Towards Cognitive Sensor Fusion in Unstructured Environments

Dr David Johnson


E300 Viewer
Span 4.8m
Weight 15kg
Duration 2.5Hrs
PATRICK
SHRIMP

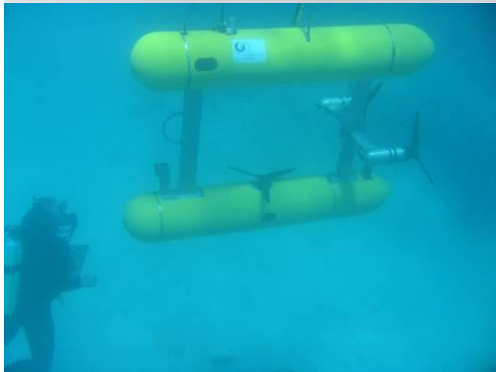
Field Robotics in Australia

- Australia leads the world in *civilian* field-robotic applications
  - Dirty, Dull and Dangerous is a way-of-life

  - Big country
  - Small population
  - Low subsidies

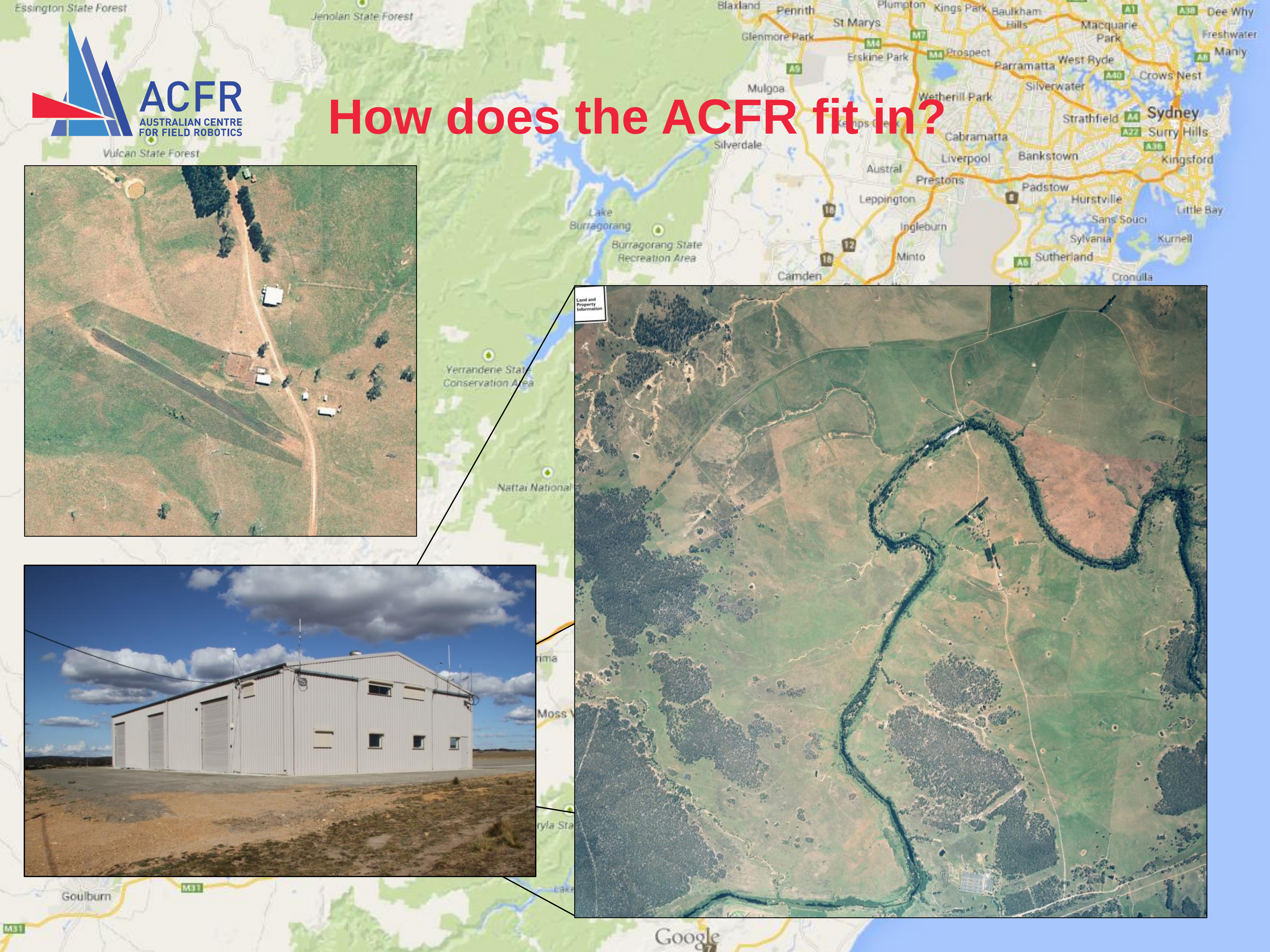
  → Innovate or perish

- **Mining**: Rio Tinto's 'Mine of the Future' program
  - World's largest non-military robotics programme
- **Agriculture**: 1^{st} IEEE Agricultural Robotics Summer School held in Sydney, Feb 2015
- **Logistics**: Port of Brisbane (and now Port Botany)
  - World's 1^{st} fully-automated container-handling terminal



ACFR
AUSTRALIAN CENTRE FOR FIELD ROBOTICS

How does the ACFR fit in?



Autonomy vs. Remote Operation

- Why bother, and what makes it hard?
- In robotics, autonomy is the automation of *independent* perception, learning and control/action.

- Humans are very good at controlling remote vehicles using low-quality visual data, as seen by FPV-racing.

- Much of this is instinctual, using *context* and *experience* to ‘fill in the gaps’ and guess what will happen next.
- It is not surprising that these tasks are difficult to automate, but we can make the sensors better, the processing faster, etc.

What is perception?

- Situational Awareness (Endsley, 1995a)
  - The *perception* of elements in the environment within a volume of time and space, the *comprehension* of their meaning, and the *projection* of their status in the near future

- Two definitions of perception (Oxford Dictionary):
  1. The ability to *see*, *hear*, or become *aware* of something through the senses.
  2. The way in which something is *regarded*, *understood*, or *interpreted*.

ACFR
AUSTRALIAN CENTRE FOR FIELD ROBOTICS

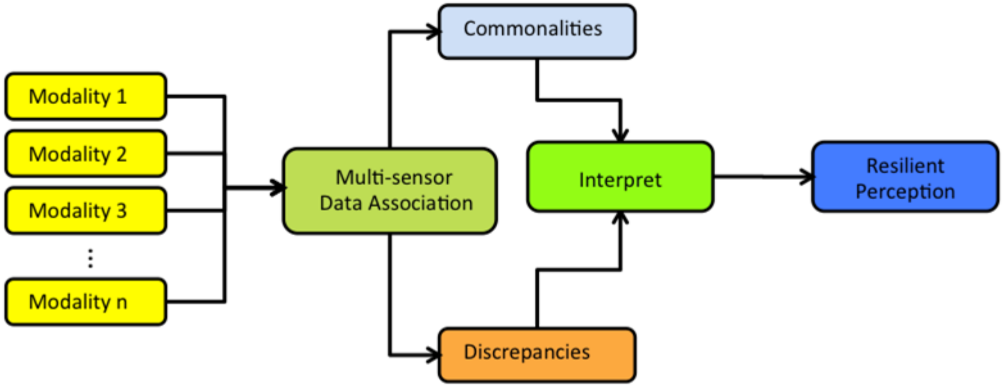
How do bats do it?

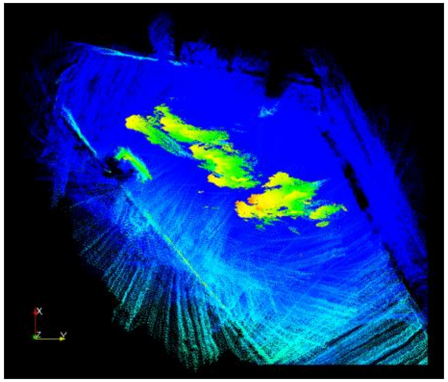
Royal Institution Christmas Lecture (1986): David Pye – The Bionic Bat

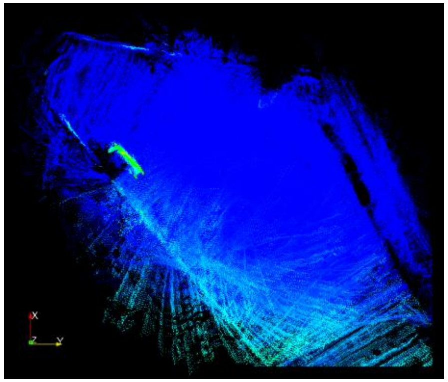
The horseshoe bat not only uses Doppler sonar to detect and home-in on moving targets, it also steers and oscillates its ears to generate its own Doppler signal for the classification of static targets.

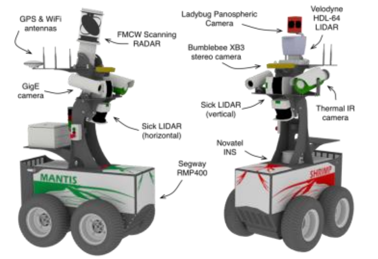
Where is the state-of-the-art?

- Multi-modal resilient perception
- Simultaneous data association and classification



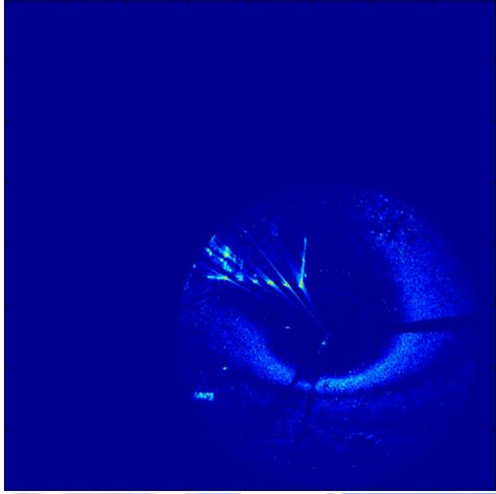


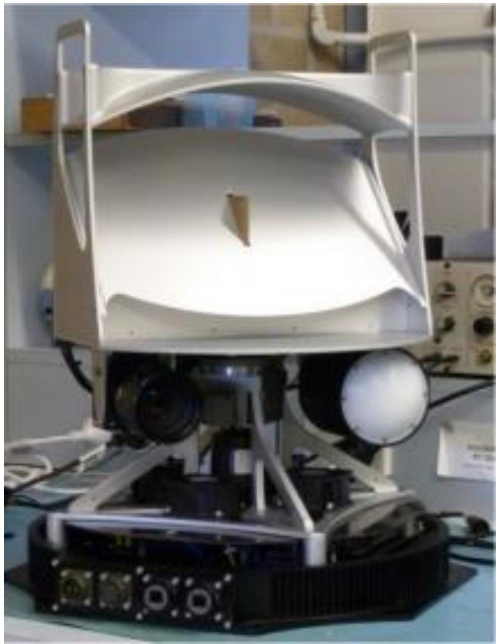




What is cognitive perception?

- (Multi-modal) sensing used to adapt sensor parameters to the environment. Based on:
  - Context
  - Experience (prior information)
  - External cues
- For example:
  - Laser/vision-guided through-wall radar
    - UWB radar prone to boundary-layer disturbance
    - Laser provides highly accurate geometric surface model
    - Combined solution allows this disturbance to be removed from the raw radar signal
    - Techniques have also been applied at MMW frequencies for imaging through foliage.



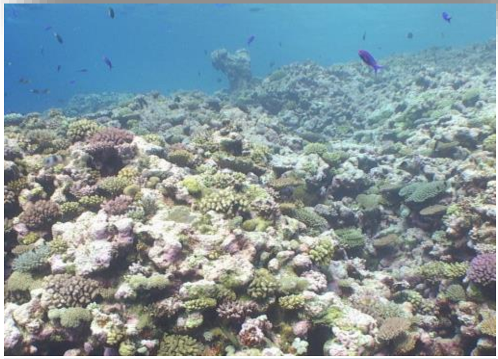


Perception Challenges

Scale *(complexity)*

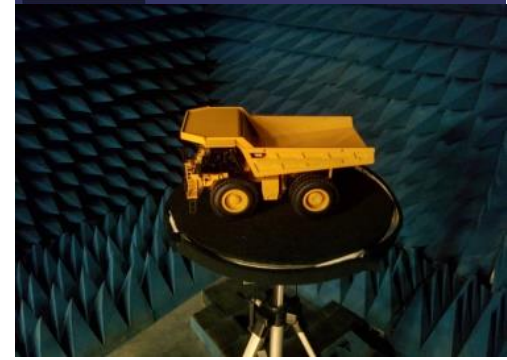
Variability *(novelty)*

Interaction *(not a black box)*



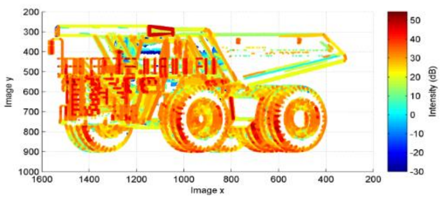
Perception Challenge #1: Scale

Space - Localisation at the mm scale across km-wide maps.

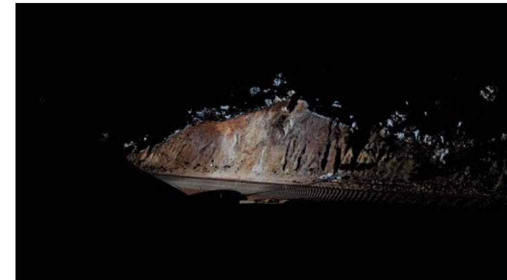


Time - Online processing with real-time requirements for high speed ground, air and water-based vehicles with revisit-times ranging from ms to years.

Frequency - Coherent sensing and communications from kHz to THz, optical and beyond



Number – Dimensionality of many different variables



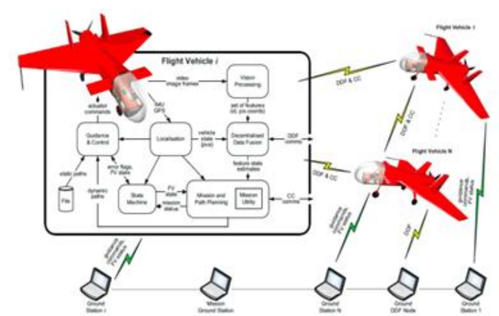
Perception Challenge #2: Variability

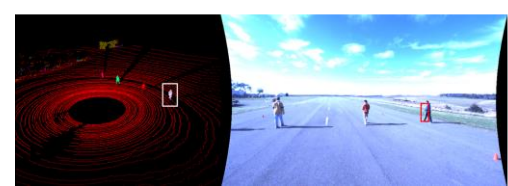
- Challenges for computer-vision:
  - Illumination
  - Object pose
  - Clutter
  - Occlusions
- Challenges for active sensors
  - Multipath
  - Interference
  - Sample-aliasing

ACFR
AUSTRALIAN CENTRE FOR FIELD ROBOTICS

Perception Challenge #3: Interaction

- Human Control Interface – User interaction, levels of autonomy
- Human Environment – Co-habitation vs. isolation
- Natural Environment – Manipulation *of* and attenuation *by*
- Machine Interaction – Systems of Systems, collaboration, communication
- Active Perception – Adaptation of perception parameters and the system itself to meet high-level goals.





Perspectives on Trends, Barriers and Drivers

- Trends
  - Smaller, cheaper, cooperative (coherent operation) is best
  - Vision for >90% of sensing problems
  - Lidar/Radar/Sonar for 24/7 mission-critical operation
  - Filtering of relevant information is vital
- Barriers
  - Spectral congestion
  - Expectation management.
  - IP restrictions to collaboration
  - Securing funding of long-term research projects
- Drivers
  - Defence / User need for increased safety and productivity

Gaps in Knowledge of Cognitive Sensor Fusion

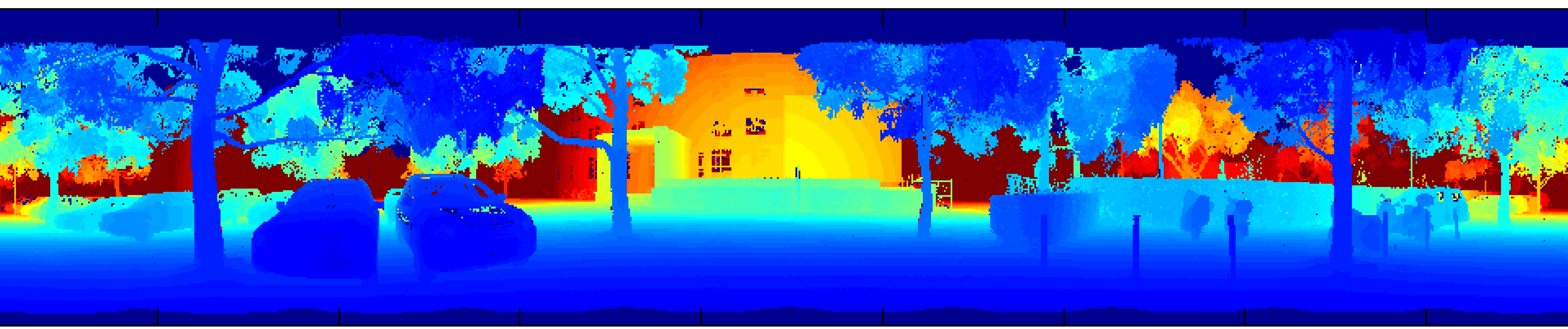
- Dealing with complexity, novelty and dynamic real-world situations
- Adapting to changing operating goals and constraints
- Operation in real-time
- Closed-loop control of multi-modal perception

- These tasks will require additional research into:
  - Compressed Sensing
  - Active learning
  - Deep learning
  - Coherent multi-spectral processing
  - Determining importance in information space in distributed manner

Technological change in 5,10 & 30 years

- 5 years
  - Flying IEDs. <$1k weaponised FPV drone easily accessible.
  - “Internet of Things” a reality.
  - Connected sensors sharing high-level information.
- 10 years
  - Better energy-storage, actuators and sensors.
  - Hybrid (system-on-chip) processing.
  - Coherent system-level perception.
  - Human-machine teaming following natural-language orders.
- 30 years
  - We may all be cyborgs, blurring the line between humans and autonomous systems.
  - Weaponised fully-autonomous systems *common* or *banned*.

Questions?



Future Work

- Research Challenges
  - Robustness
    - Robust to purpose (*reliability*)
      - Minimal false-negatives / false-positives
    - Robust to the environment (*persistence*)
      - Minimal unknown failure modes
      - Onboard diagnostics
    - Robust to the (less-skilled) operator (*trust*)
      - Functional safety
      - Intuitive operation
    - Robust to scale (*cost*)
      - Designed for mass-production
      - Full product life-cycle considerations
      - Spectrum congestion
      - Standards compliance
      - ‘Big-Data’ processing