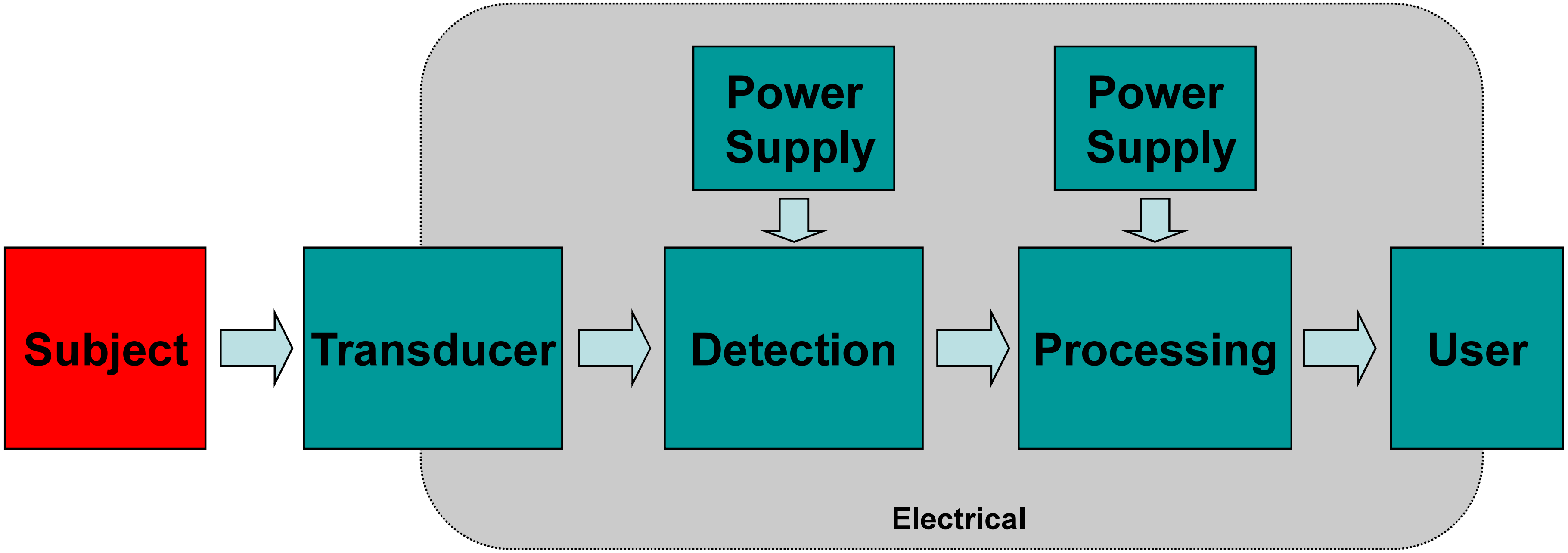
Sensor Systems – Sensor Fusion

Simple Sensor



The simplest implementation of a sensor system consists of a chain of operations from a single subject through to an end user. Increasingly systems are departing from this model and there is considerable research activity in developing new sensor systems for increased capability, reliability and flexibility.

Navigation sensors

GPS

Inertial

Radio

Which sensor systems tell the aircraft where it is?

Multiple Sensors

- **What do we do with mutliple sources of information?**
  - **We ‘fuse’ them together!**

  “Sensor fusion is the combining of sensory data or data derived from sensory data from disparate sources such that the resulting information is in some sense better than would be possible when these sources were used individually” *wikipedia*

Sensor Fusion

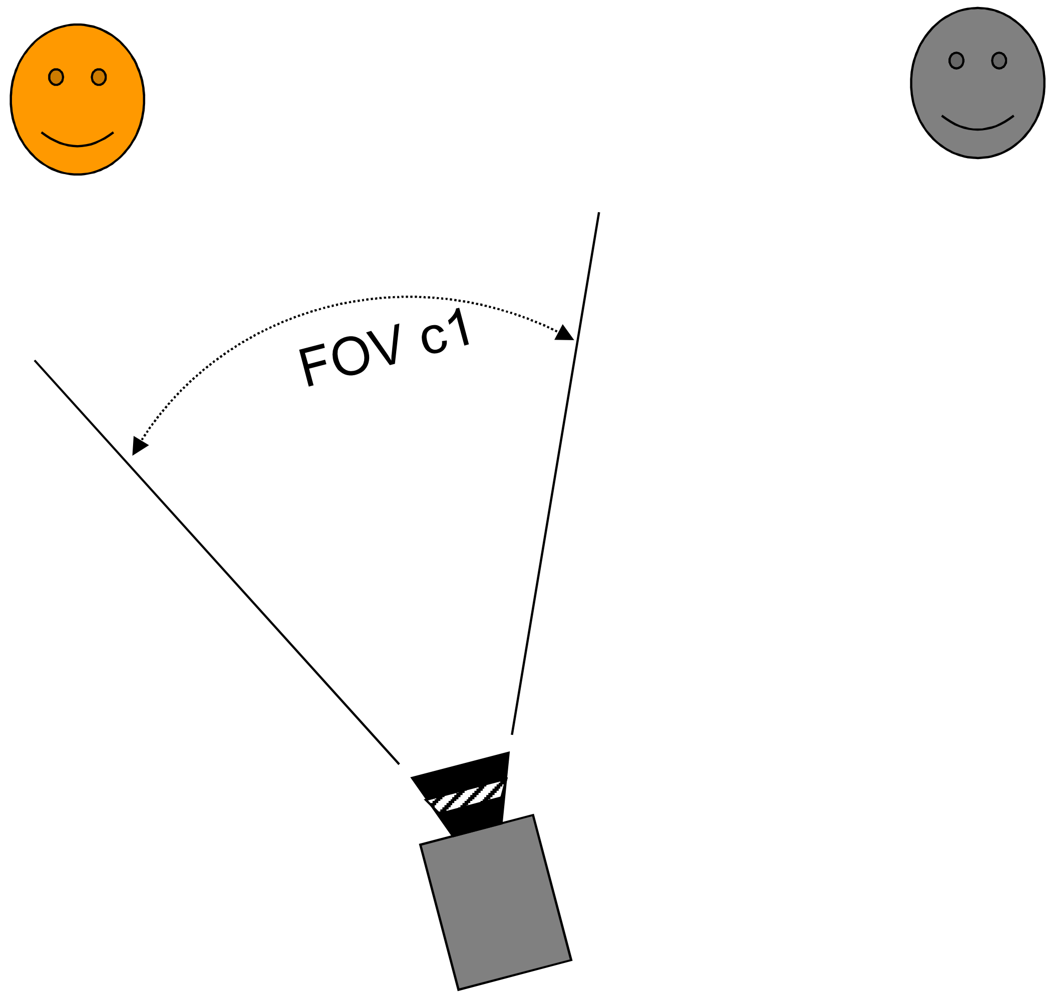
The information from different sensors can be combined in a several ways to provide various types of improved functionality, there are three main types;

1. Complementary

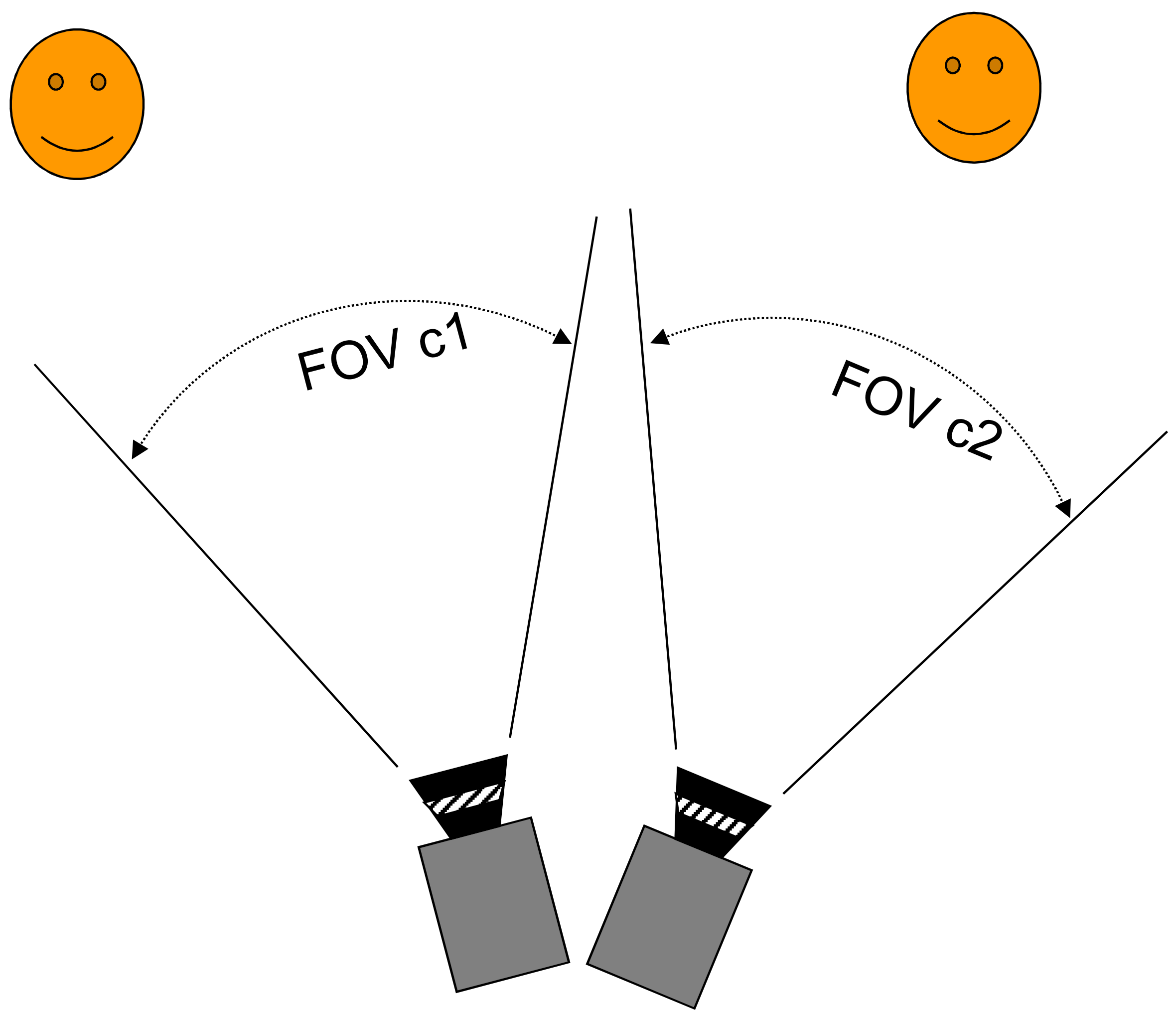
2. Competitive

3. Co-operative

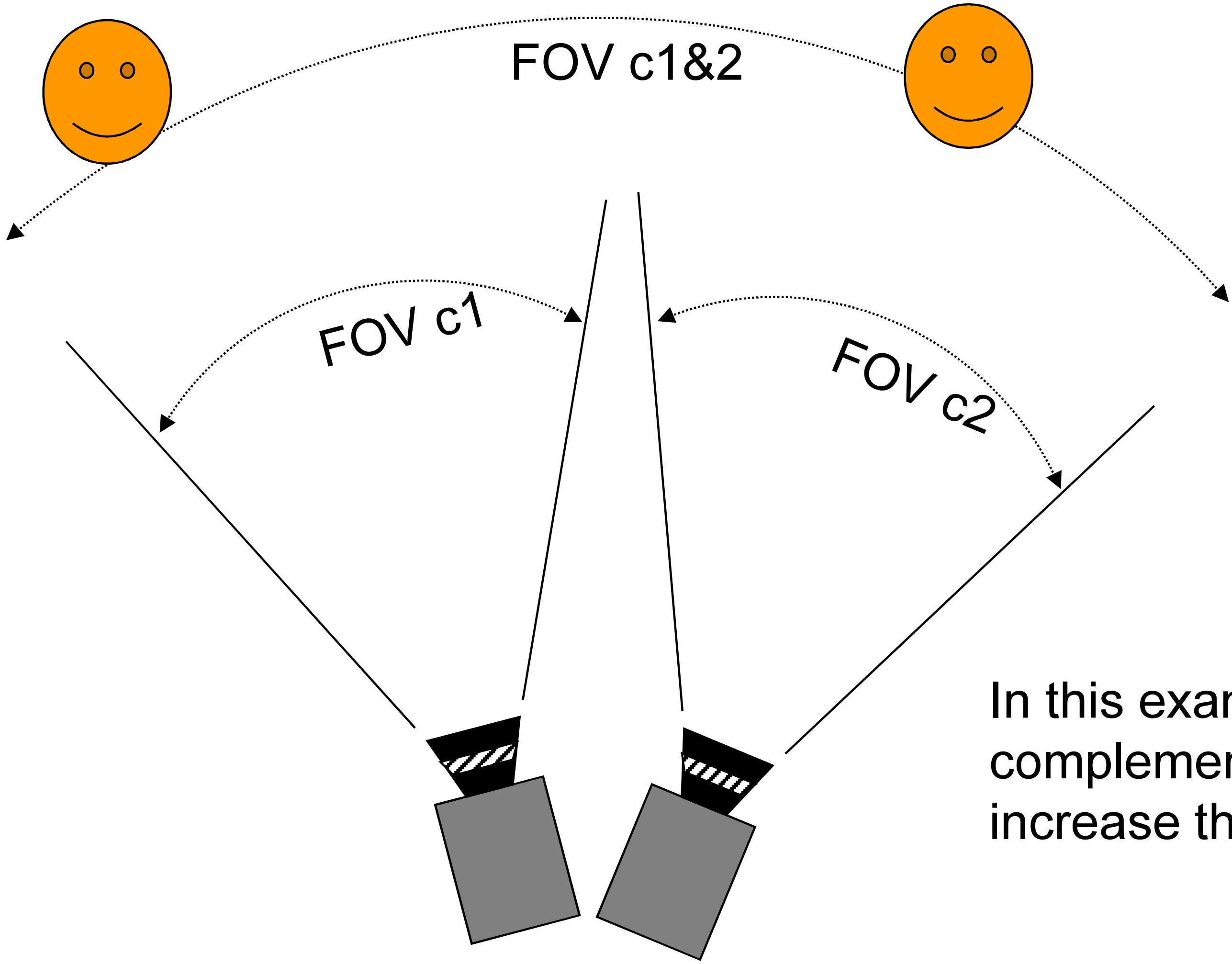
Complementary Sensors



Complementary Sensors

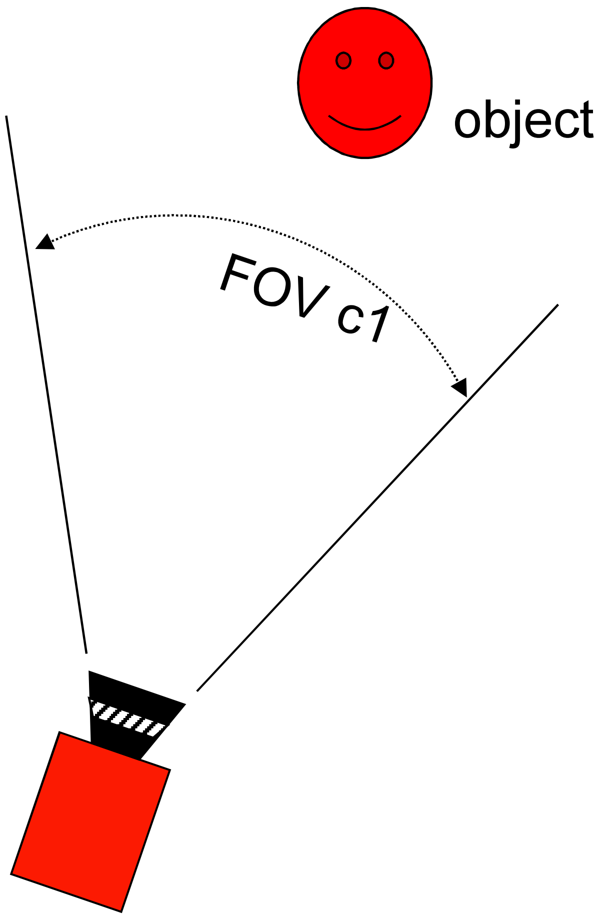


Complementary Sensors

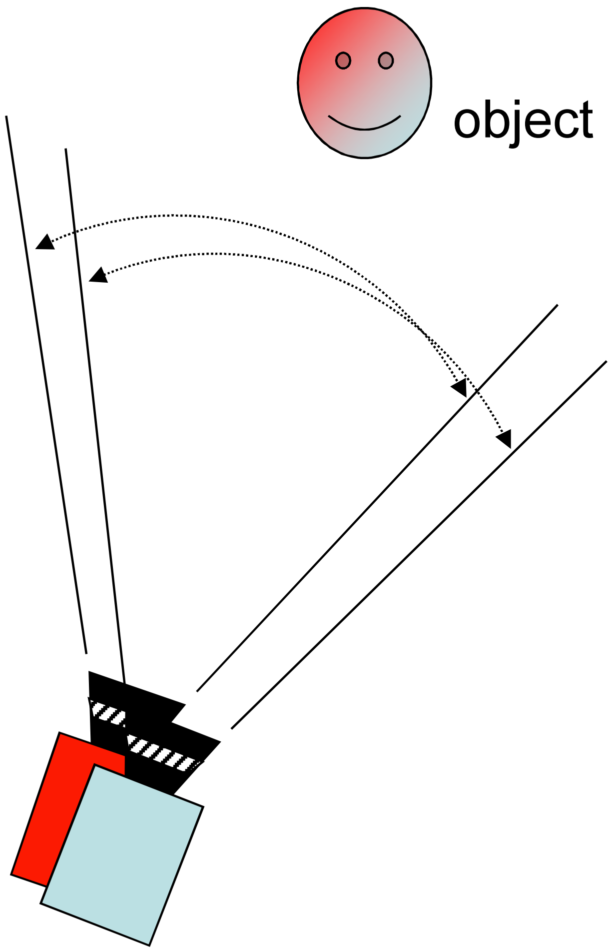


In this example complementary sensors increase the field of view.

Competitive Sensors



Competitive Sensors



Competitive sensors provide information on the same object. In this example two cameras provide redundancy.

Competitive Sensors

Often it is desirable to have more than one sensor providing information in the same spatial and temporal domain. Competitive sensors can be broken down into two sub-categories.

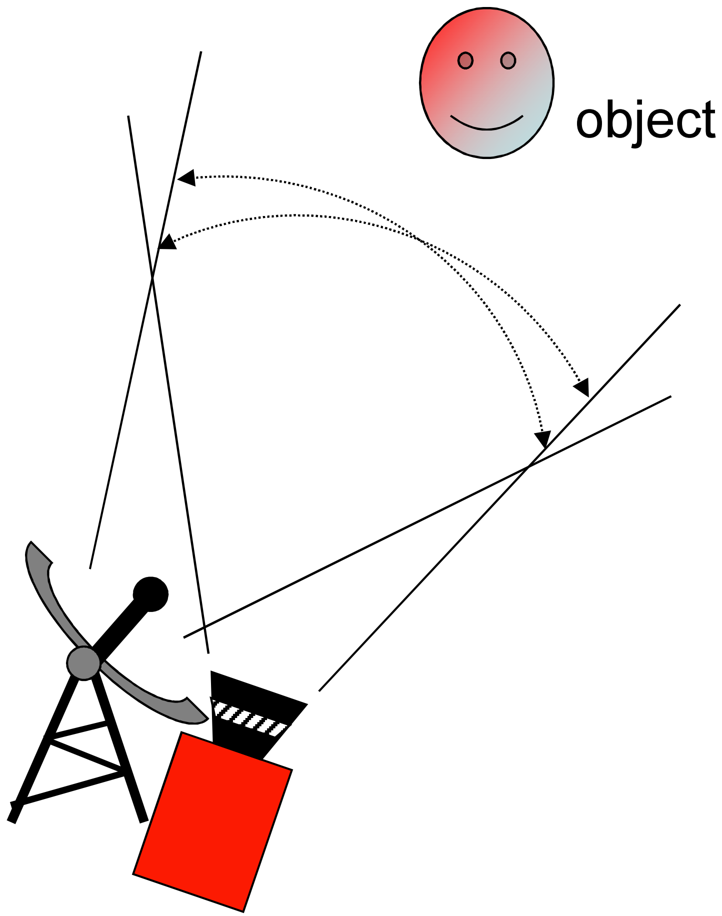
Same Sensor Type Systems

Duplicating the same sensor twice provides redundancy and builds in a degree of fault tolerance.
The choice of which sensor to use can be a simple binary decision based on output constraints or a more complex continuous estimation based on an algorithm combining the sensors outputs.

Differing Sensor Type Systems

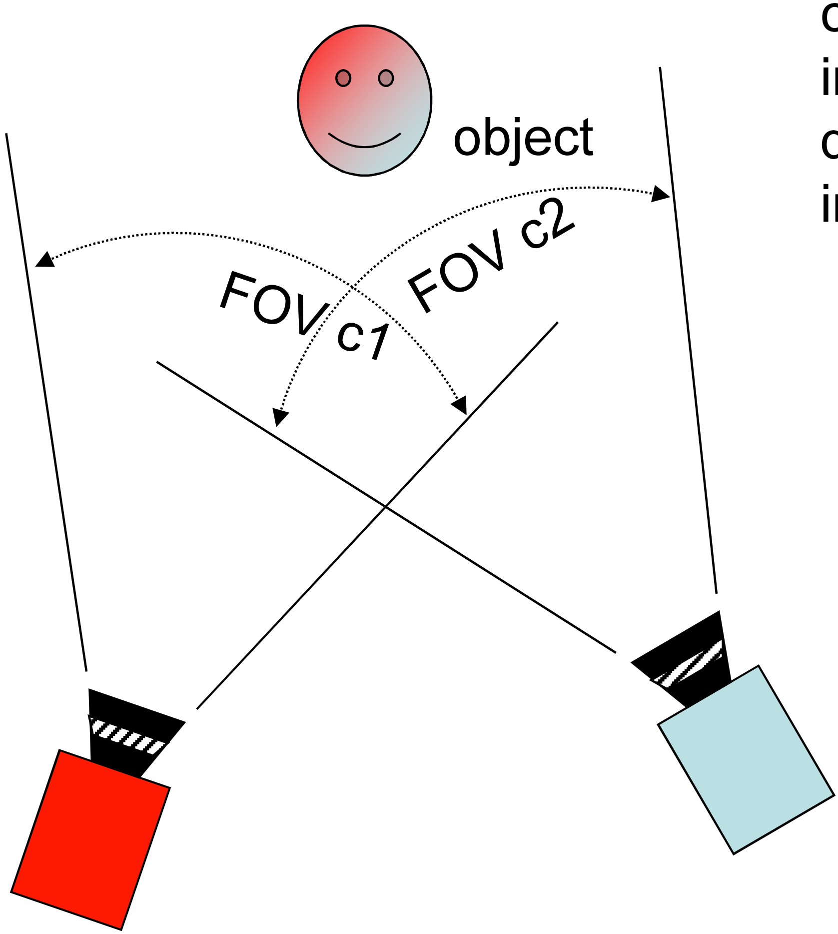
It can be advantageous to employ differing sensor types when the 'target' could be identified by more than one sensor type. This type of system provides cross-correlation, enhancing accuracy and only limited redundancy. It is still necessary to combine sensor outputs using a suitable algorithm.

Competitive Sensors



Again, competitive sensors provide information on the same object. In this example two differing sensors provide the information on the same object.

Cooperative Sensors



Cooperative sensors provide information that no one sensor could provide – in this example we can derive 3D position information.

Sensor Fusion

- Complementary

  The simplest case of sensor fusion. Ideally the sensors provide non-overlapping information that allows a ‘bigger picture’ to be formed. Can be spatial or temporal. No conflicting information.

- Competitive

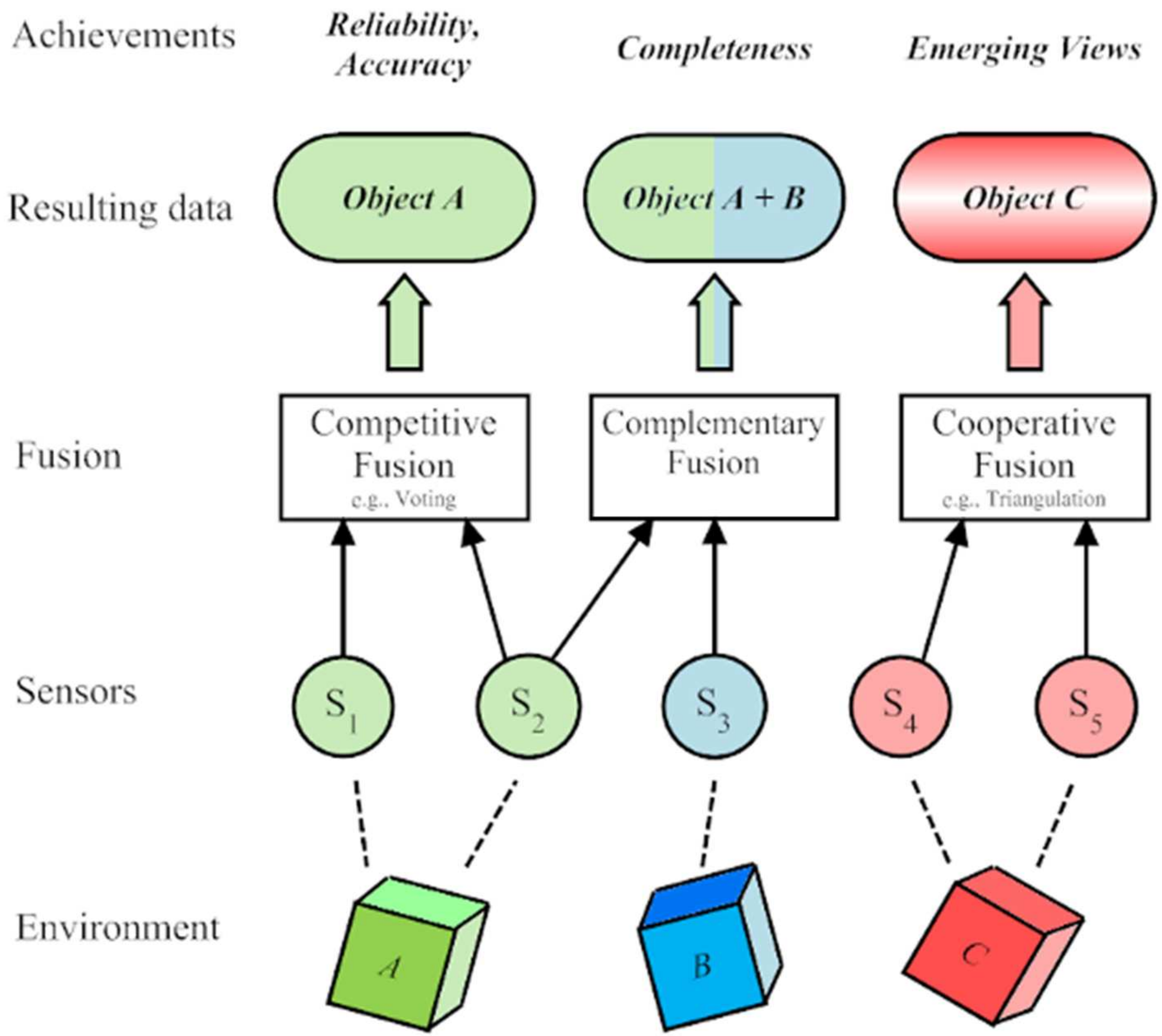
  Sensors provide information on the same subject. The true picture is aggregated. System features redundancy and/or cross-correlation. Potential for conflicts.

- Cooperative

  Sensors together provide information neither sensor alone could provide. Overlap with competitive sensors since both have same subject. Potential for conflicts.

Note: as this is a research field you will find some variability in how the terms are applied, and systems that fall into two categories!

Sensor fusion

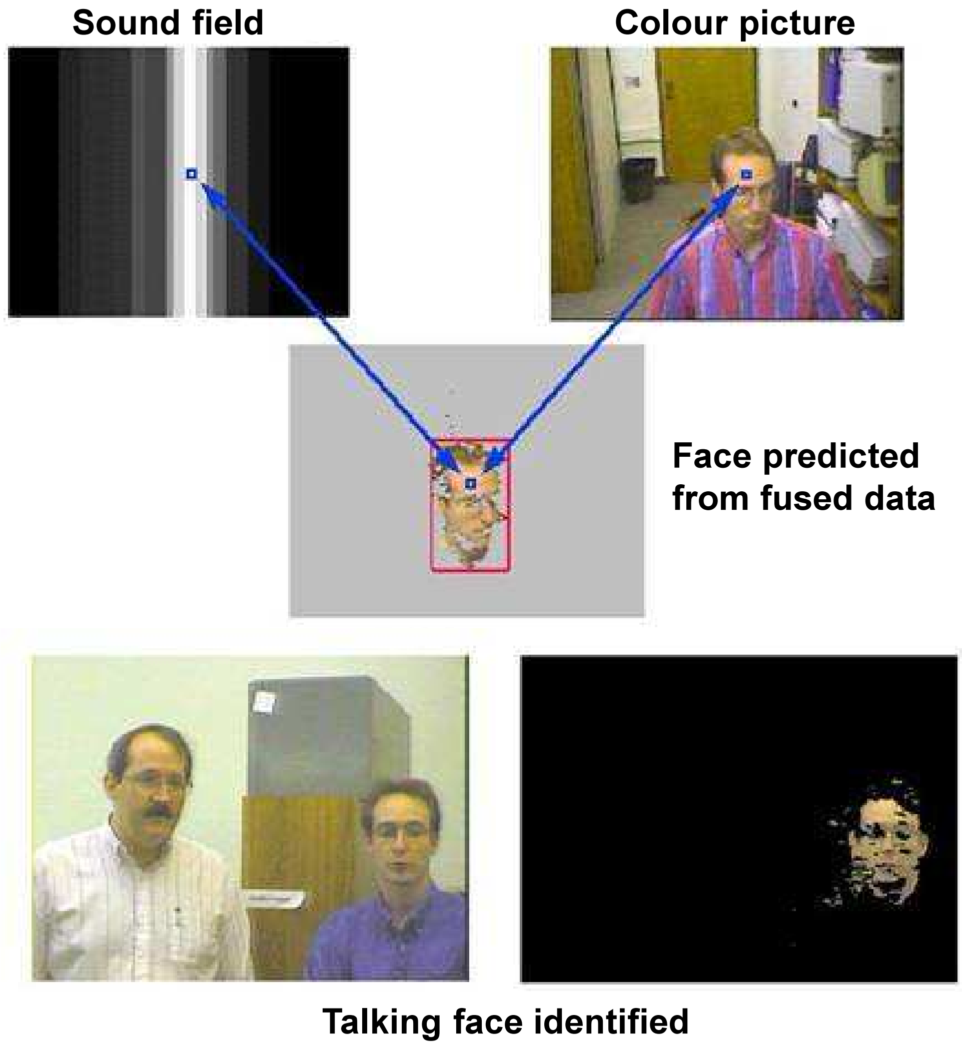


http://netwerkt.wordpress.com/2011/03/30/the-different-types-of-sensor-fusion-complementary-competitive-and-cooperative/

Combining Sensor Data - Images

In this example information about the audio field is combined with information about the tone of a colour image to identify a talking face. Probability techniques are used to fuse the data.

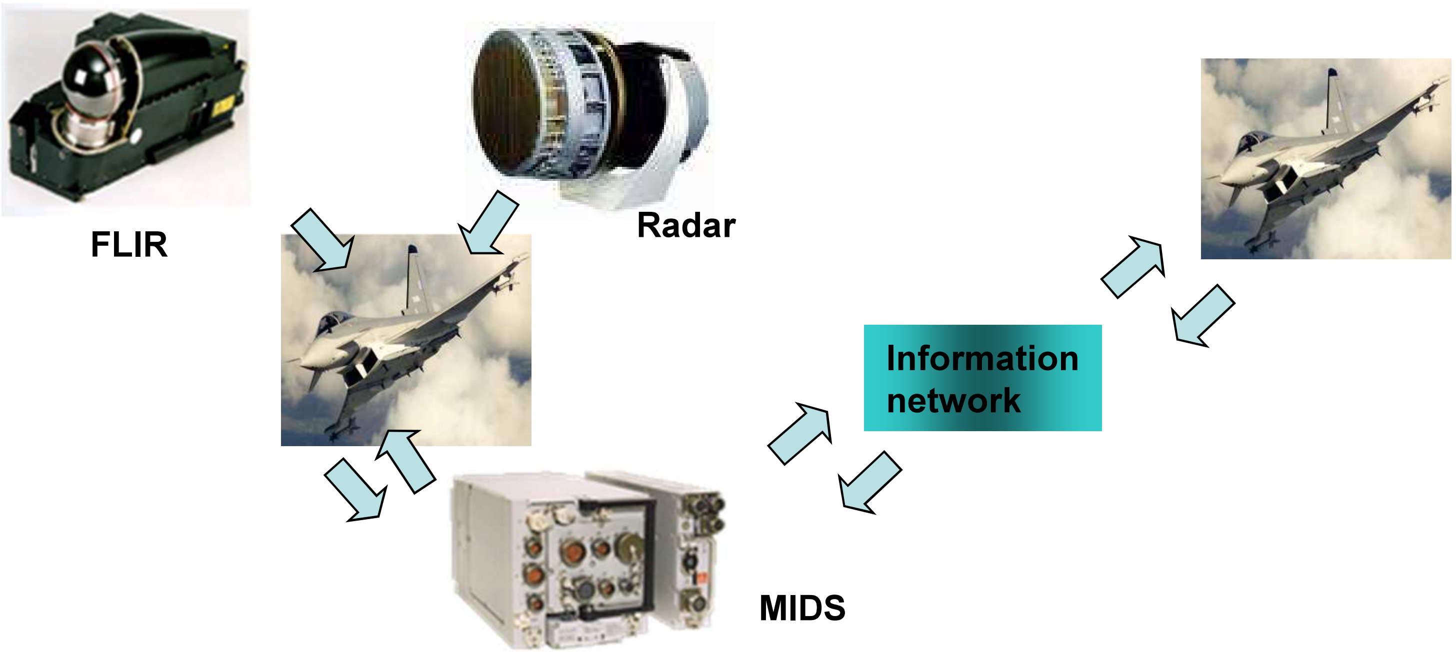
This approach could also be use to fuse data from a IR image to a visible light image. In target tracking applications false alarms are reduced because of the extra information and counter measures are less effective.



Pictures: S. Goodridge

Avionics applications

Sensor fusion is a key technology on the electronic battlefield. This fusion occurs on several levels – the Typhoon fuses data from the FLIR and the Radar locally for search and track operations but can also integrate its own systems within a larger information sharing network or MIDS (Multi-Function Information Distribution System).



Battle-space information networks

A first generation MIDS (Multi-function Information Distribution System) is JTIDS (Joint Tactical Information Distribution System), used primarily in air and air defence roles. JTIDS occupies the L band (969-1206MHz), uses a TDMA scheme and the Link 16 data exchange format.

TDMA (time division multiple access) – a robust and secure multiple access technique regularly used for military applications. Multiple users occupy the same frequency band.

Link 16 – A data exchange format used extensively by NATO with well defined structure. Normally TDMA in L band, but also SATCOM.

BAE systems

Battle-space information networks

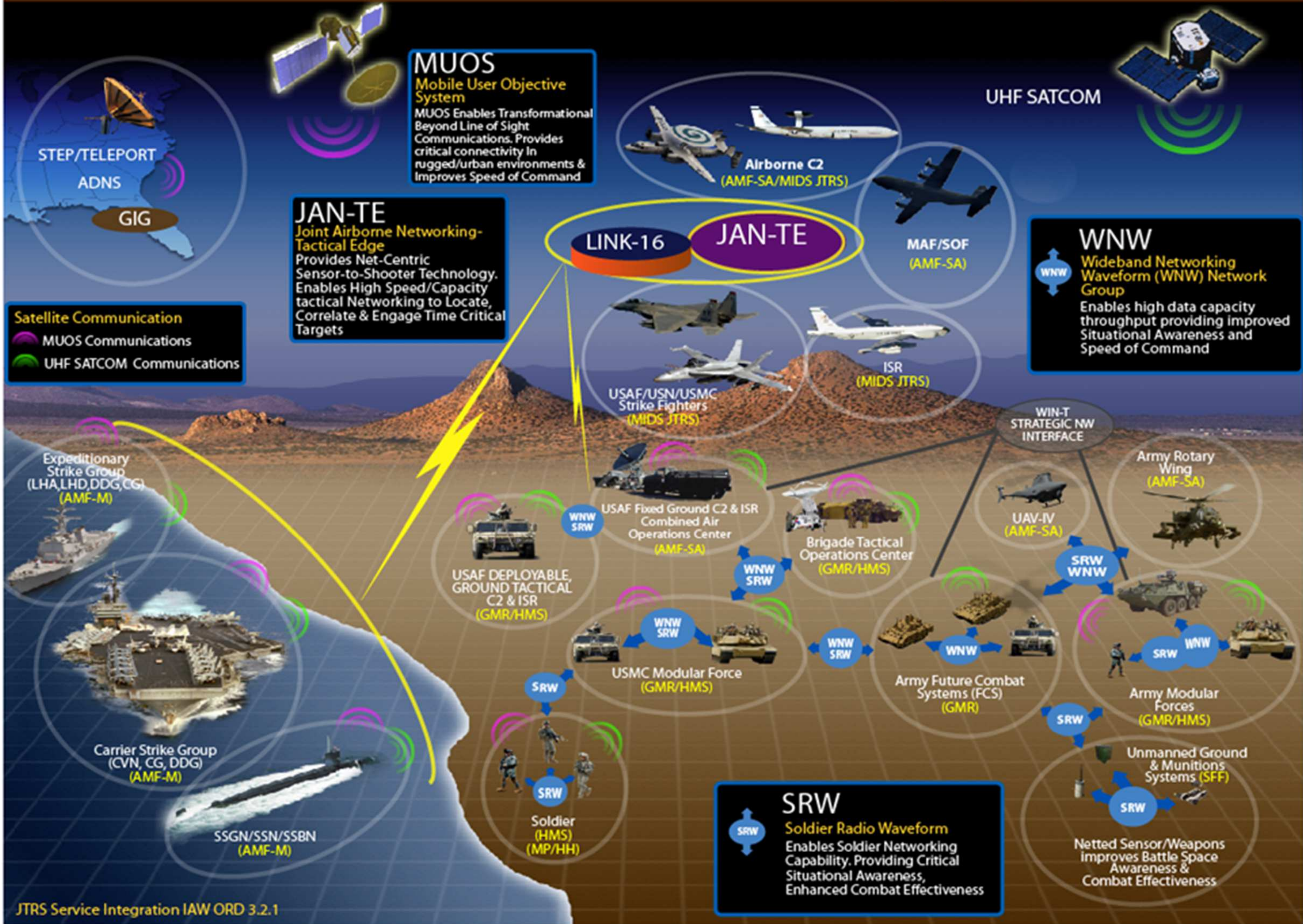
Second generation systems such as JTRS (Joint Tactical Radio System) are based on software radio to allow much wider connectivity, embracing a range of radio platforms. New exchange protocols are also being developed to support ad-hoc networking, e.g. Link 22. The first 'increment' of JTRS covers the following 'Waveforms';

>> Wideband Networking Waveform (WNW)
>> Soldier Radio Waveform (SRW)
>> Joint Airborne Networking–Tactical Edge (JAN-TE)
>> Mobile User Objective System (MUOS)
>> SINCGARS
>> Link-16
>> EPLRS
>> High Frequency (HF)
>> UHF SATCOM

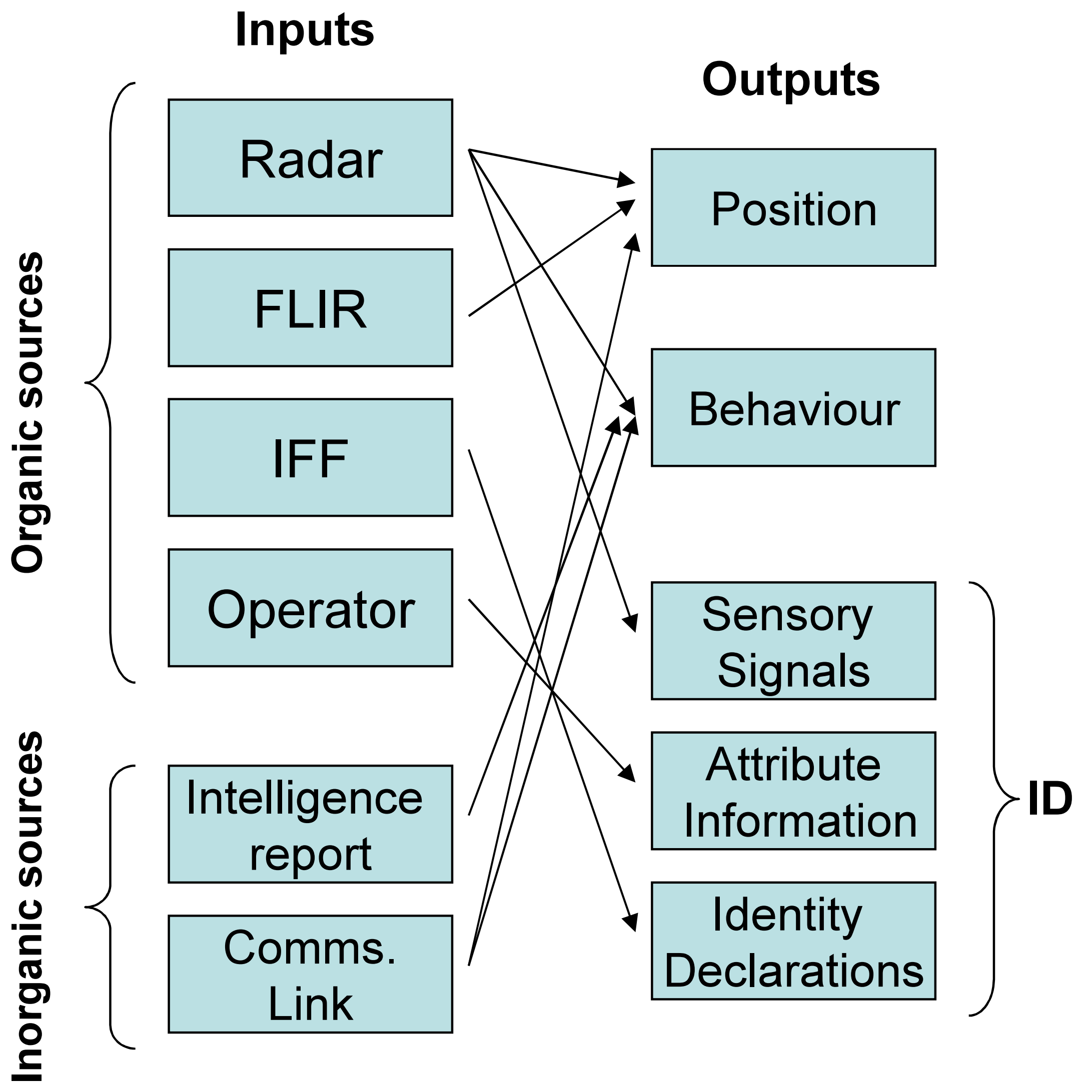
Ad-hoc networks are reconfigurable data networks that can automatically accommodate new users or change network structure.

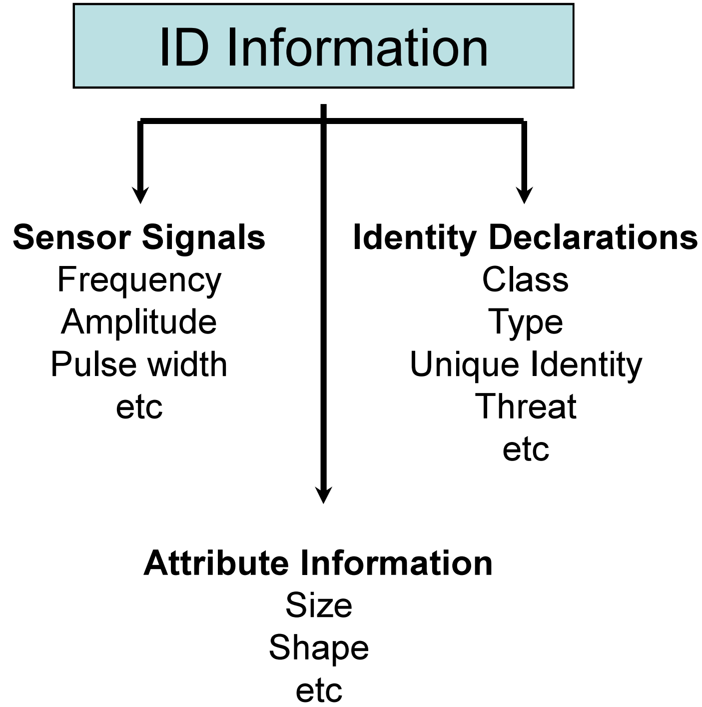
US DoD Joint Program executive office

JTRS Increment 1 Tactical Networking Capability



Multi-Sensory Systems





So, how do we do it?

- There are many approaches to sensor fusion………

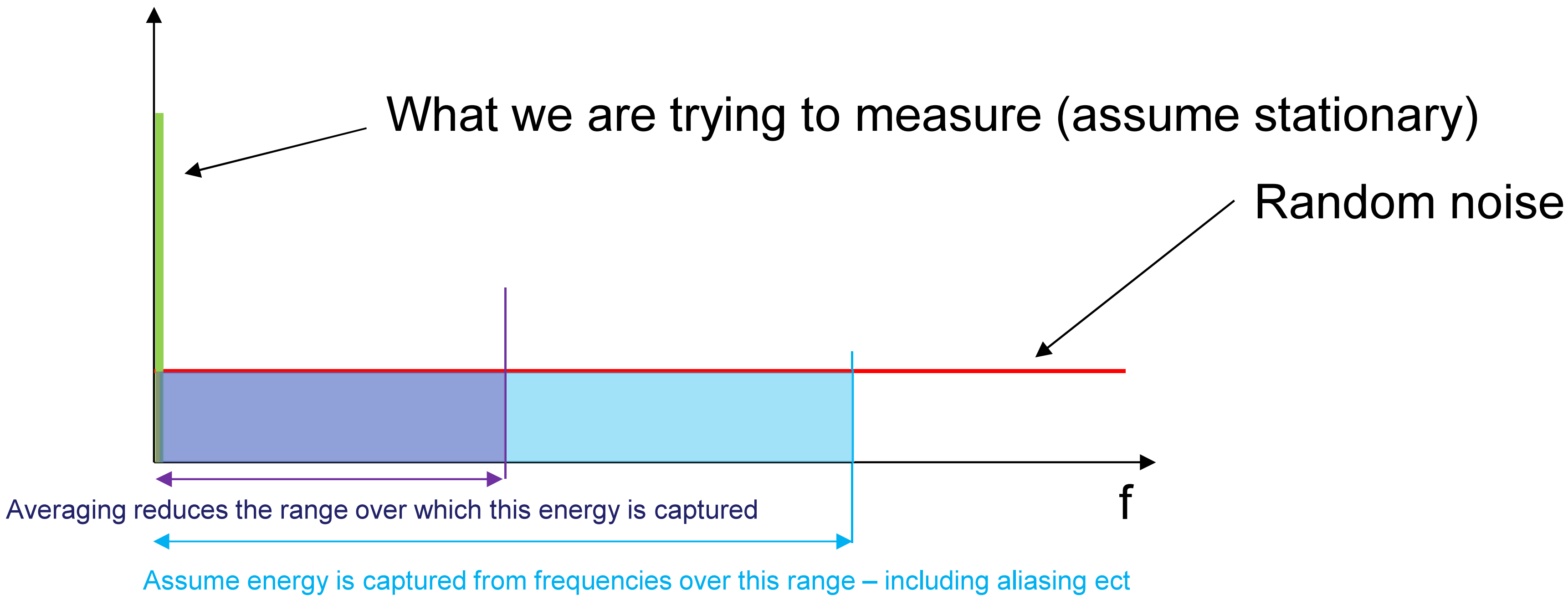
Averaging – the first data fusion?

- Although not often described as fusion, random errors can be reduced by taking the arithmetic mean of multiple readings
- The standard error of an averaged value is reduced by the square root of the number of samples:

$$\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{N}}$$

- This follows from probability theory for random errors which have Gaussian or normal distribution. If the error is not random, then this approach may still work.
- Most often this is used with one sensor sampled at differing times, but in certain cases it can be used for with multiple sensors sampling at the same time – the requirement is that the error is uncorrelated between sensors.

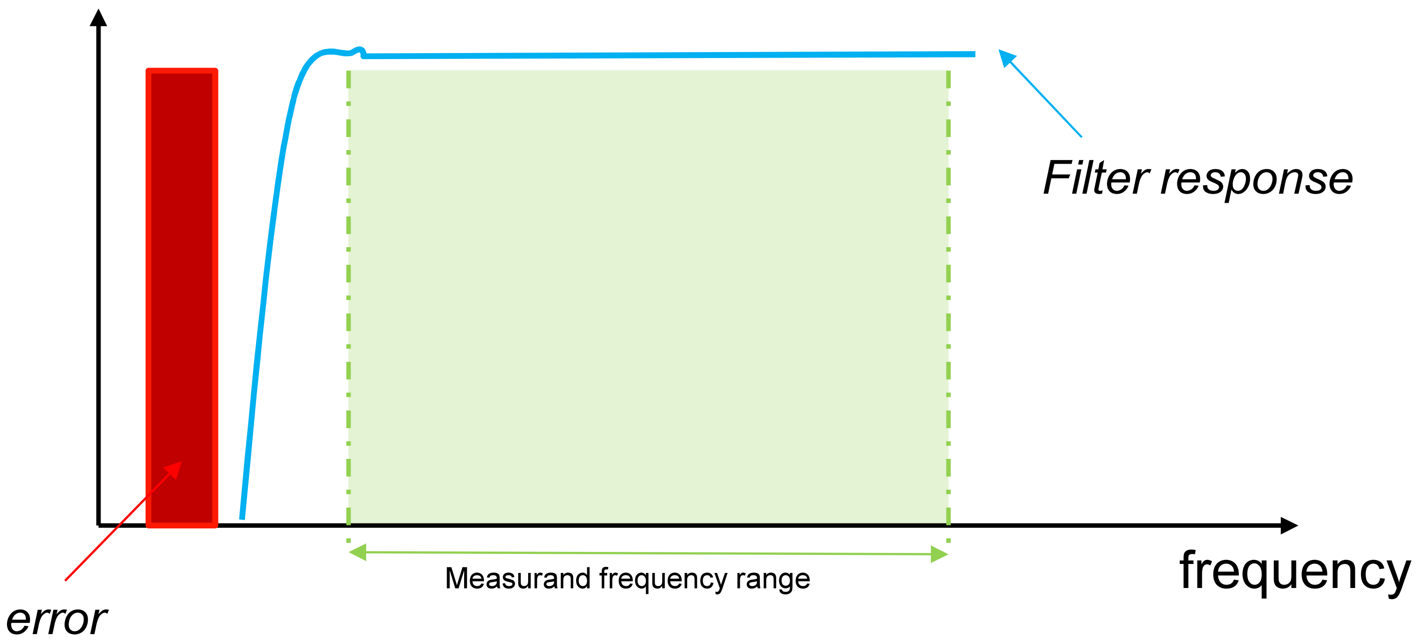
Averaging – in the frequency domain



- By averaging samples the amount of noise captured in the measurement is reduced because higher frequency noise components are excluded.
- We can achieve the same effect by reducing the sample rate – energy will still be present as reflected components

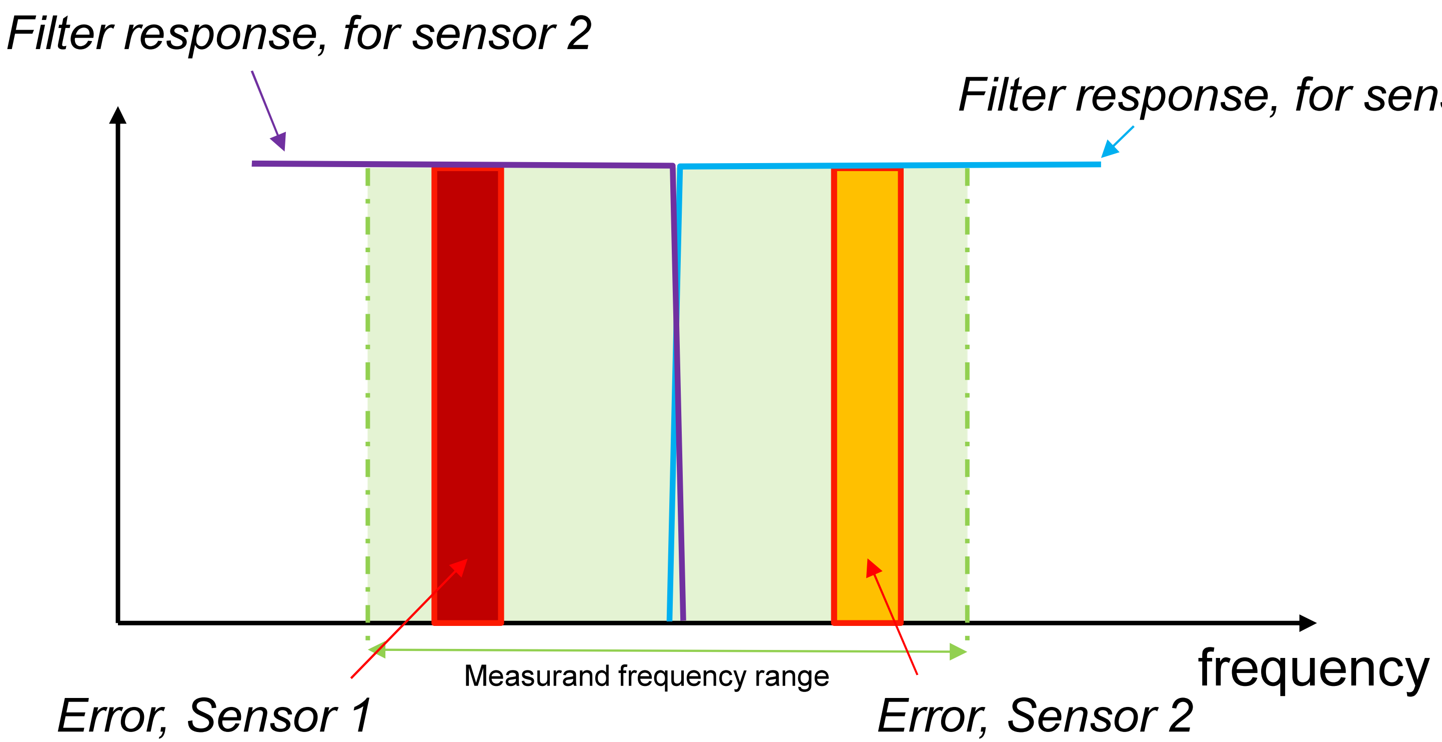
Filtering

- When sensors have errors outside the measurand frequency range, we can use filters to select the 'useful' frequency range.
- But what about if the error and measurand range overlap?
- Filtering will lose some of the useful measurand range



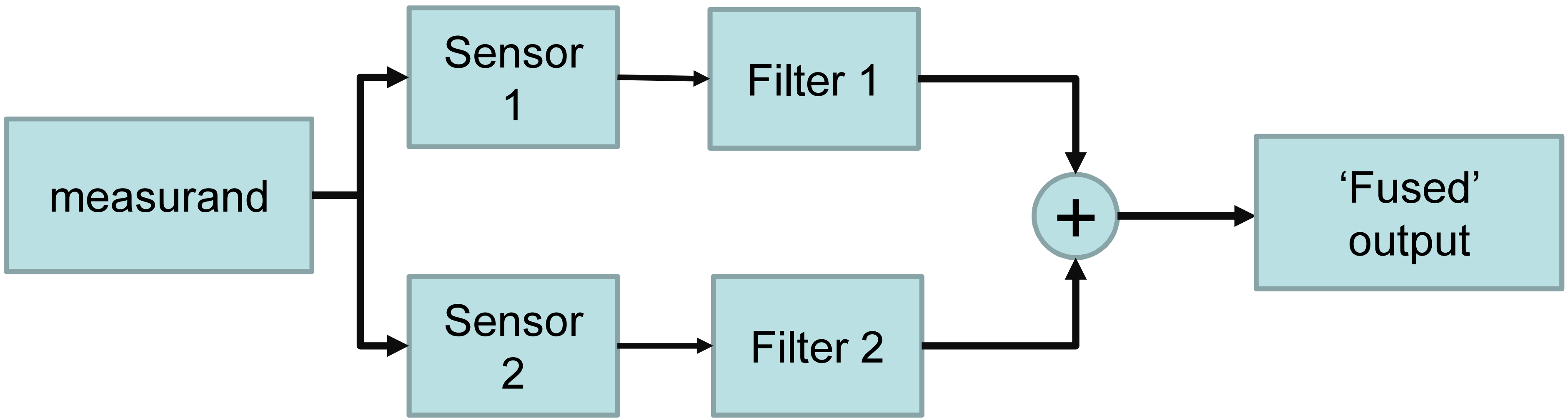
Complementary filtering

- If we can find two sensors with differing error characteristics we can filter the ‘good’ signal from each.
- This is called complimentary filtering.



Complementary filtering

- You will use this type of sensor fusion in the coursework
- We want the system to have unity gain for all frequencies so we make the filters complimentary, i.e; $H_1(s) + H_2(s) = 1$



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