Technology Challenges for Artificial Intelligence based Defence and Aerospace Applications

Dr. Guy Kouemou, Dr. Michael Brandfass, Christoph Neumann, Peter Ahlemann

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Detect and Protect.

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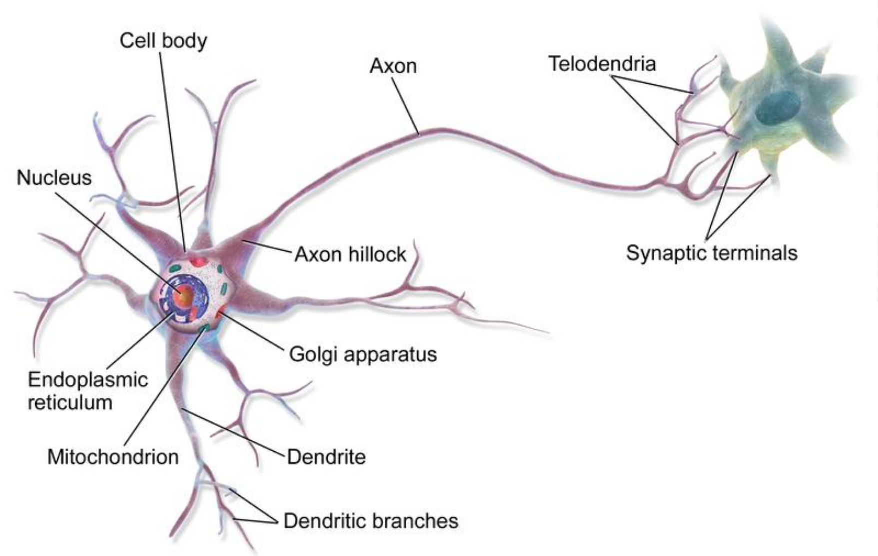
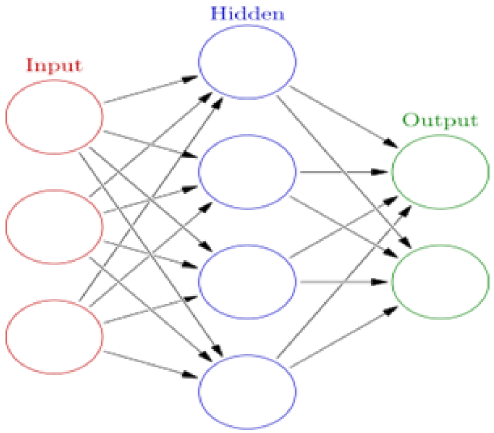
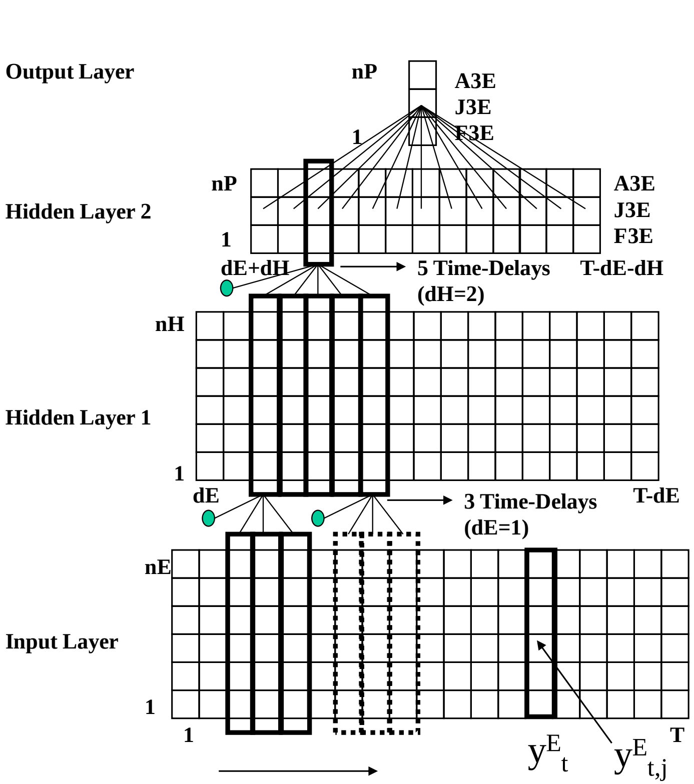
Content

History on AI and Neuronal Networks

From Biological Intelligence to Artificial Intelligence







$$\mathbf{Y}^o = \begin{pmatrix} y^o_1 \\ \blacksquare \\ y^o_{np} \end{pmatrix}$$

$$\mathbf{Y}^P=(y^P_{dE+dH} \cdots y^P_{T\text{-}dE\text{-}dH})$$

$$\mathbf{W}^{P,-2},\ldots,\mathbf{W}^{P,2},\mathbf{b}^P$$

$$\mathbf{Y}^H=(y^H_{dE} \cdots y^H_{T\text{-}dE})$$

$$\mathbf{W}^{H,-1},\mathbf{W}^{H,0},\mathbf{W}^{H,1},\mathbf{b}^H$$

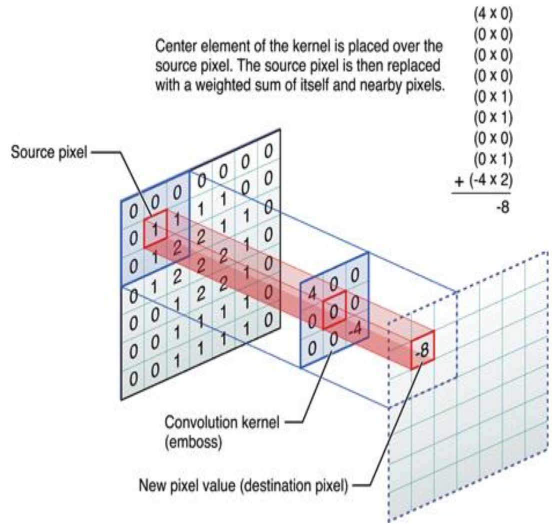
$$\mathbf{Y}^E=(y^E_1 \ldots y^E_T)$$

Deep Learning Basics (I)

Deep Learning networks: special kinds of Neuronal Networks

- “Deep” ⇨ # of layers between (signal) input and (classification) output
- Local node connections from layer to layer
- Also recursive data flows possible ⇨ large memory depth
- Each layer can be considered having a special task

Example: Edge detection



Deep Learning Basics (II)

Benefits and drawbacks compared with conventional Neuronal networks

Conventional NN, drawbacks

- "black box" design
- not suitable for unsupervised training
- Huge computational resources necessary at large data sets

Conventional NN, benefits

- small computational resources necessary at operational runtime
- Arbitrary probability distribution functions for input signals

⇨ Very good for classification tasks at well known feature characteristics

Deep Learning CNN, drawbacks

- Radar: few experience up to now
- others: huge training data sets required in some applications

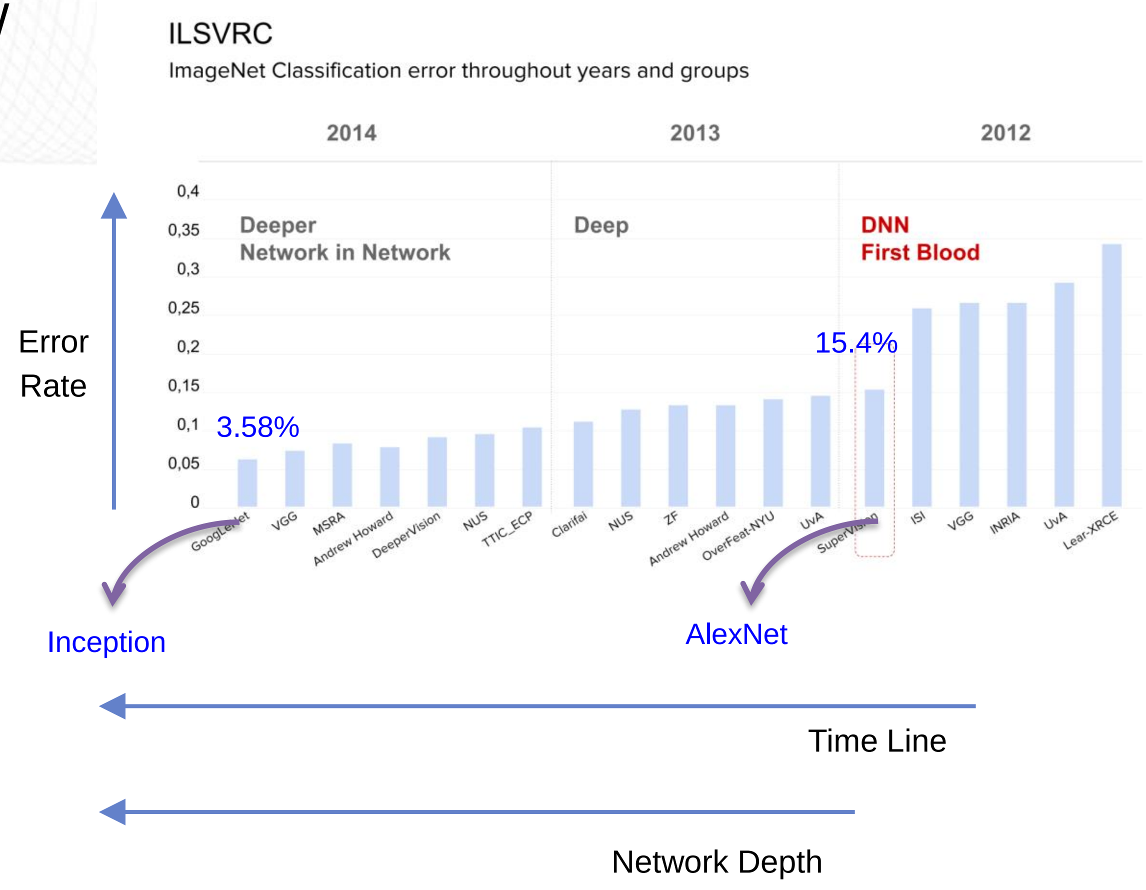
Deep Learning CNN, benefits

- clear design concept
- implicit feature extraction
- Modular architecture: special "radar layers" separable from "general" layers", also at training process

Recent Advances on Deep Learning

Legend:
DNN First Blood: Commercial Image Rec. SW
AlexNet: ImageNet Challenge winner
Inception: Google DNN product

Other Milestones:
AlphaGo (Google DeepMind, 2016)
DeepFace (Facebook,
face identification, 2015ff)

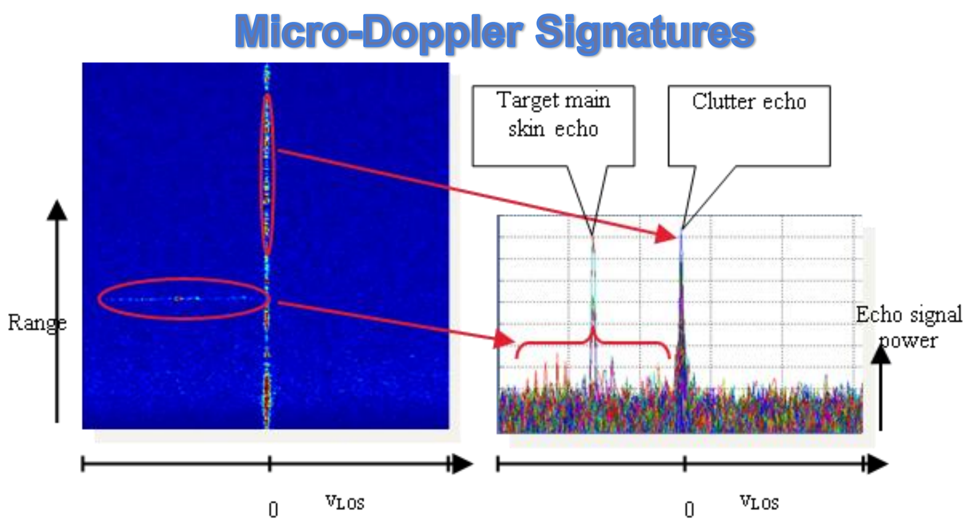


Convolutional Neuronal Networks on radar Applications (I)

Radar signature characteristics

Radar Application characteristics

- Active radar: favoured sensor for long range / high resolution target aqu.
  - High resolution target signatures from up to several 100 km and beyond
  - Challenges: automatic SAR image screening, automatic target classification
  - High diversity in signal appearance, depending on radar mode of operarion



Convolutional Neuronal Networks on radar Applications (II)

AI based Signal and Data Processing Tasks

Target detection and signature acquisition:

- Use a priori information to improve signal detection by adaptive filtering
- Automatic interference assessment / situation awareness
- Intelligent tracking methods / situation adapted radar modes

Signal Evaluation and assessment:

- Automatic extension of signature data base (e.g. Micro-Doppler)
- Automatic SAR image “interpretation”: Image ⇨ Symbol representation
- Automatic consideration of “best moments” for recogniton waveforms
- Complete battlefield assessment with tecommendations for operators

Radar Target Classification Applications and Scenarios

Security:

- Harbour/costal surveillance,
- Prevention of smuggling, illegal fishing, illegal immigration, piracy

Protection:

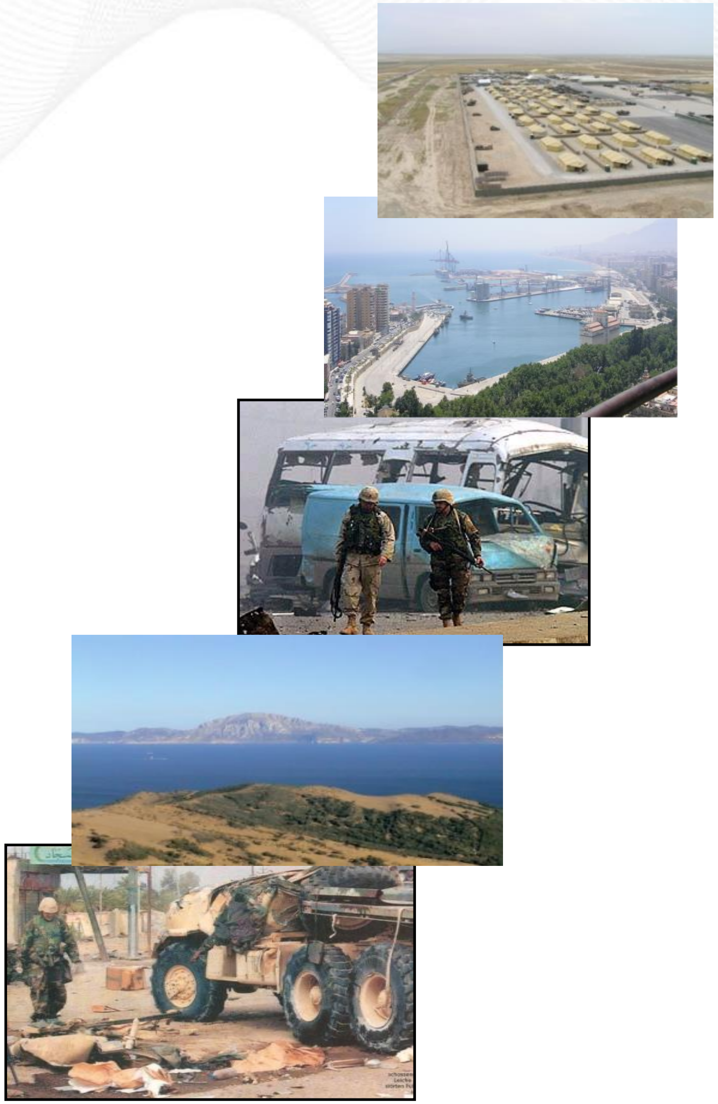
- Protect navy ships: Passage of strait, entering port, putting to sea, docking, lying in the roads
- Force protection: Camp, convoy, air base

Defence:

- Anti asymmetric warfare,
- Littoral operations
- Drones detection, tracking, classification, identification

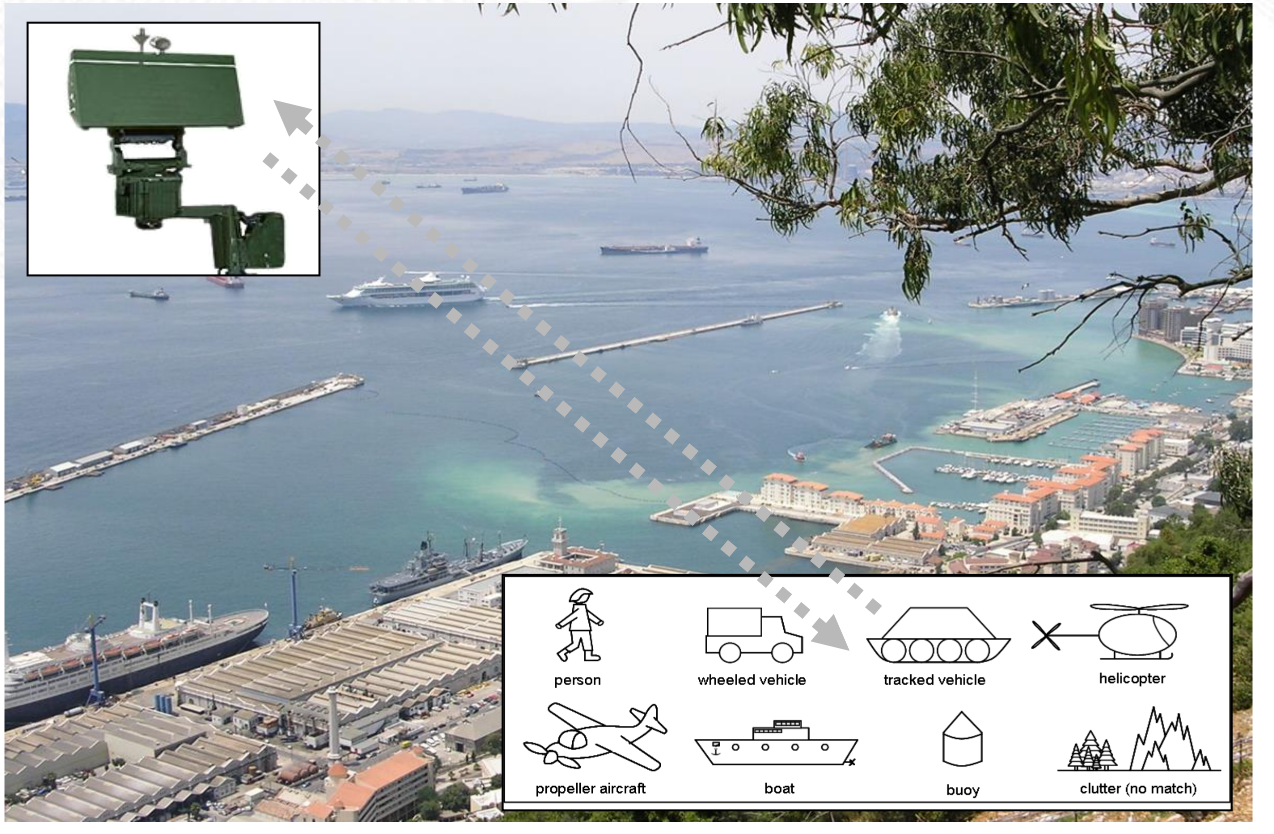
Space:

- debris,
- Jamming, Cyber



Radar Target Classification Scenarios and Requirements

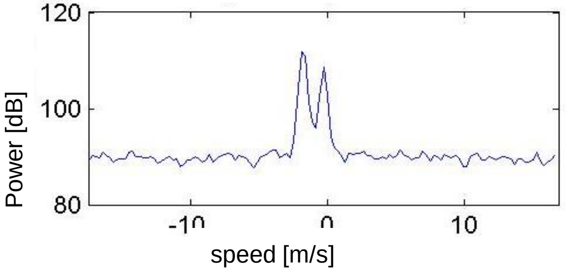
- Situation Awareness:
  - Complex scenarios
  - Multitarget/Dense
  - Long duration
- Response Management:
  - Prohibit collateral damage,
  - Law of armed conflicts: civil population/adversary, proportionality of resp.
  - Escalation dominance



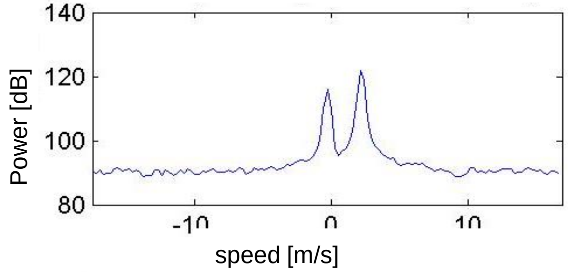
- Request for special **Radar sensors** for these scenarios to improve:
  - Detection, Tracking
  - And **additional classification** capabilities through the **Doppler sound** of a target

Radar Target Classification derived from Biological Intelligence Human Capabilities (Operator): Doppler Sound based Classification

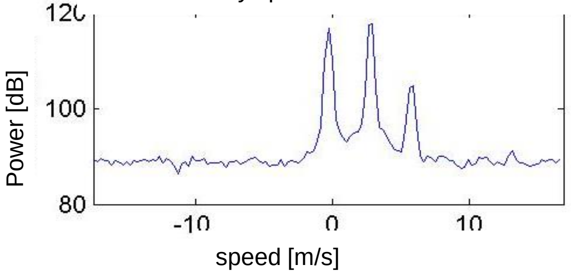
Power density spectrum pedestrian



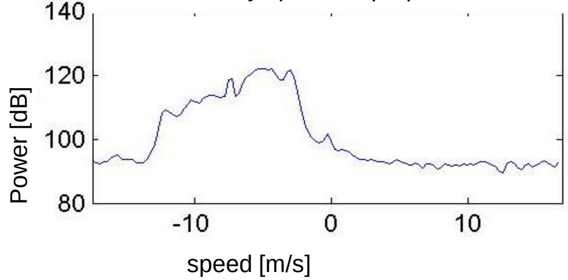
Power density spectrum wheeled vehicle



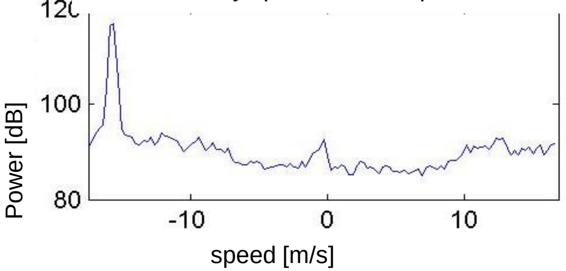
Power density spectrum tracked vehicle



Power density spectrum propeller aircraft

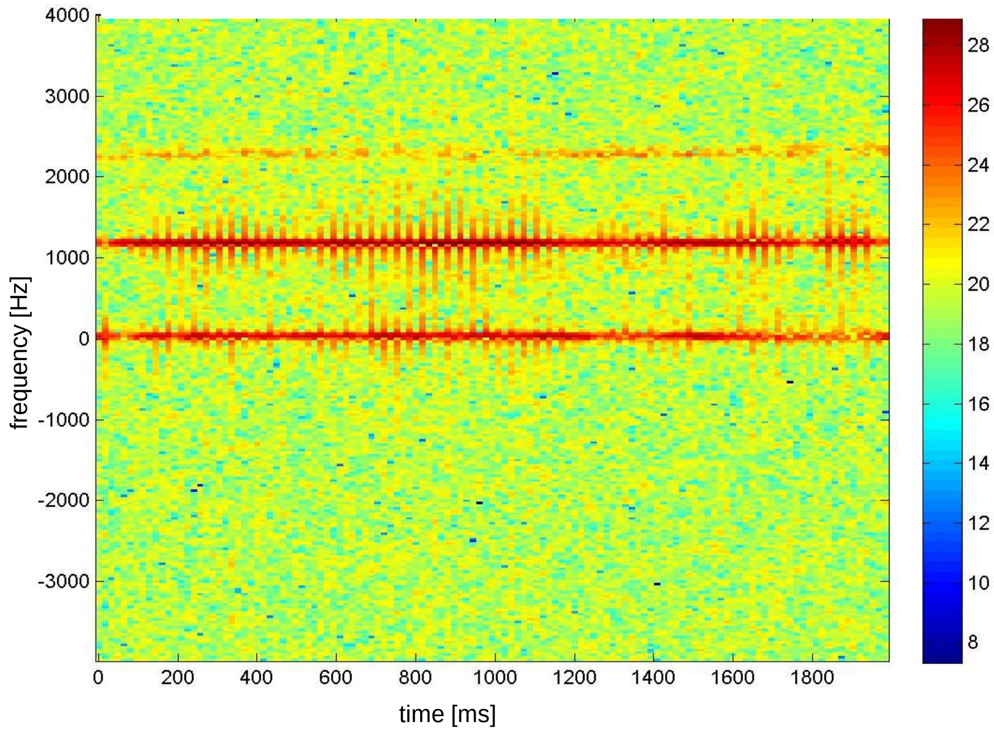


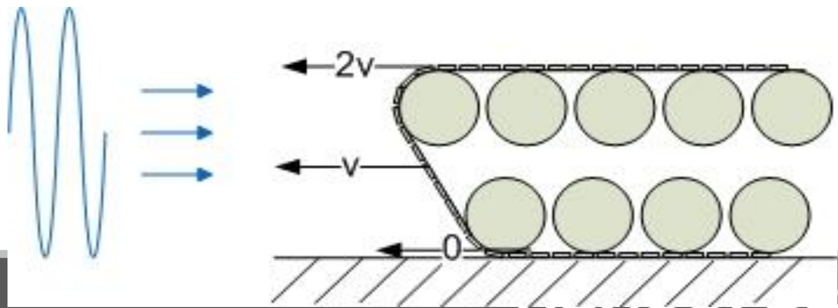
Power density spectrum helicopter



power density spectrum

spectrogramm tracked vehicle





Radar Target Classification
Example Standalone Doppler Sound based Classification

Doppler Sound is used to

- Improve detection and to classify plots on **signal processing level (JDL 0)**
- Possible categories X:
  - Ground: Person, wheeled vehicle, tracked vehicle, impact
  - Maritime: Buoy, small boats, ships
  - Air: Propeller aircraft, helicopter
  - No match (Clutter, others: animals, windmills, air condition, ...)
- Technology: Hidden Markov Models or Neuronal Network

Problems/Potential for improvement

- No classification history available on plot level: Only single, separated classification results
- No usage of dynamical behaviour
- Ambiguity: Range rate/range
- Elevation is not available: 2d radars

Radar Target Classification
Example Combined Doppler Sound / Tracking based Classification

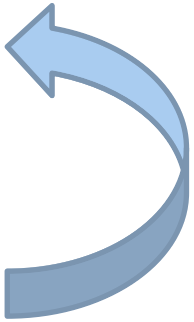
Combine Doppler sound classification with tracking

- Classify on **track level** instead of plots level, i.e. move from JDL Level 0 **to JDL Level 1**
- Advantages/Synergies between tracking and classification:
  - **History** of classification results through data association instead of single plot results
  - **Additional attributes** through tracking: Speed, course, acceleration
  - **Reduction of ambiguities**: Unique range/range rate, improved RCS
- Further system integration benefits e.g. **SIP** (Sensor Integration Package)
  - Usage of digital terrain maps
  - Usage of road maps
  - Fusion with optical sensor classifications (IR, TV) within a
  - Integrated multisensor environment

Radar Specific Classification Challenges
Uncertainties in Combined Classification and Synergies

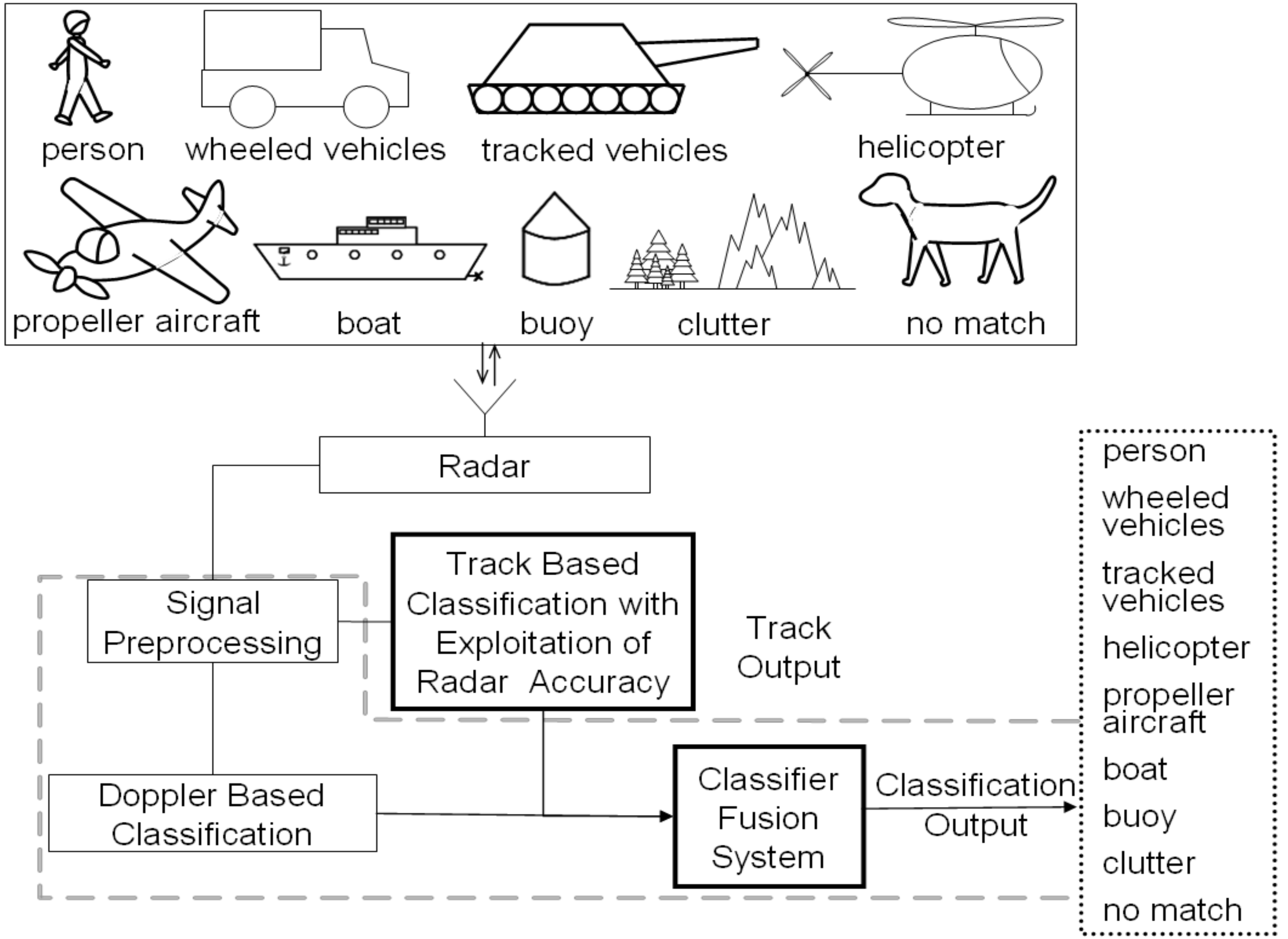
- Doppler Analysis related Uncertainties
  - Visibility of features
    - E.g. aspect angle dependency for Doppler sound,
    - Geographic occlusions
    - Target modification
  - Physical ambiguities/uncertainties range/Doppler/RCS

- Tracking related Uncertainties
    - Accuracy of Estimation (Filtering)
    - Data Association (plot – track association)
    - Run in behaviour



Radar Specific Classification Challenges

Simplified illustration of processing chain



Typical AI-Evaluation Method using Confusion Matrix
Example of Experimental Results using single Sensor (Radar)

Confusion Matrix for Doppler Classifier with 10% False Training Ratio (in %)

labeled as \ recognized as	person	wheeled vehicle	tracked vehicle	helicopter	propeller aircraft	buoy	boat	seaclutter no match
person	**96**	0	0	0	0	0	0	4
wheeled vehicle	0	**84**	16	0	0	0	0	0
tracked vehicle	0	26	**74**	0	0	0	0	0
helicoper	0	0	0	**70**	0	0	0	30
propeller aircraft	1	0	0	5	**92**	0	0	2
buoy	0	0	0	0	0	**84**	16	0
boat	0	0	0	0	0	8	**92**	0
sea clutter no match	30	0	0	11	0	0	0	**59**

Confusion Matrix for Combined Classifiers Using not cont. membership fct Dempster-Shafer with 10% False Training Ratio with Rejection Rate (in %)

labeled as \ recognized as	person	wheeled vehicle	tracked vehicle	helicopter	propeller aircraft	buoy	boat	seaclutter no match	rejection
person	**100**	0	0	0	0	0	0	0	0
wheeled vehicle	0	**87**	12	0	0	0	0	0	1
tracked vehicle	0	26	**74**	0	0	0	0	0	0
helicoper	0	0	0	**89**	0	0	0	0	11
propeller aircraft	0	0	0	8	**92**	0	0	0	0
buoy	0	0	0	0	0	**84**	16	0	0
boat	0	0	0	0	0	0	**100**	0	0
sea clutter no match	31	0	0	11	0	0	0	**58**	0

False Classification

- 0-2%
- 6-9%
- Improvement of classification
- 3-5%
- >= 10%
- Deterioration of classification

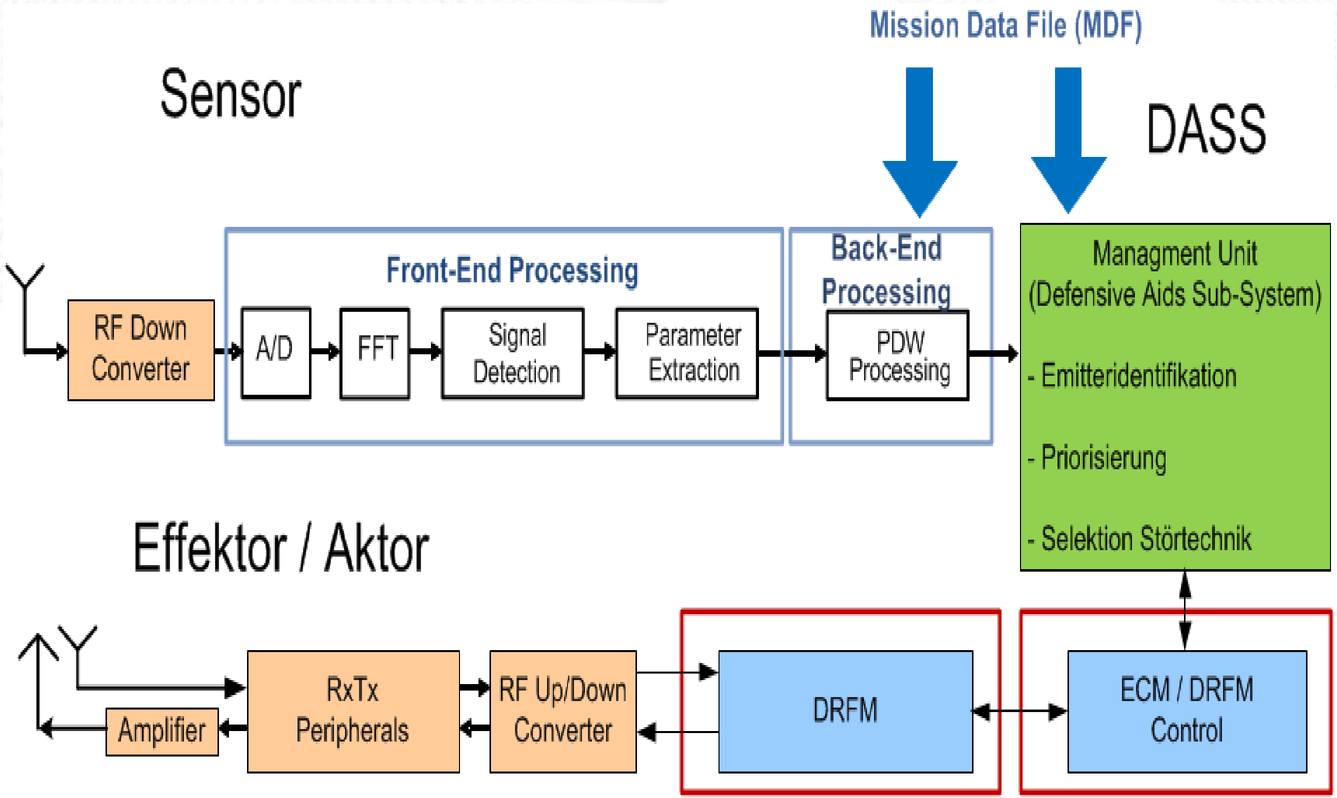
Cognitive Aspects in Electronic Warfare (1)

Current EW systems

- operate using database of known threats along with predefined countermeasures to these threats. Such EW systems cannot adapt to new unknown types of threats.
- The EM landscape in which radar and EW systems operate is quickly changing. When operating in anti-access/area denial (A2/AD) environments, EW systems must detect and identify unknown radar signals in heavily dense EM environment as well as generate effective ECMs against these threats.

The goal of cognitive EW

- create electronic warfare (EW) systems that are able to counter new and unknown threats, e.g., threats from cognitive and adaptive radars in real time.



Simplified example of a state-of-the-art RESM/RECM system architecture.

Cognitive Aspects in Electronic Warfare (2)

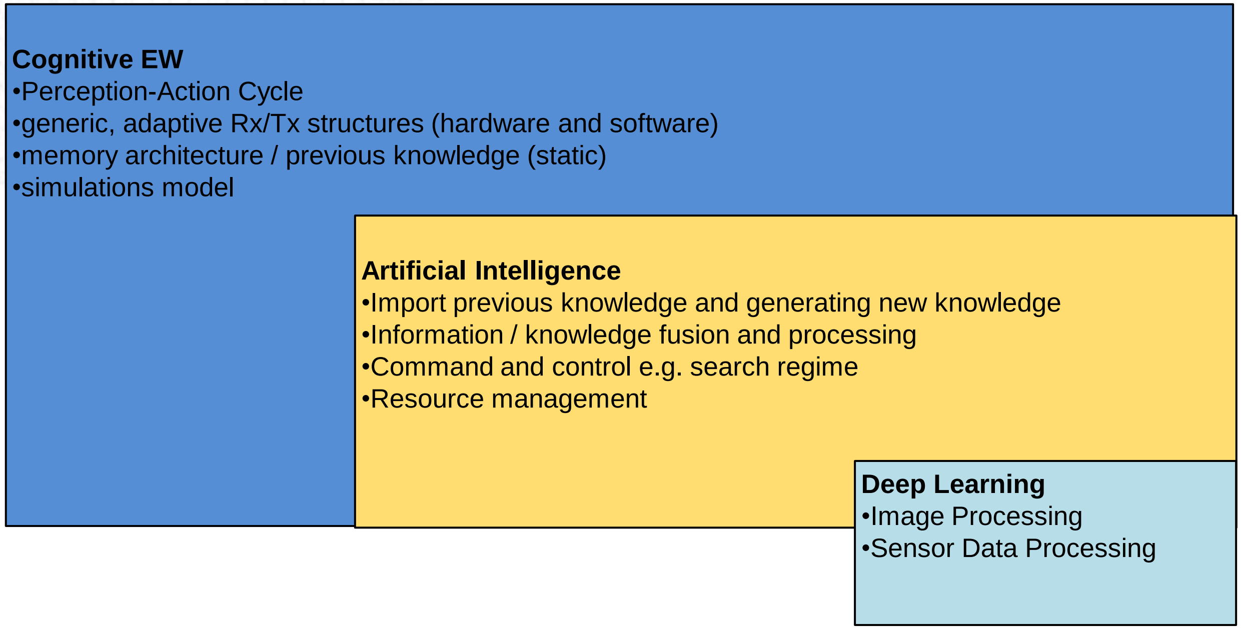
Typical Cognitive System consist of 4 integral parts according to

- A dynamically programmable transmitter and receiver.
- A cognitive memory architecture.
- A perception-action-cycle with cognitive intelligence & attention.
- A statistical information model about the environment

A sophisticated ESM system is characterized by

- Ability to recognize and classify unknown modes (blindly) without much pre-knowledge
- Generic algorithms for determination of radar intention without explicit using info from MDF (Mission Data File)
- Accurate and reliable determination of the inter- and intra-pulse modulation parameters (center frequency, pulse duration, pulse repetition frequency, pulse modulation, etc.)
- Powerful de-interleaving and classification algorithms (Unsupervised M-dimensional clustering, multi-hypothesis analysis, ...)
- Generic DRFM: Extension of jamming signal generation in order to send generic jamming signals with variable parameters adapted to the respective threat scenario

Simplified Hierarchical structure of a cognitive EW system.



Cognitive Aspects in Electronic Warfare (3)

- **Data modulation class**
  - **ASK2**
  - **FSK2**
  - **PSK2**
  - **PSK4**
  - **SIN**
  - **NOISE**
- **Speech modulation class**
  - **A3E**
  - **J3E**
  - **F3E**

Confusion Matrix

	A3E	J3E	F3E	ASK2	FSK2	PSK2	PSK4	SIN	NOISE	NOMATCH
A3E	99,20	0,62	0,18	0,00	0,00	0,00	0,00	0,00	0,00	0,00
J3E	1,20	98,30	0,40	0,00	0,00	0,00	0,00	0,00	0,00	0,10
F3E	0,40	0,40	98,00	0,40	0,60	0,00	0,20	0,00	0,00	0,00
ASK2	0,00	0,40	0,48	95,60	2,00	1,00	0,42	0,10	0,00	0,00
FSK2	0,00	0,06	0,00	0,19	97,20	1,49	0,06	0,00	0,00	1,00
PSK2	0,00	0,00	0,00	0,06	1,54	88,00	9,78	0,42	0,20	0,00
PSK4	0,00	0,00	0,00	0,00	0,32	7,60	92,00	0,08		0,00
SIN	0,00	0,00	0,00	0,00	0,00	4,00	6,20	88,00	1,80	0,00
NOISE	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	100,00	0,00
NOMATCH	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

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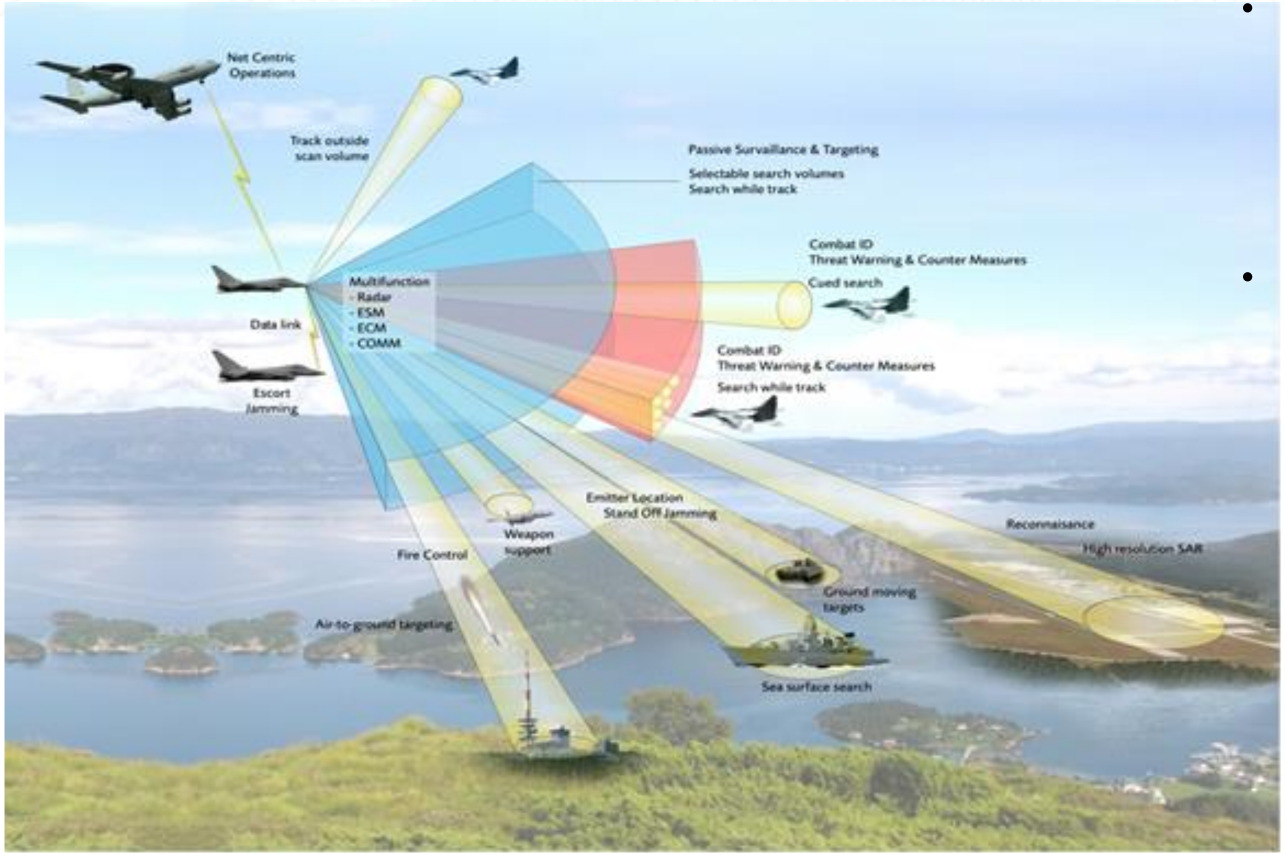
Artificial Intelligence based Resource Management



- Resource management problem is to allocate resource and select control parameters for each individual sensor task such that the best global system performance is achieved subject to the requirements or objectives of the current mission role.
- Such optimization cannot be achieved by so-called
  - **rule based methods** where rules specify the radar control parameters for a collection of tasks leading to performance variations depending on scenario.
  - An intelligent resource management such as the so-called **Quality of Service Method** is required where quality requirements determine the Radar control parameters, i.e. qualities rather than rules determine the resource allocation of each task.

System Application Examples (1)

Naval based Scenario

- Detection/Tracking/Classification/Identification of small/big & slow/fast targets in sea environment (e.g. sea clutter, drones, cyber)
- Integration of new AI-based modules into existing and approved devices and systems
- Design, develop & certification of new AI-based system (Manned, Unmanned)
- Ethics issues

Ground based Scenario

- Detection/Tracking/Classification/Identification of small/big & slow/fast targets in ground environment (e.g. sea clutter, drones, cyber)
- Integration of new AI-based modules into existing and approved devices and systems
- Design, develop & certification of new AI-based system (Manned, Unmanned)
- Ethics issues

System Application Examples & Challenges (2)

Airborne Scenario

- Detection/Tracking/Classification/Identification of small/big & slow/fast targets in sea environment (e.g. volume clutter, drones, cyber)
- Integration of new AI-based modules into existing and approved airborne devices and systems
- Design, develop & certification of new AI-based system (Manned, Unmanned)
- Ethics issues

Space Scenario

- Detection/Tracking/Classification/Identification of small/big & slow/fast targets in space environment (e.g. space debris, space jamming, cyber)
- Integration of new AI-based modules into existing and approved space devices and systems
- Design, develop & certification of new AI-based system (Manned, Unmanned)
- Ethics issues

Conclusion

- Future challenges are the insertion of further Artificial Intelligence of next generation Radar, EW and EO sensors in systems for defense & aerospace applications as shown, giving the advantage of more valuable information.
- How to make deep learning technologies to almost been certifiable and deterministic despite even empirical, experimental or strong stochastic generation process (Neural Network, Hidden Markov Model, Support Vector Machine, Self Learning Machines)
- Detection/Tracking/Classification/Identification of small/big & slow/fast targets in ground/naval/air/space environment (e.g. very small target under volume/sea clutter, space debris, space jamming, cyber)
- Integration of new AI-based modules into existing and approved space devices and systems
- Design, develop & certification of new AI-based system (Manned, Unmanned)

- Companies liabilities/ responsabilities issues for more automation unmanned activities, autonomy, robotics.

- The well understanding of biological intelligence and how the brain works is essential for effective improvements and optimization of future Artificial Intelligence based applications.

- Ethics issues

- Hensoldt is at the forefront in designing novel products using latest AI technology.

Thank you for your attention!