-	8.9
Tactical vehicles	R	Military vehicles, R	4K	3.1	-	6.2
Tactical vehicles	D	Vehicles (moderate clutter), D	4K	3.1	-	1.4
Human	I	Two-handheld objects I, all aspects	2K	0.25	-	8.6
Human	R	Human activities, I, front aspects	3K	0.75	-	5.8
Human	D	Humans, D, moderate clutter	3K	0.75	-	1.4
NATO target	I	NATO target, I	2K	2.3	6	14
NATO target	R	NATO target, R	2K	2.3	3	7
NATO target	D	NATO target, D	2K	2.3	1	2.3

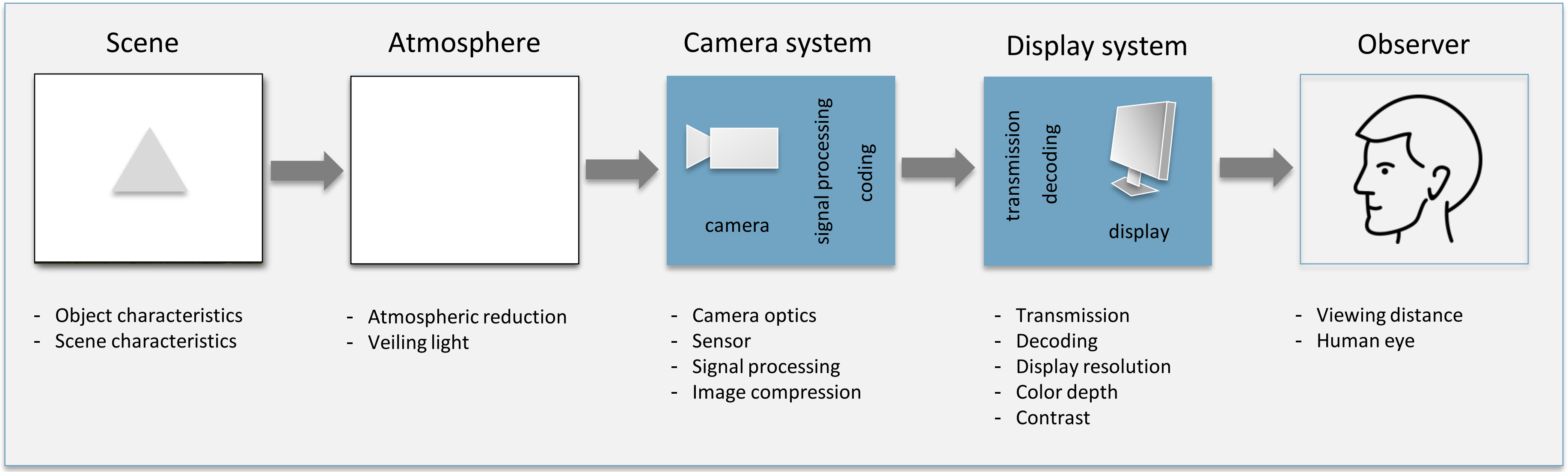


Modelling the Imaging chain: why?



- Performance in terms of DRI depends on a large number of factors and non-linear effects
- Assuming a linear systems approach can be very inaccurate, especially for state-of-the-art imaging systems
- Simulation results can be used in the design phase to predict performance against SWAP-C before the system is built
- Simulation results can be used to illustrate potential customers the images they may expect

Modelling the Imaging chain: How?



- TOD method very-well suited for image-based modelling:
  - test, camera system, eye
- TNO image-based models over the years:
  - De Lange et al. (2000, 2001); Hogervorst et al., (2003); Bijl et al., (2008); Kessler et al. (2017) (ECOMOS); Bijl & Hogervorst (2019) (EXIST)
- Current status:
  - static chain model, classical static Human Visual System (HVS) model based on correlation and human eye resolution and contrast limitations

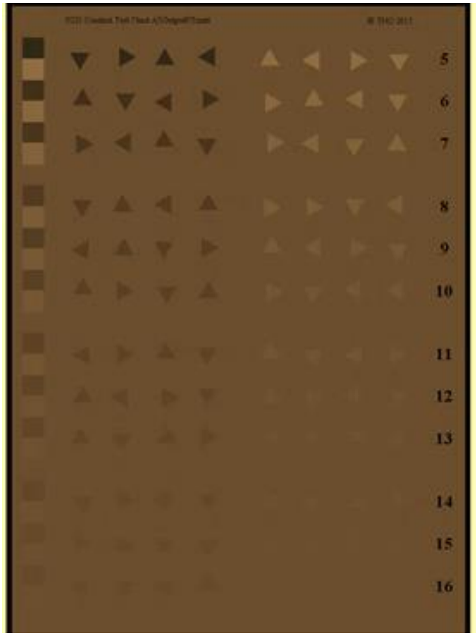
Current operational models

- EDA ECOMOS (European Target Acquisition software Model), combination of
  - TRM4 (German classical Target Acquisition model with great user interface),
  - MATISSE (French atmosphere model) and
  - TOD model (Netherlands analytical and image-based simulation model + HVS + DRI range model)

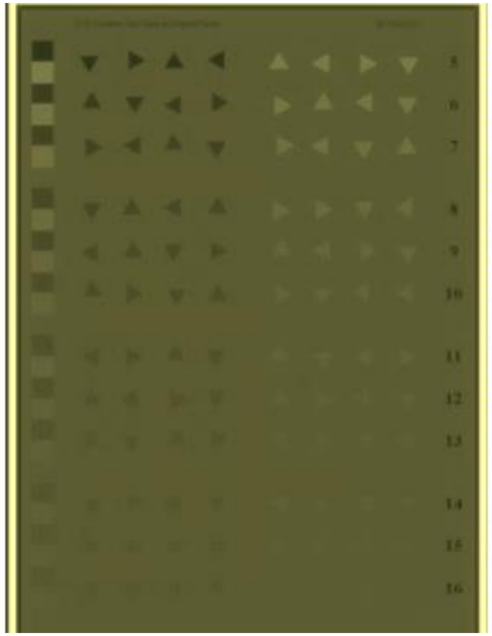
- TOD analytical and HVS model developed on relatively small dataset:
  - TNOs “Fanning set”: 24 sensors, 4 optical blur to detector size ratios; 3 noise levels, 2 up-sampling types
  - Validated against several historical camera tests

- ISET-based visual camera model (developed in EXIST)
  - static chain simulation for RGB cameras to dynamic
  - Validation on a limited set of camera-optics combinations
  - No HVS model implemented yet

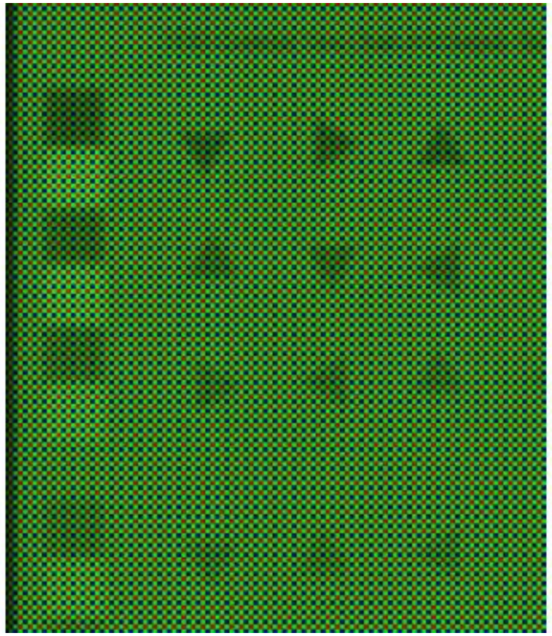
ISET simulation of an RGB imaging system



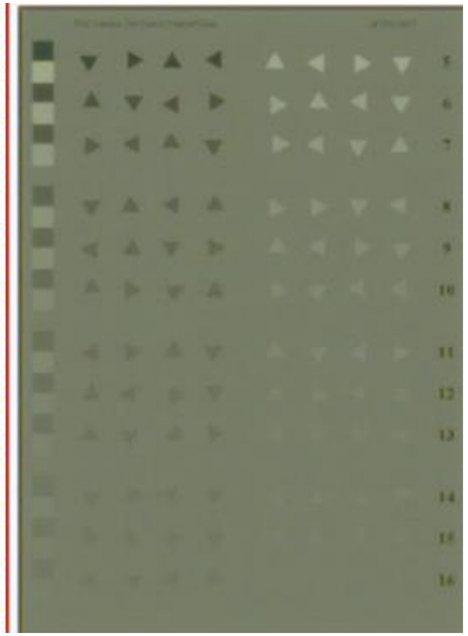
Input: Test chart illuminated by illuminant A



Optics



Sampling + Bayer



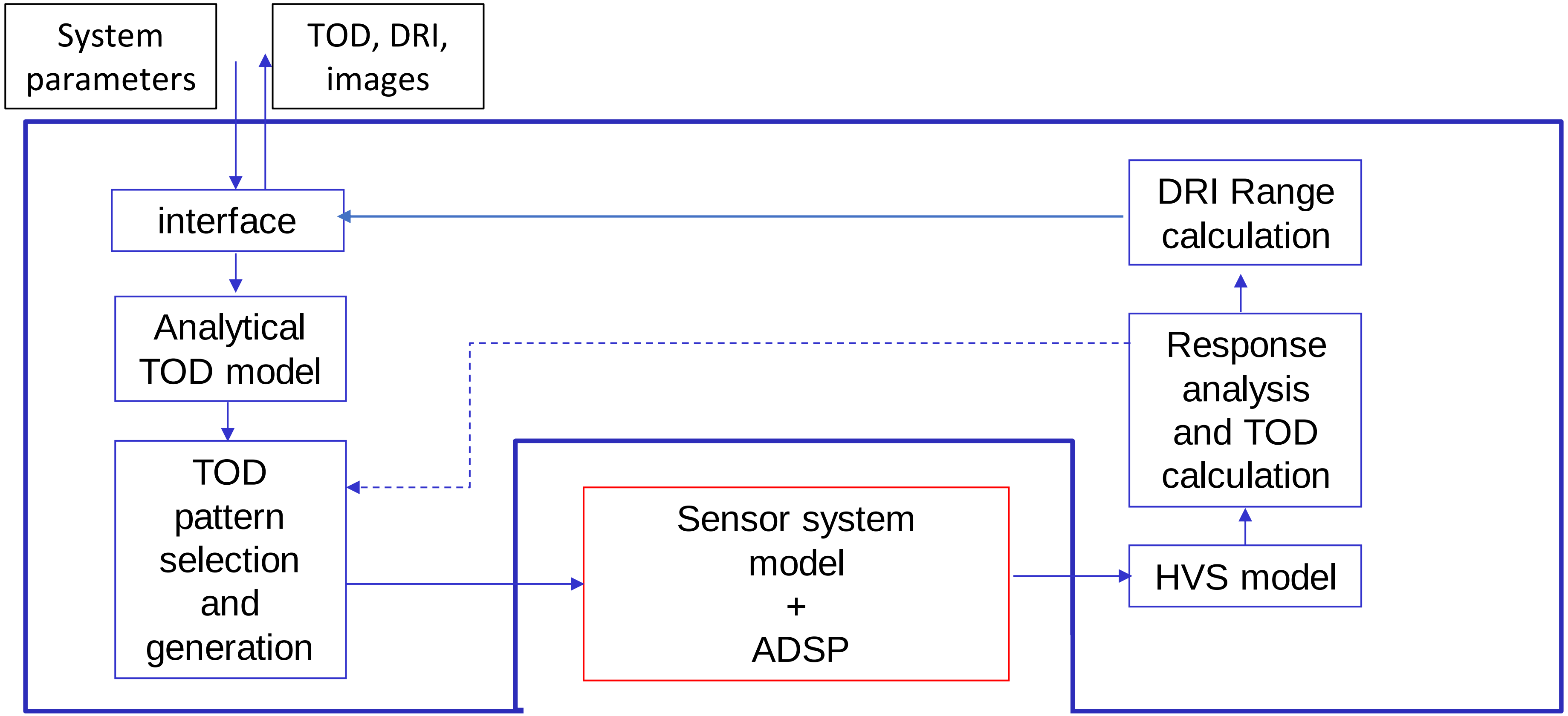
Reconstruction + grey world assumption

Current R&D goals within EU PENTA MANTIS

- Build a large database of TOD perception data for a range of simulated sensor systems, including advanced signal processing, compression, with target motion
  - this is a major extension of TNOs “Fanning set”
- Based on this perception dataset, extend the static classical HVS model to
  - a dynamic classical HVS model
  - a dynamic AI-based HVS model
- Extend the static chain simulation for RGB cameras to dynamic
  - MANTIS Year 2 demonstrator
- Complete the chain with the TOD test and the HVS model
  - MANTIS Year 3 demonstrator
- Validate the model predictions against real camera performance

Final goal: separate camera model + TRAPPIST

- TRAPPIST: TOD-based RAnge Performance Prediction for Imaging SysTems



Additional goal: support the selection of suitable camera optics

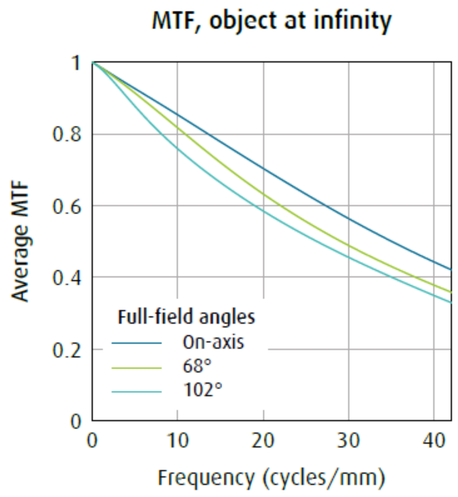
- Thermal imager: Ideas LWIR core microbolometer
  - Resolution = 640 x 480, spectral range = 8-14 µm, pixel pitch = 12 µm, frame rate = 30Hz, NETD: typical
- Use case: Situational Awareness[1].
  - DRI requirements: Detection of humans @ 90 m, Recognition of human (i.e. human activities) @ 40 m (75% correct level)
- Anticipated solution: three thermal cameras to cover 180 degrees, see picture
  - With the chosen thermal imager, this requires a lens focal length of about 6 mm
- A potentially suitable lens was found on the market
  - Umicore 6.2 mm with F/1 optics

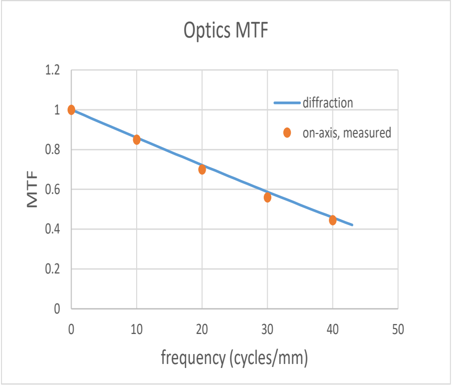
1) Situational Awareness (SA) use case, in the classical definition: being aware of what is happening around you in terms of where you are, where you are supposed to be, and whether anyone or anything around you is a threat to your health and safety. Our definition of situational awareness is where a number of camera's cover a 360-degree field of view and provide a constant real time image on the surroundings for all users of a mobile platform.

Additional goal: support the selection of suitable camera optics

- Question:
  - Does the 3-camera solution provide sufficient DRI performance?

- First impression with the 6.2 mm lens
  - HFOV = 63.6 degrees.
    - Just above the required angle
  - Pixel angular subtense: IFOV = 1.94 mrad
    - 1 pixel subtends 0.2 m at 100 m. This should be sufficient for Detection of humans
  - Lens blur
    - On-axis MTF close to diffraction limit
    - Off-axis MTF at 68 degrees full field about 0.8 times diffraction limit
  - Is the system resolution limited by pixel size or optical blur?
    - $F\lambda/d$ is a measure of blur to sampling ratio. $F = f/D$, λ = wavelength, d = detector size
    - $F\lambda/d = 1.0 * 11$ mu / 12 mu ≈ 0.92 => detector size is dominant



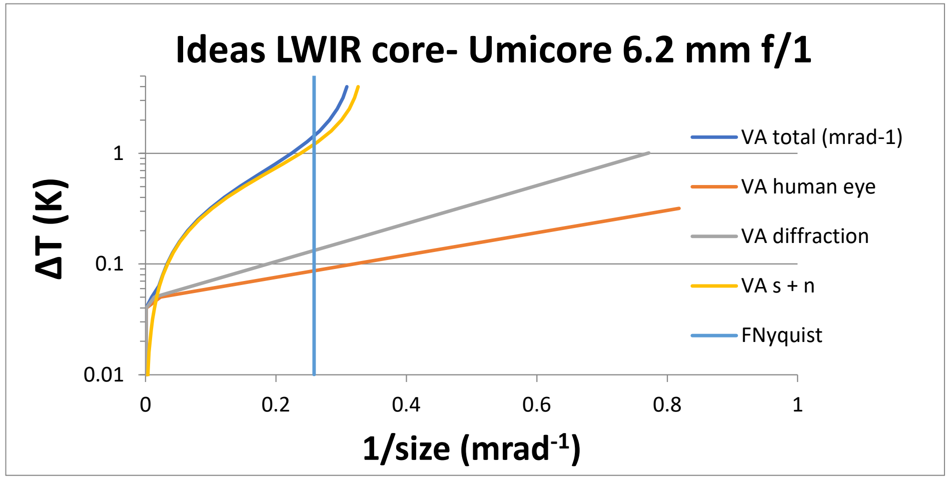


Additional goal: support the selection of suitable camera optics

- TOD calculations
  - No complex signal processing or image motion is used:
    - the analytical TOD model can be used
  - Results: see plot
    - Clearly sampling and noise limited
    - VA cut-off = 0.31 $mrad^{-1} \approx 1/5^{th}$ of human Visual Acuity

- Range calculations using the DRI range model and Table of slide 11
  - Human D range = 166 m @75%, sufficient
  - Human R range = 40 m @ 75%, just sufficient

- Conclusion
  - Ideas LWIR core- Umicore 6.2 mm f/1 optics combination meets the range performance requirements
  - An acceptance test on the real camera + optics system can verify whether the predicted TOD performance is really met



target & task	range (m)
tactical vehicle I	108
tactical vehicle R	155
tactical vehicle D	684
Human I	9
Human R	40
Human D	166

Summary

- Camera system operational performance tests and models have been developed to support:
  - Procurement processes and acceptance testing of advanced imaging systems
  - Complex camera system design

- The current focus in MANTIS Vision is to provide a dynamic image-based simulation of camera systems with (black-box) advanced signal processing, including a performance test, a validated Human Visual System model, and a DRI range model

- Simulation results can be used in the system design phase to
  - predict performance against SWAP-C before a camera system is built
  - predict whether a camera system will meet the requirements
  - illustrate potential customers the images they may expect

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MANTIS and IMAGINATION with AENEAS support

THANK YOU

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