Miniature UAV Radar System
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Background

- **UAV/UAS demand is accelerating**
  - **Shift from military to civilian applications**
  - **Decreasing acquisition costs**
  - **Increased public awareness**

- **A 2kg UAV hitting a business jet at cruising speed transfers 57kJ while a 20mm anti-aircraft cannon shell delivers 54kJ**
- **The following is required by the FAA for UAV integration into the National Airspace System (among other things)**
  - **Sense and avoid systems (e.g. RADAR, cameras, etc…)**

Why Radar?

- **In addition to optical systems (as required by the FAA) our radar system offers:**
  - **Lower computational requirements**
  - **Immunity to sunlight and other light sources**
  - **Less affected by “optical clutter” (Dust, glass, etc…)**
  - **Multimode operation:**
    - **Range detection, Doppler sensing, SAR mapping, etc…**
  - **Does not require inter-vehicle cooperation as is the case with other systems do (TCAS, PCAS, FLARM)**

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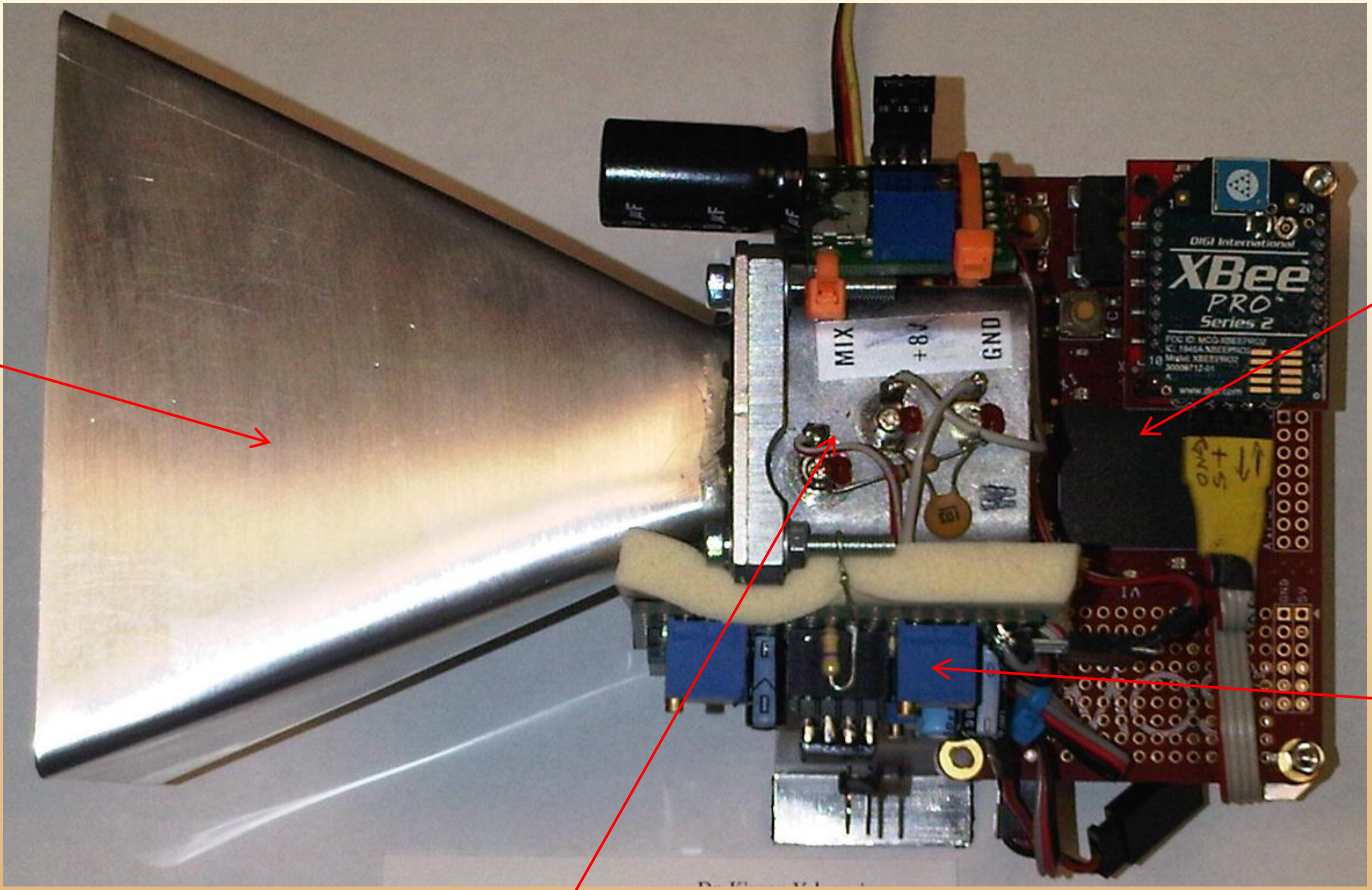
Fully Integrated Working Prototype



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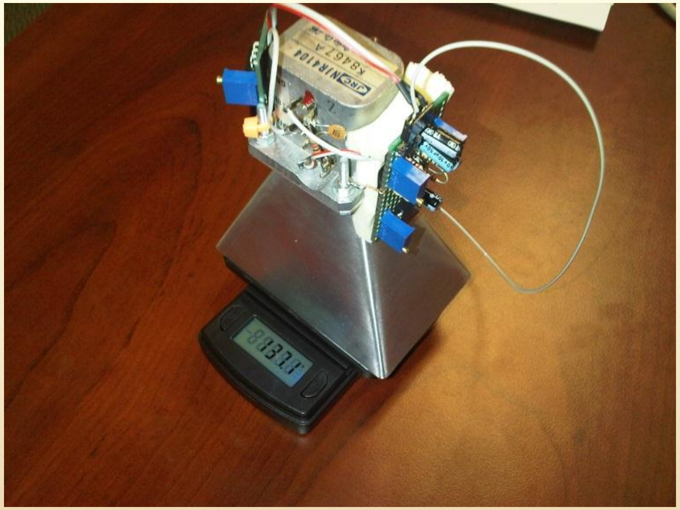
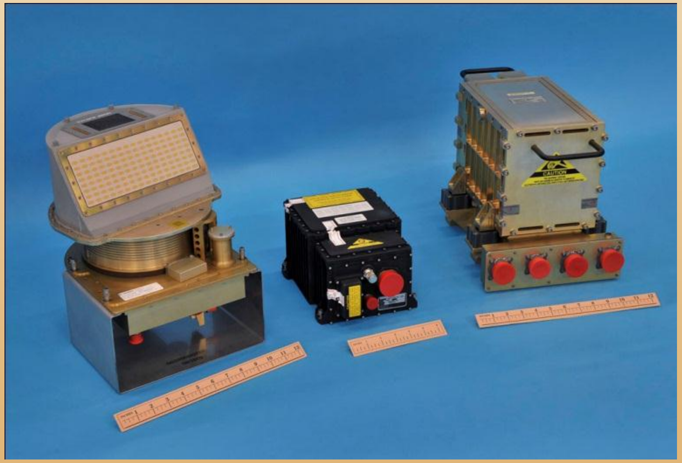
Fully Integrated Working Prototype





- Small size: 15.5 x 10 x 9 cm (1395 cc)
- Lightweight: 230grams
- Power consumption: 4.5W
- Fully integrated system capable of independent operation

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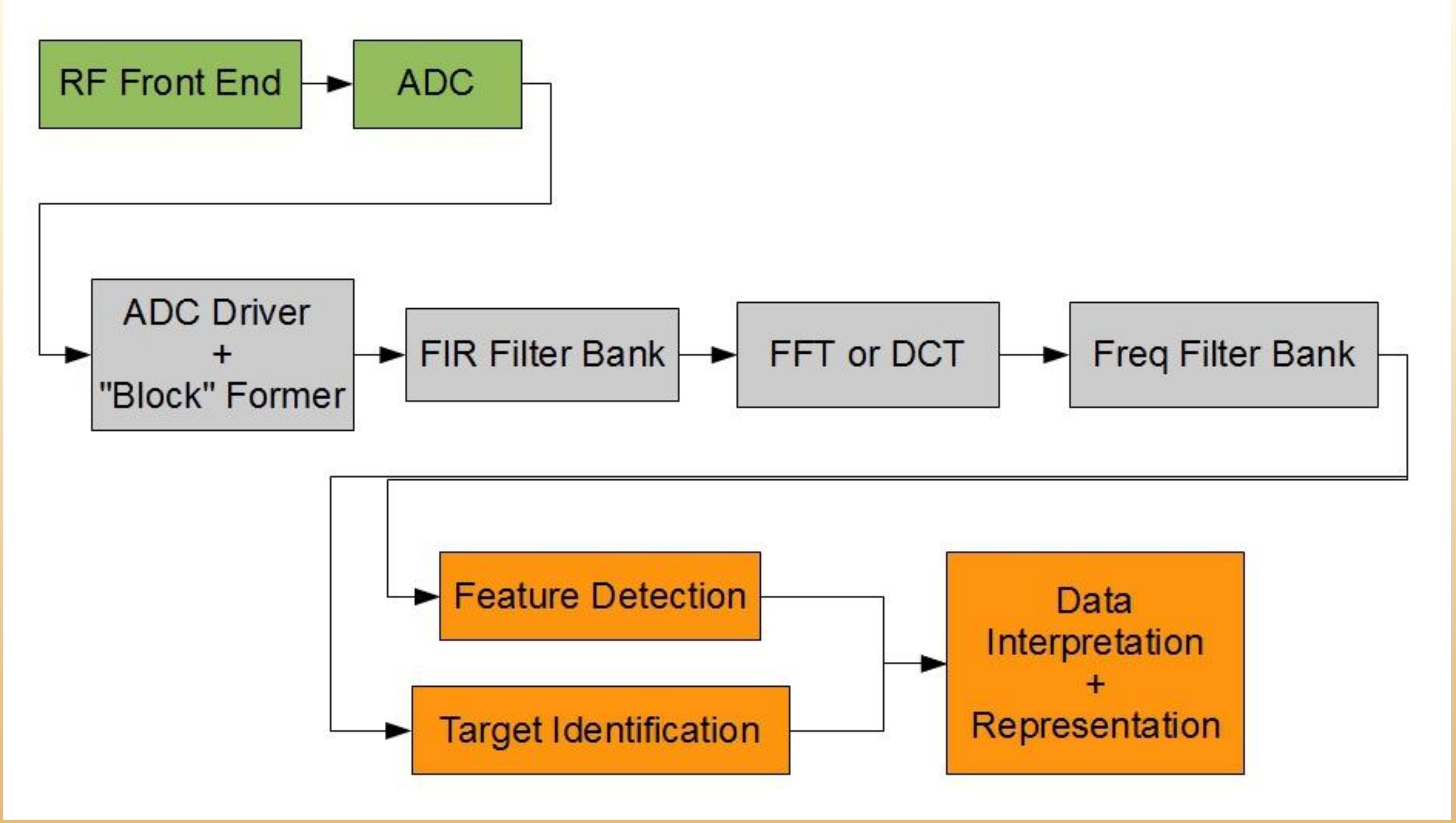
Technical Details: Data Flow



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Technical Details: Basic Signature Origins

$$\Delta F = F_T\left(\frac{2v}{c - v}\right)$$

$$\Delta F \approx 70.048v$$

C = Speed of light
V = Object velocity
F_T = Transmit frequency (10.5GHz)
ΔF = Frequency shift

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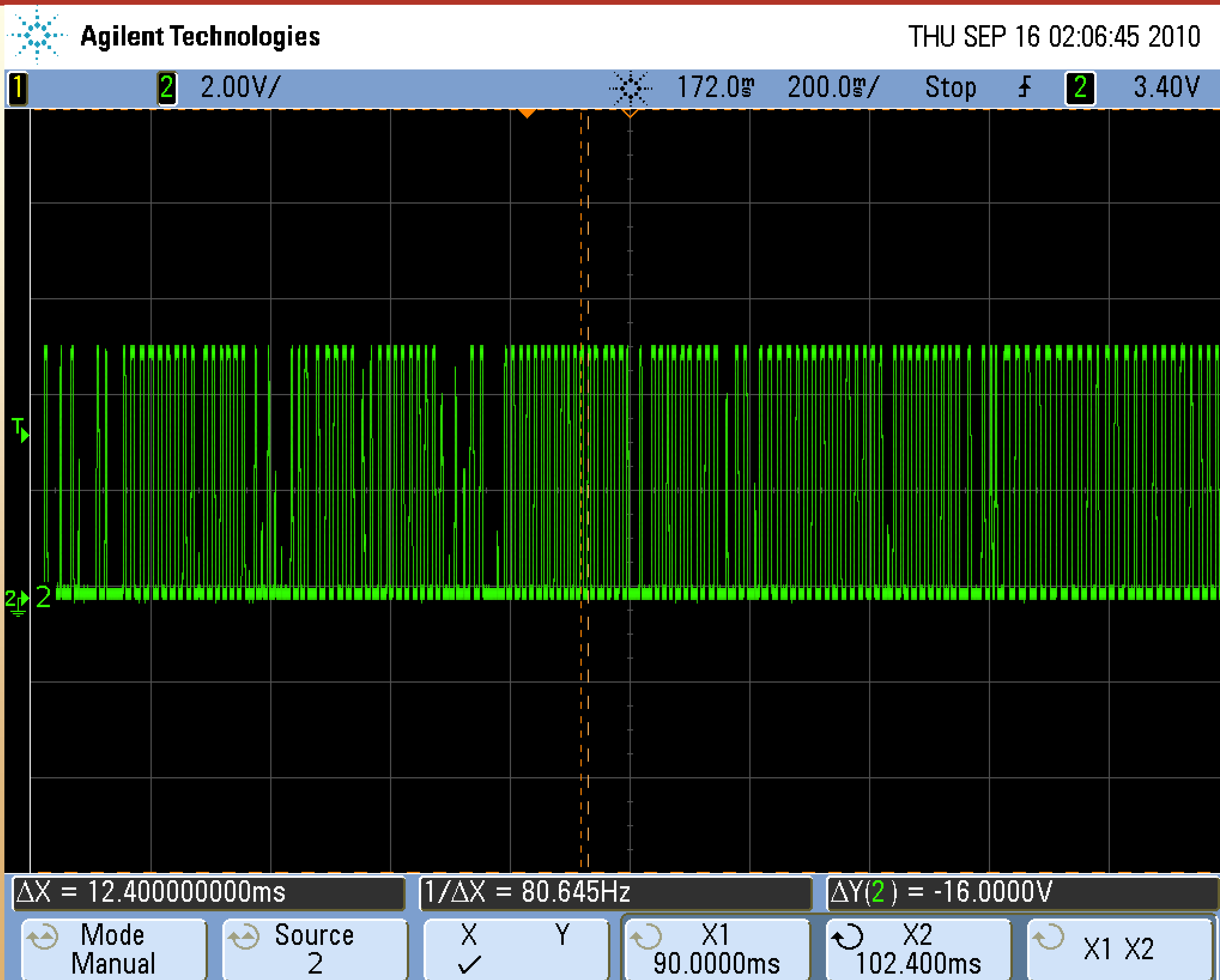
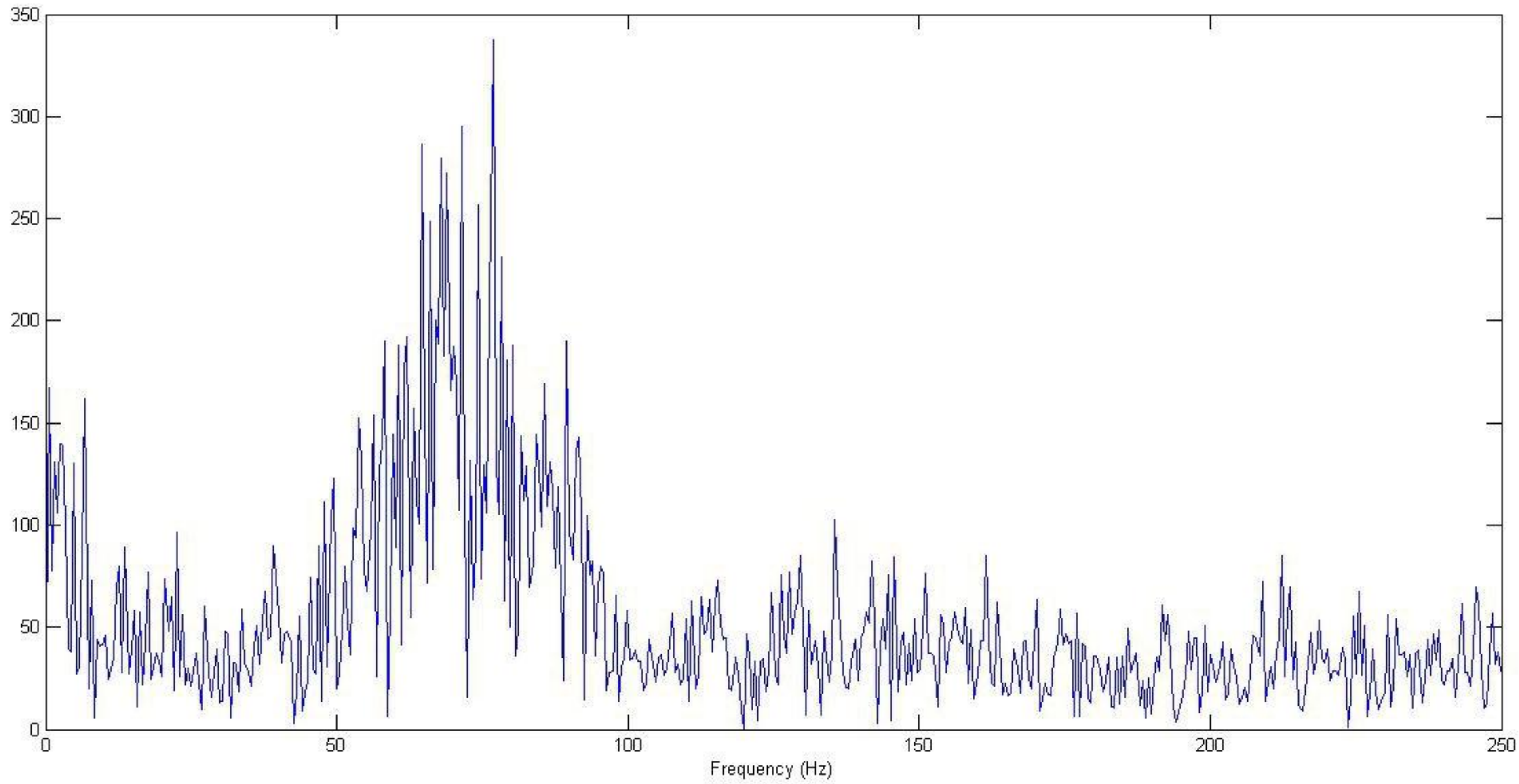
Target Detection (Walking Human)



Target Detection (Walking Human)



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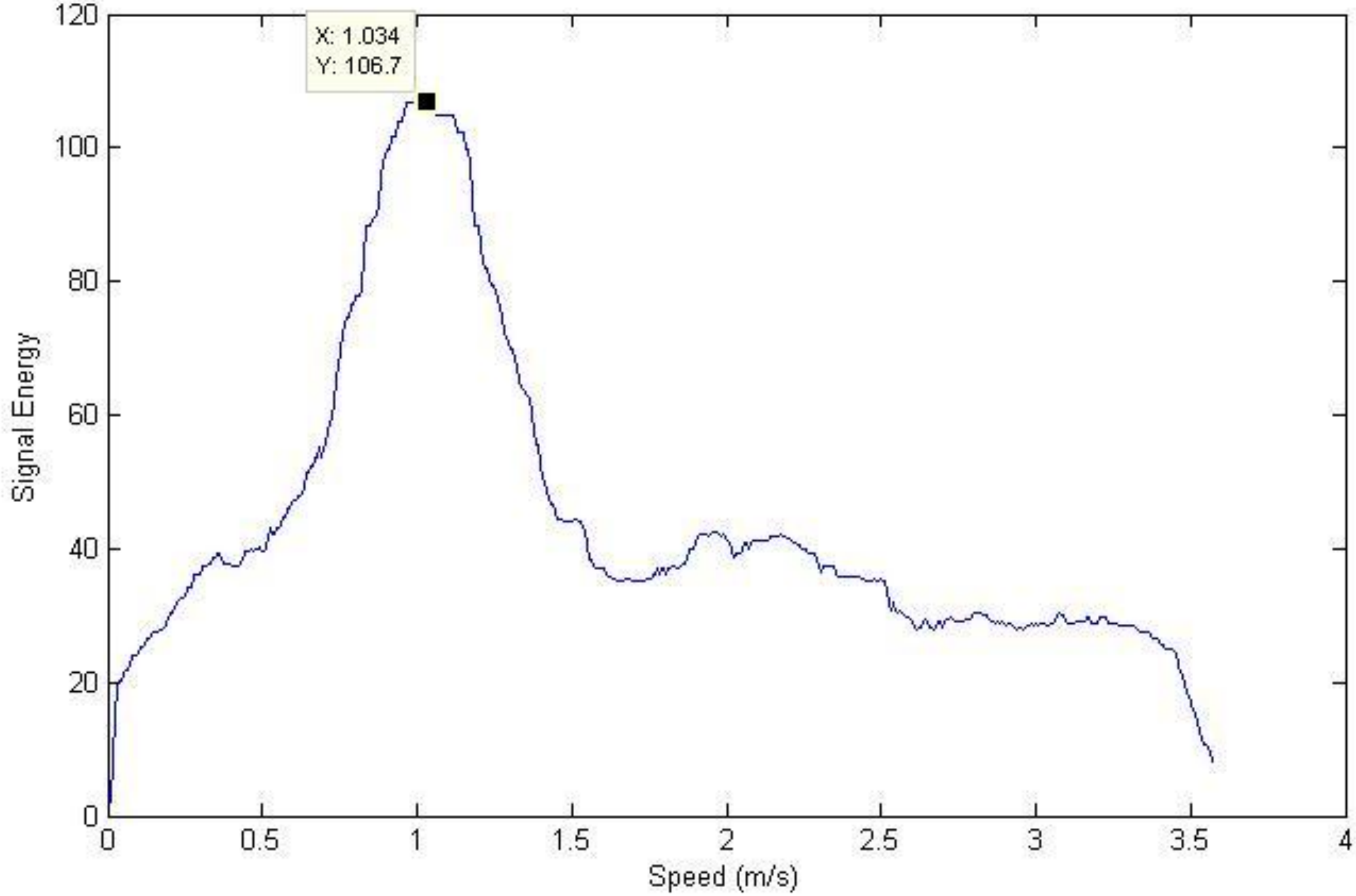
Target Detection (Walking Human)



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Origin of Complex Signatures: Conventional Helicopter

$$Helicopter\_Spectrum(T) = \left(\frac{2F}{c}\right)\left[\frac{\pi d_{mr}}{T} + \frac{\pi d_p}{T} + \frac{\pi d_{tr}}{T/_{4.24}} + Aux(T)\right]$$

d = Component diameter
T = Rotational period of main rotor
F = RADAR transmit frequency (10.5GHz)
c = Speed of light

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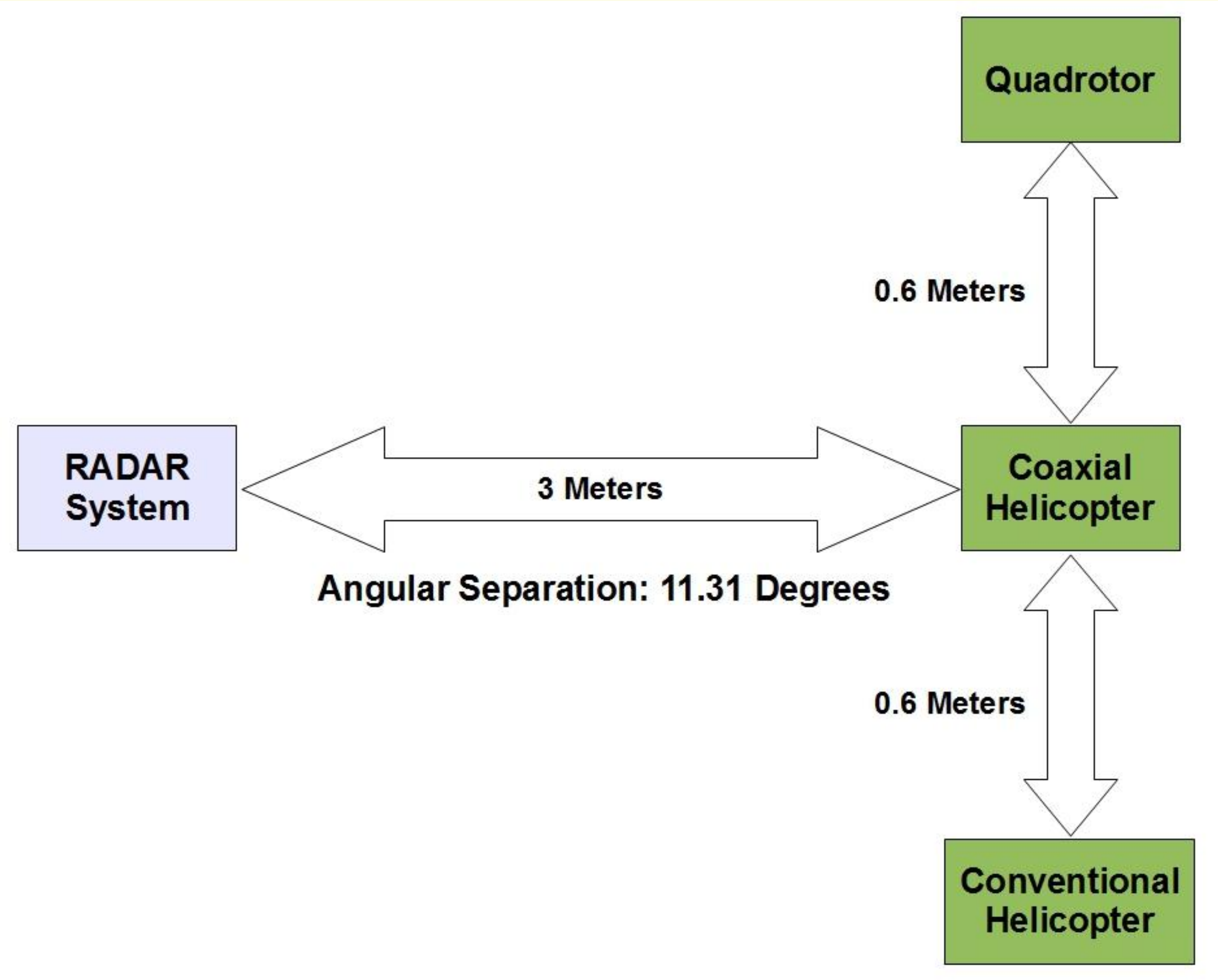
Experimental Setup



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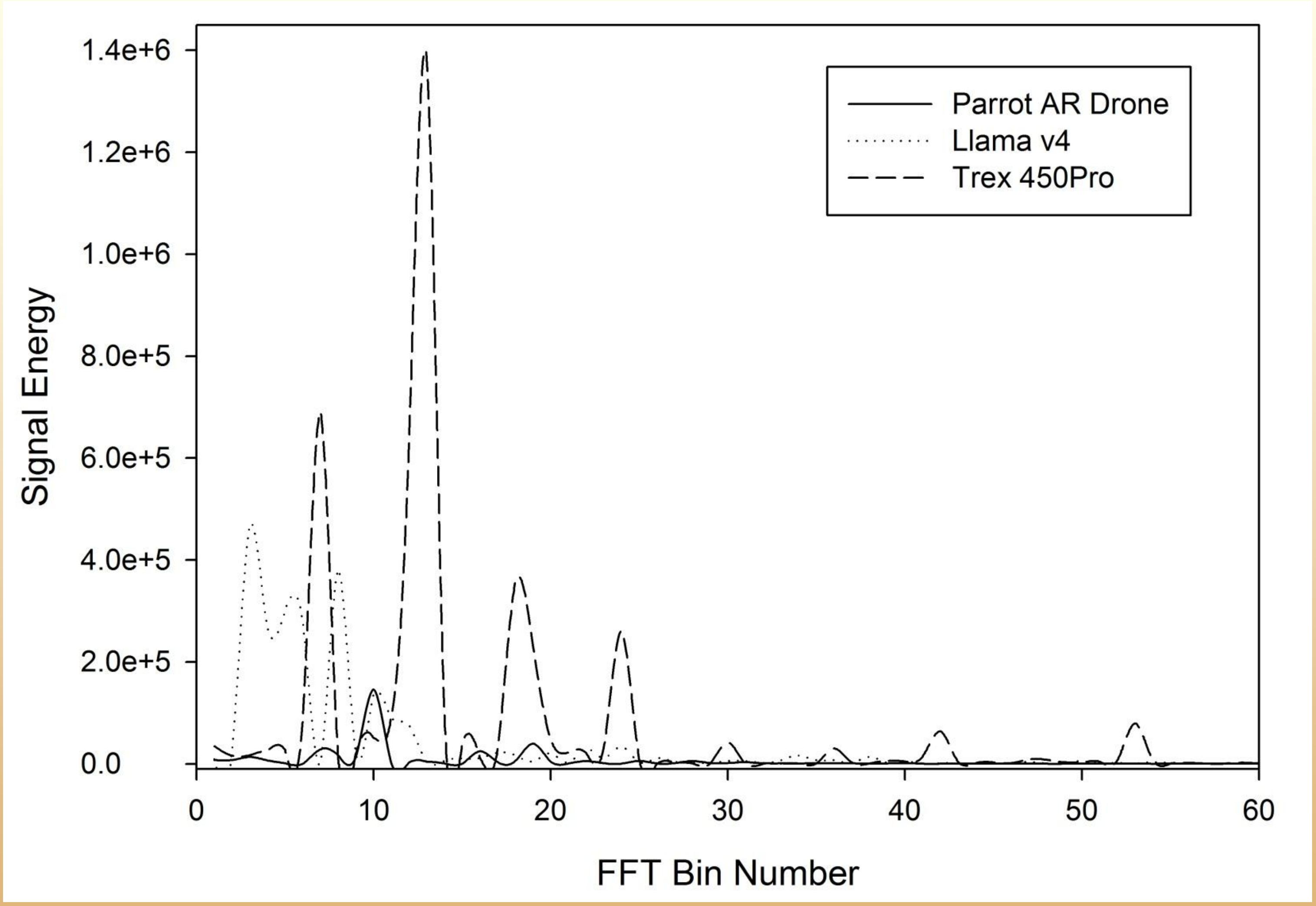
Technical Details: Rotorcraft Signatures



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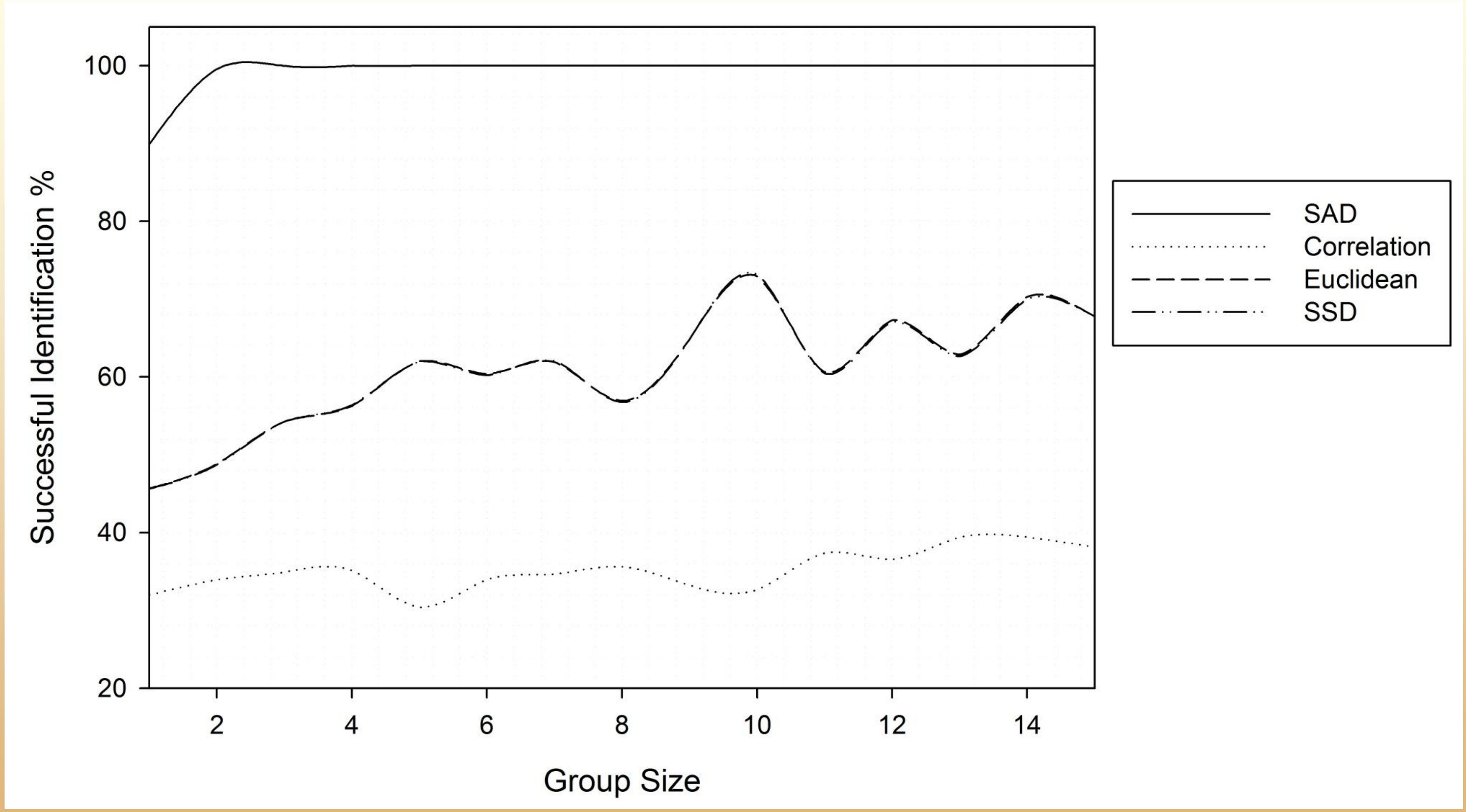
Processing Algorithms



Linear Discriminant Analysis (LDA)

- **Collected a dataset of DFT vectors by:**
  - **Imaging 2 different frames (coaxial, quadrotor)**
  - **At full and half throttle**
  - **At a constant distance form the sensor**
  - **At angles of 0° ,90° ,180° and 270° with respect to the sensor**
- **The result was a dataset with 1439 samples.**
- **Using LDA we calculated a hyperplane (*A*) and a threshold (*B*) such that for any radar sample *x*:**
  - **If $Ax + B < 0$ then x is a quadrotor, otherwise it is a coaxial**

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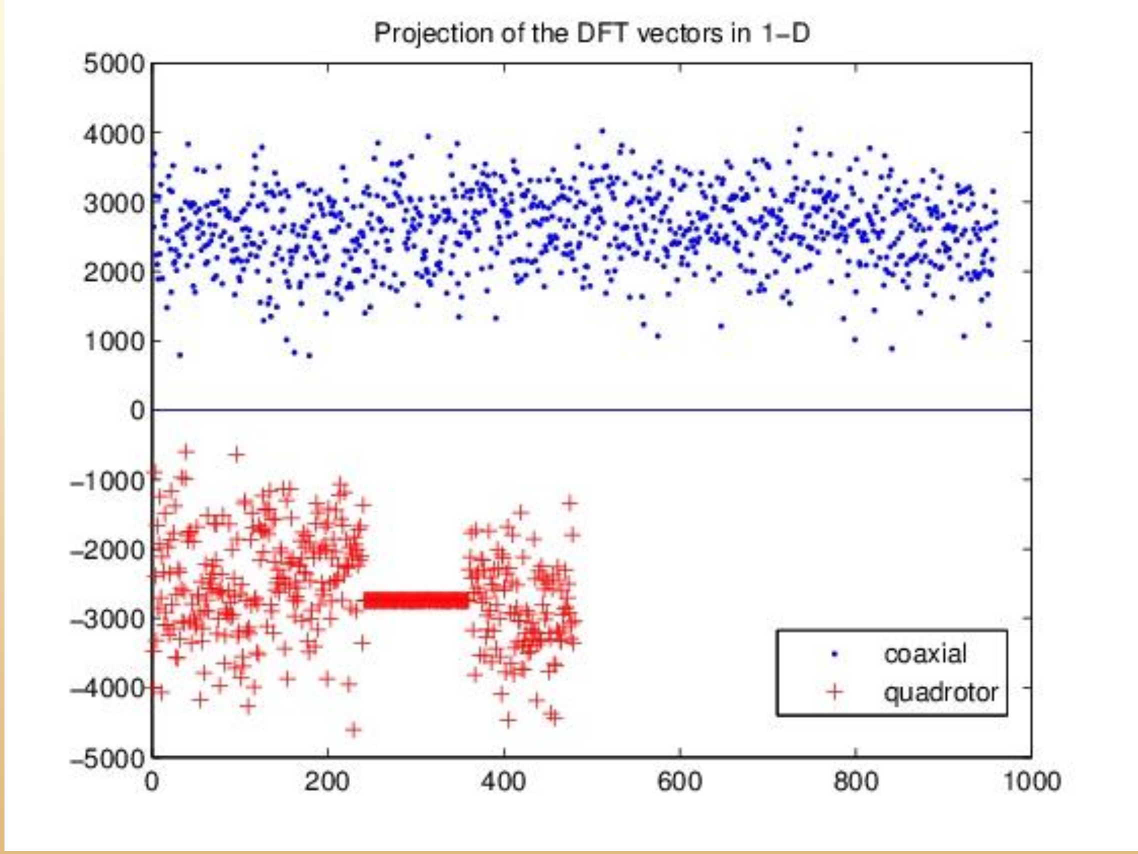
Linear Discriminant Analysis (LDA)



Samples belonging to the ‘coaxial’ class

Samples belonging to the ‘quadrotor’ class

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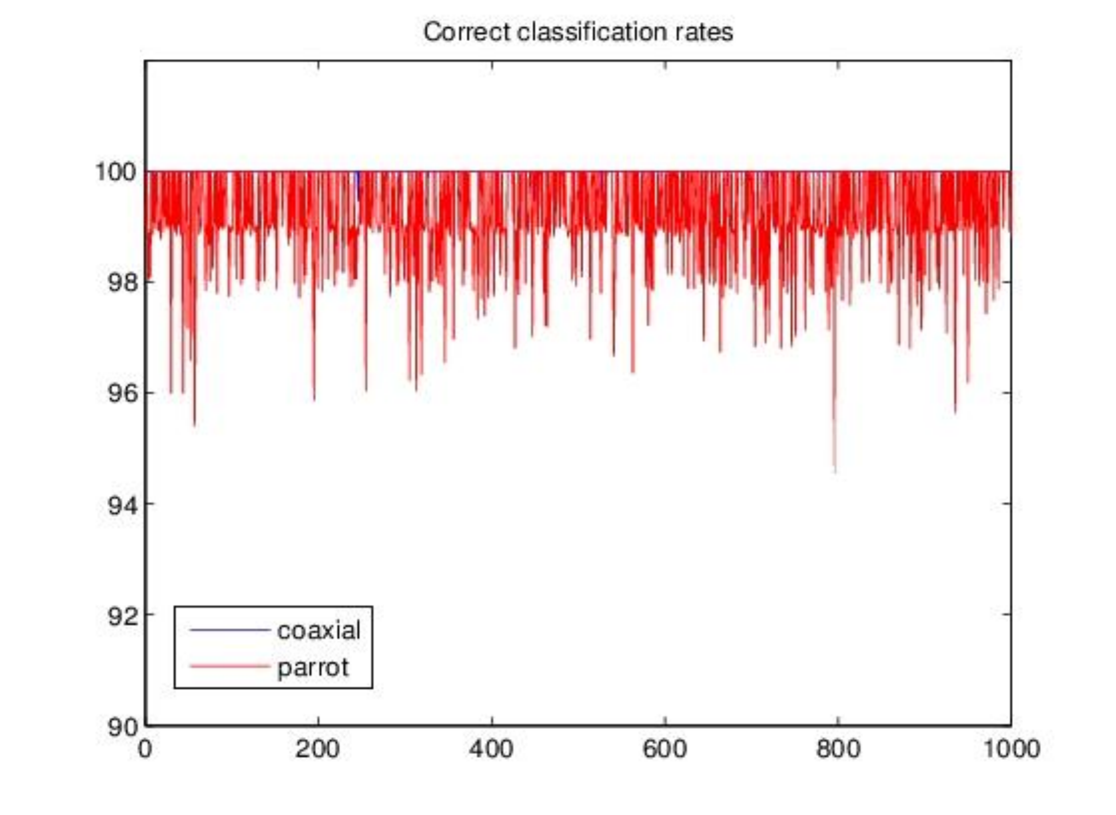
Linear Discriminant Analysis (Results)

- **Classification rates evaluated by randomly selecting 80% of the dataset as training and the remaining 20% as a testing.**
- **Repeating the process 1000 times yields:**



- **Average correct classification rates**
- **Coaxial → 99.99%**
- **Quadrotor→99.23%**

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Applications: Manned Aircraft Evasion

UAV	Evasion Region	Detection Region	Safety Region	Other Air Traffic

- **Evasion scenario divided into range “shells”**
  - **Evasion – Determined by opposing aircraft dimensions and UAV’s acceleration**
  - **Detection Region – Determined by target RCS**
  - **Safety region – ”N” multiple of the combined Evasion and Detection Regions**
- **All regions affected by the combined vehicle velocities.**

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Uniqueness

- **Other devices address larger vehicles, therefore the large acquisition costs and export restrictions hinder widespread implementation**
- **Furthermore, commercially available, miniature airborne radar systems do NOT address the air to air collision scenario. There are, however, systems for the following:**
    - **SAR Mapping**
    - **Radar Altimetry**
- **Our system is capable of addressing the above scenarios IN ADDITION to air-air collision mitigation**

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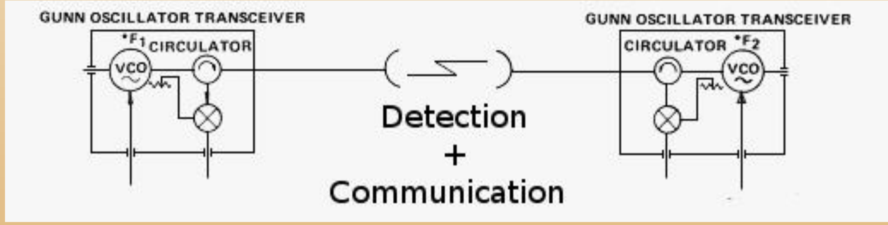
What can we do with this?

- **Detection of air traffic will enable**
  - **Cooperative UAV behaviors**
  - **Non-cooperative Air Traffic Collision avoidance**
- **Additional system benefits (independent of the sense and avoid mission)**
  - **Faster data communication**
  - **Signals intelligence:**



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Future Work

- **Improve antenna design**
  - **Variable directionality**
  - **Beam steering**
  - **Target tracking**
    - **Refined target evasion techniques**
- **Outdoor range testing**
  - **Improves power requirement estimates**
- **Development of target library (both manned and unmanned)**

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Questions ?

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Additional Technical Slides

Technical Details: Scattering Regions