



UNIVERSITY OF TRENTO

Autonomous VTOL for Avalanche Buried Searching Avionics

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Ingegneria Meccatronica Robotica

Outline

Introduction to Mountain Rescue

Design of a Digital ARTVA

Drone Avionics

Simulations

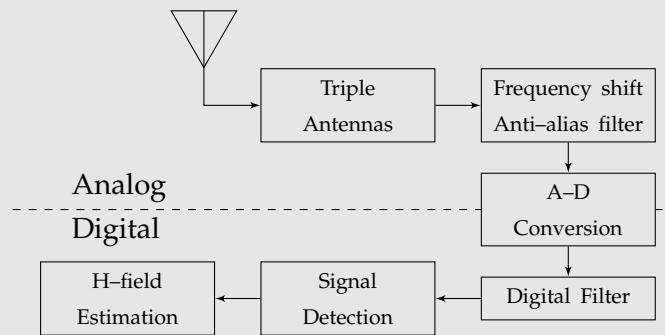
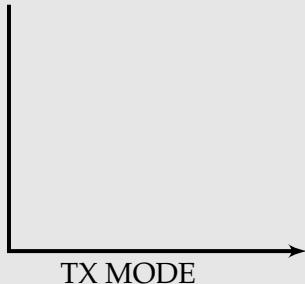
Mountain Rescue Intervention

- ▶ Call from witness or hikers in danger
- ▶ Helicopter mission
- ▶ **Evaluation of critical risk**
- ▶ Searching on avalanche surface
- ▶ Searching for ARTVA signal presence
- ▶ Fine ARTVA searching
- ▶ Buried extraction

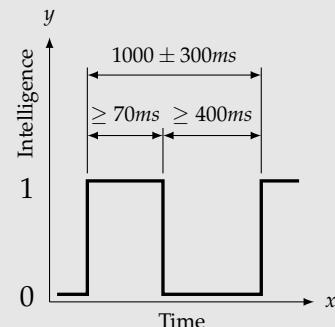
ARTVA Beacons Overview



RX MODE



- ▶ A1A Signal:
 - ▶ amplitude modulated digital signal
 - ▶ one carrier frequency: 457kHz
 - ▶ frequency error $\pm 80\text{Hz}$
- ▶ H-field peak at 10m
 - ▶ $\geq 0.5 \mu\text{A m}^{-1}$
 - ▶ $\leq 2.23 \mu\text{A m}^{-1}$



State of the Art

Projects

- ▶ SHERPA: Universitá di Bologna
- ▶ Universitá di Torino
- ▶ Project Alcedo Eidgenössische Technische Hochschule Zürich

Digital searching algorithms

- ▶ H-Field Lobe Following and pinpointing
- ▶ Fast identification with SLAM and sum of Gaussian

Maxwell Formulation

Application of potential vectors and recalibration map to Maxwell's eq.

$$\left\{ \begin{array}{l} \nabla \cdot \mathbf{B} = 0 \\ \nabla \times \mathbf{E} = -\frac{\partial}{\partial t} \mathbf{B} \\ \nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0} \\ \nabla \times \mathbf{B} = \mu_0 \left(\mathbf{J} + \epsilon_0 \frac{\partial}{\partial t} \mathbf{E} \right) \end{array} \right. \xrightarrow{\text{Recalibration Map}} \left\{ \begin{array}{l} \mathbf{B} = \nabla \times \mathbf{A} \\ \mathbf{E} = -\nabla \phi - \frac{\partial \mathbf{A}}{\partial t} \\ \mathbf{A}' \mapsto \mathbf{A} + \nabla \psi \\ \phi' \mapsto \phi - \frac{\partial \psi}{\partial t} \\ \nabla \cdot \mathbf{A}' = -\frac{1}{c^2} \frac{\partial^2 \psi'}{\partial t^2} \end{array} \right. \left\{ \begin{array}{l} \nabla^2 \phi - \frac{1}{c^2} \frac{\partial^2 \phi}{\partial t^2} = -\frac{\rho}{\epsilon_0} \\ \nabla^2 \mathbf{A} - \frac{1}{c^2} \frac{\partial^2 \mathbf{A}}{\partial t^2} = -\mu_0 \mathbf{J} \end{array} \right.$$

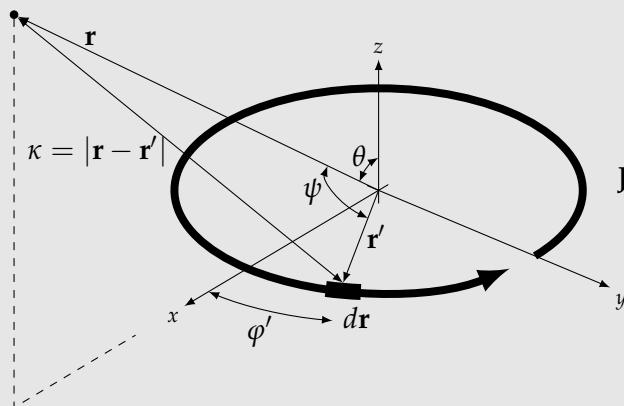
Application to our problem: integral formulation

$$\begin{aligned} \phi(\mathbf{r}, t) &= \frac{1}{4\pi\epsilon_0} \int_{\Omega} \frac{1}{|\mathbf{r} - \mathbf{r}'|} \rho \left(\mathbf{r}', t - \frac{|\mathbf{r} - \mathbf{r}'|}{c} \right) d\mathbf{r}' \\ \mathbf{A}(\mathbf{r}, t) &= \frac{\mu_0}{4\pi} \int_{\Omega} \frac{1}{|\mathbf{r} - \mathbf{r}'|} \mathbf{J} \left(\mathbf{r}', t - \frac{|\mathbf{r} - \mathbf{r}'|}{c} \right) d\mathbf{r}' \end{aligned}$$

Magnetic dipole problem

For a **magnetic dipole** problem: $\phi = 0!$

Solution for boundary condition problem



$$\mathbf{A} = \frac{\mu_0 m_0}{4\pi r} \sin(\theta) \left(\frac{1}{r} \sin(\omega_0(t - r/c)) - \right. \\ \left. + \frac{\omega_0}{r} \cos(\omega_0(t - r/c)) \right) \hat{\phi}$$

Under the hypothesis: $r' \ll r$ and $r' \ll \lambda$

B-Field solution

$$\tau = t - \frac{r}{c}$$

$$B_r = \frac{\mu_0 m_0}{2\pi r^2} \cos(\theta) \left(\frac{1}{r} \cos(\omega_0 \tau) - \frac{\omega_0}{c} \sin(\omega_0 \tau) \right)$$

$$B_r = \frac{\mu_0 m_0}{4\pi r^3 c} \sin(\theta) ((c^2 - \omega_0^2 r^2) \cos(\omega_0 \tau) - \omega_0 r c \sin(\omega_0 \tau))$$

H-Field in Transmission

Field Complexity

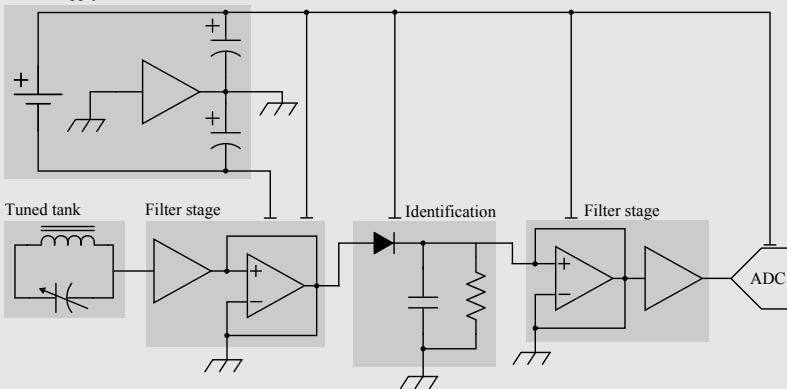
Simplified Equations for H-field

$$\mathbf{B}(\mathbf{r}, \mathbf{m}) = \frac{\mu_0}{4\pi r^5} \begin{bmatrix} 2x^2 - y^2 - z^2 & 3xy & 3xz \\ 3xy & 2y^2 - x^2 - z^2 & 3yz \\ 3xz & 3yz & 2z^2 - x^2 - y^2 \end{bmatrix}$$

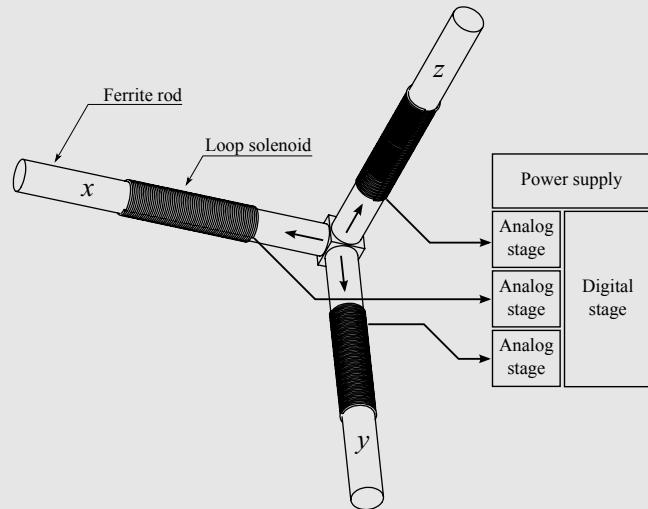
Design of a Digital ARTVA

General Overview

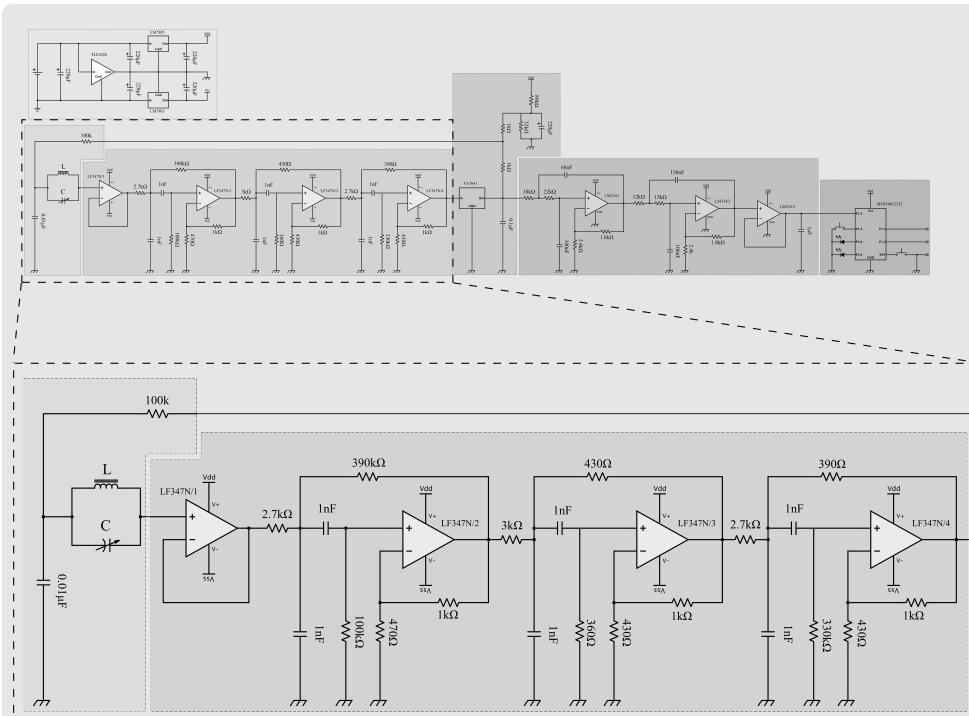
Power supply



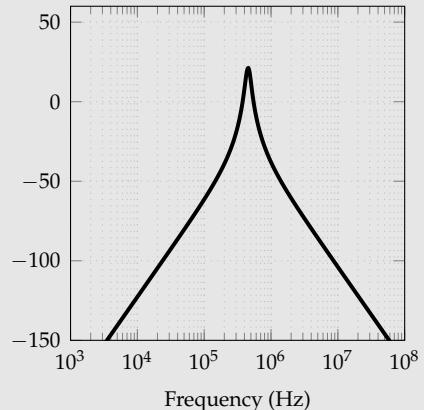
Triple antennas



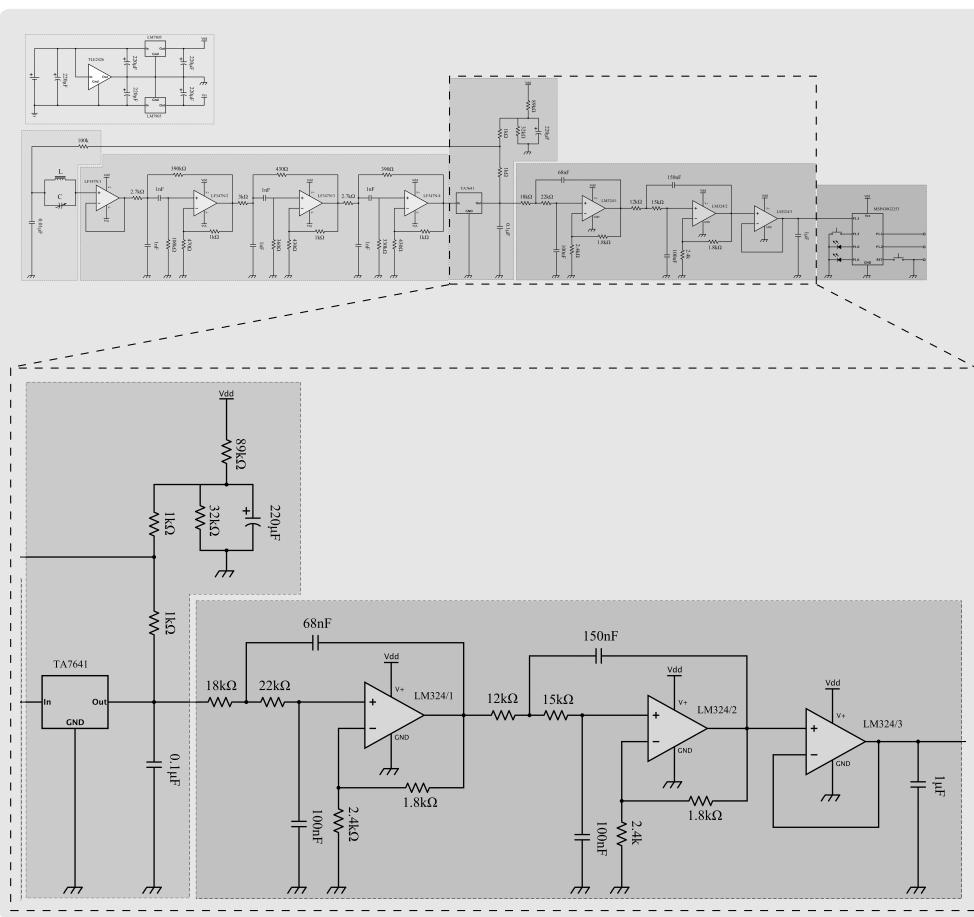
Schematics – Antenna and PreAmplifier



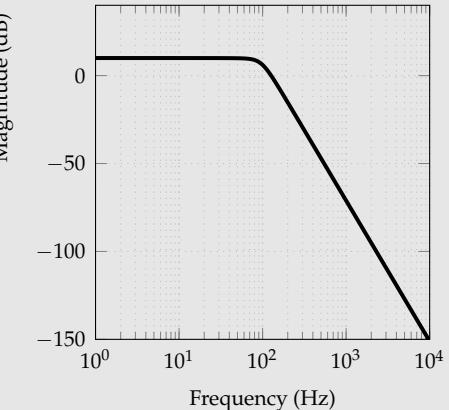
PreAmplifier Characteristic



Schematics – Identification and Amplifier

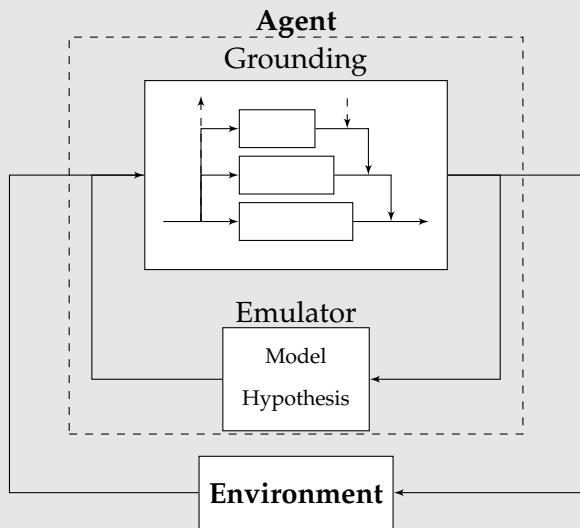


Amplifier Characteristic

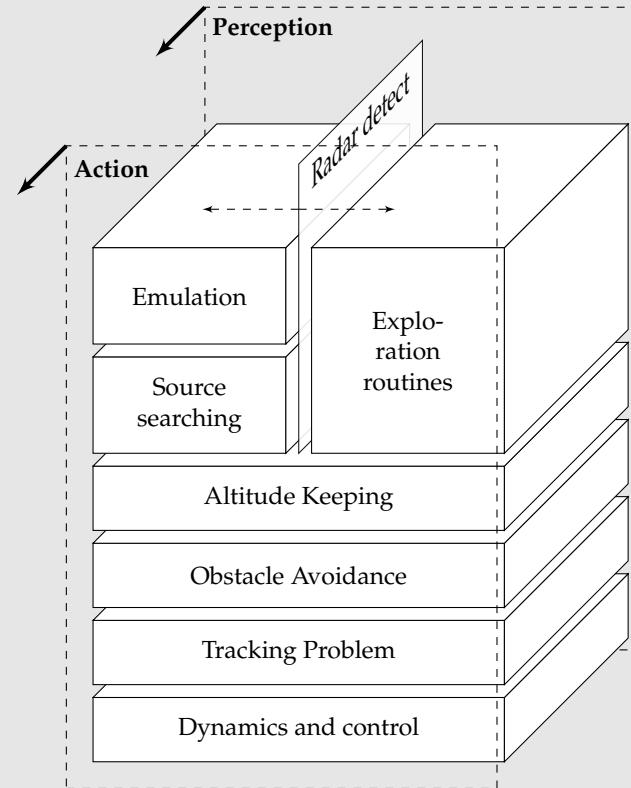


Perception–Action Map

Litterature overview...

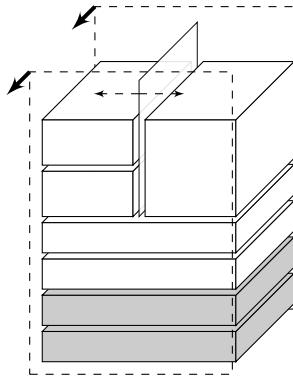


... applied to our agent

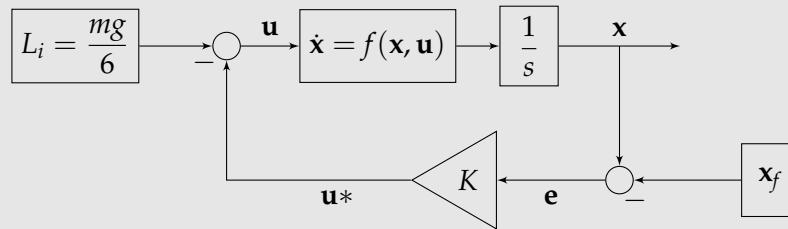


- ▶ Subsumption and grounding
- ▶ Emulation

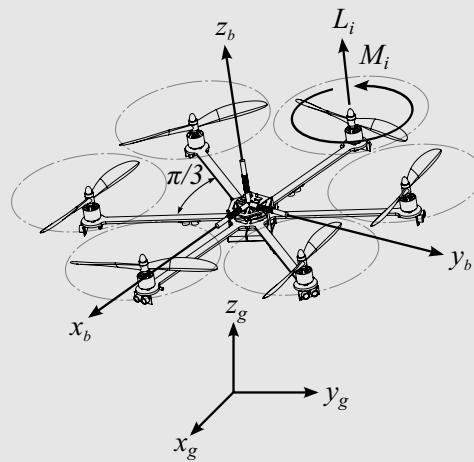
Dynamics, control and tracking



LQR Control



Newton–Euler Equations

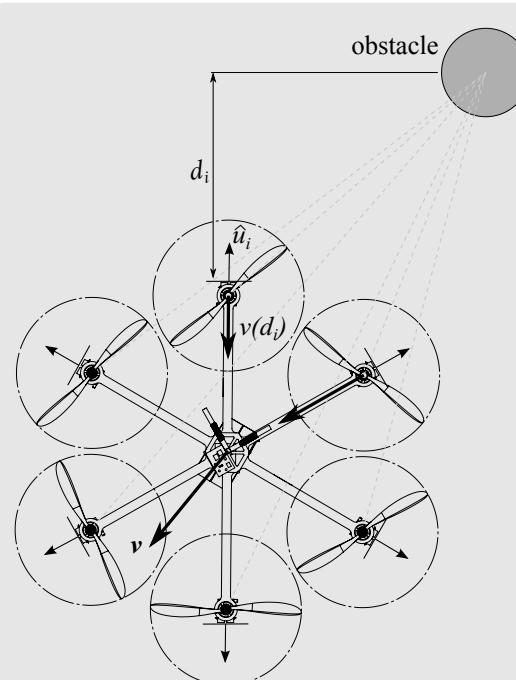
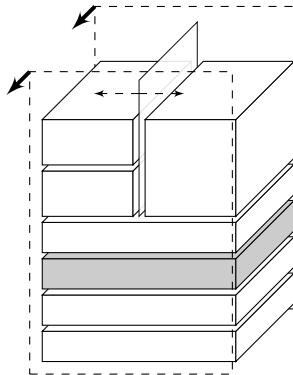


$$\mathbf{x} = [x, y, z, \phi, \theta, \psi, u, v, w, p, q, r]^T$$

$$\mathbf{u} = [L_i : i = 1..6]$$

$$\dot{\mathbf{x}} = f(\mathbf{x}, \mathbf{u})$$

Obstacle Avoidance



$$\mathbf{v} = \mathcal{R}(\phi, \psi, \theta) \sum_{i=1}^6 v(d_i) \begin{bmatrix} \cos((i-1)\frac{\pi}{3}) \\ -\sin((i-1)\frac{\pi}{3}) \\ 0 \end{bmatrix}$$

► Advantages

- low computation needed
- minor constraint on upper layers
- fit QFD constraints

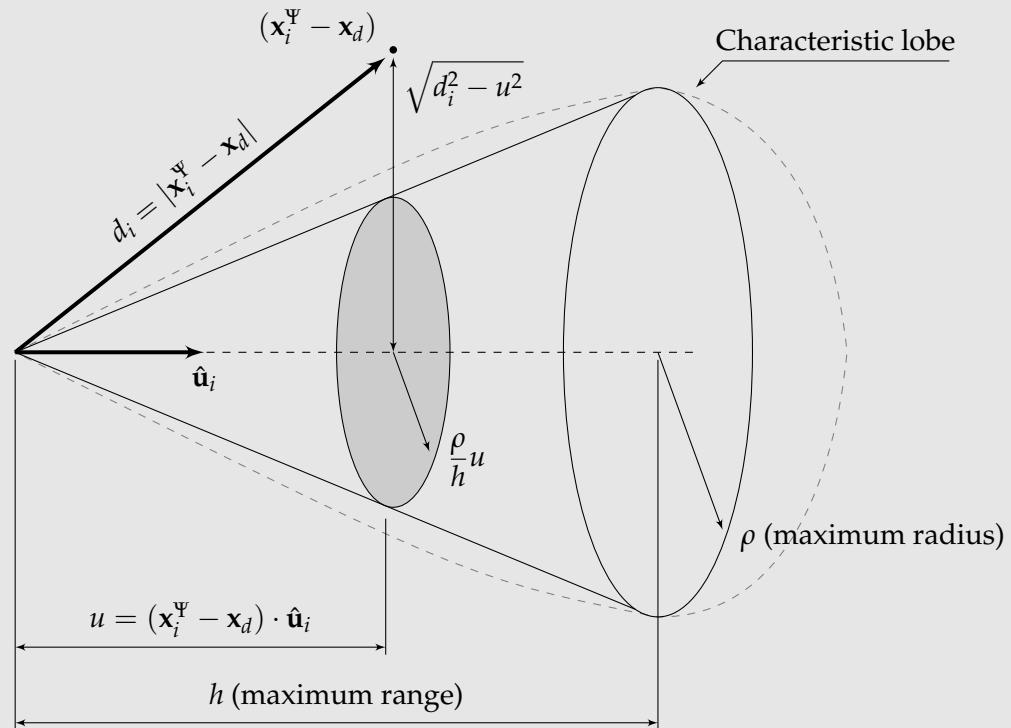
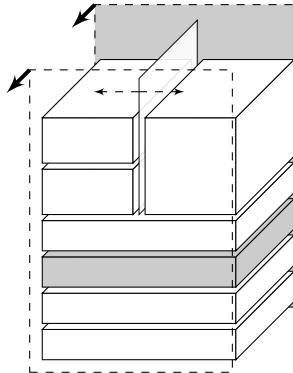
► Drawbacks

- non-optimal paths
- limited reliability

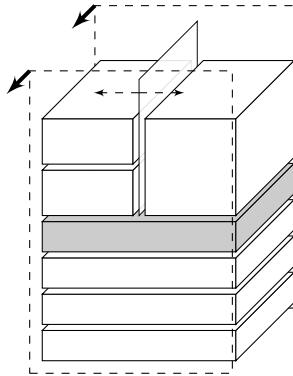
Speed function example:

$$v(d_i) = p_3 \left(\frac{1}{1 + e^{4\left(\frac{p_1}{2} - d_i\right)\frac{p_2}{p_3}}} - 1 \right)$$

Simulating a Range Finder

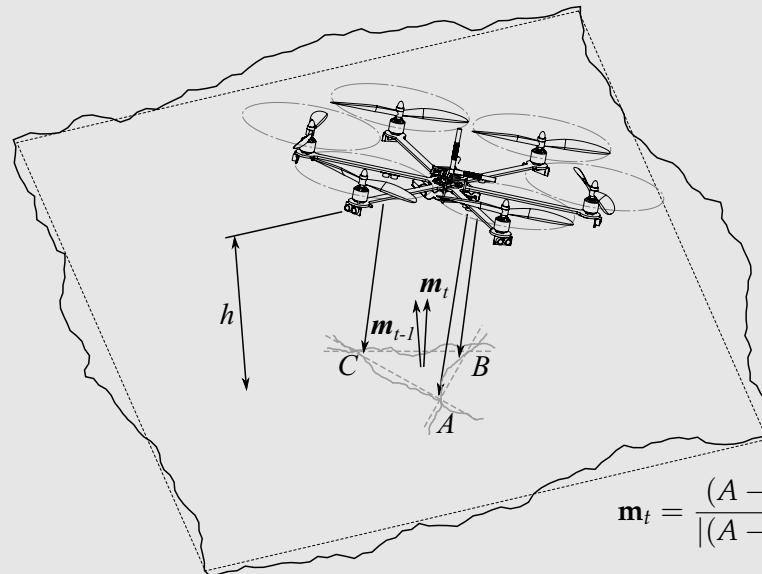


Altitude Keeping



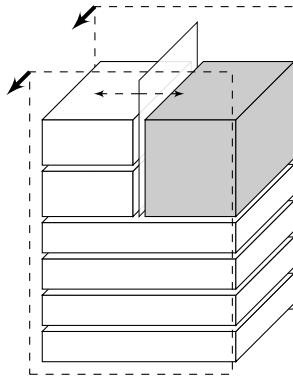
Identification of the surface normal \mathbf{m} \rightarrow S.L.A.M. Problem

$$\begin{bmatrix} \mathbf{x} \\ \mathbf{m} \end{bmatrix}$$

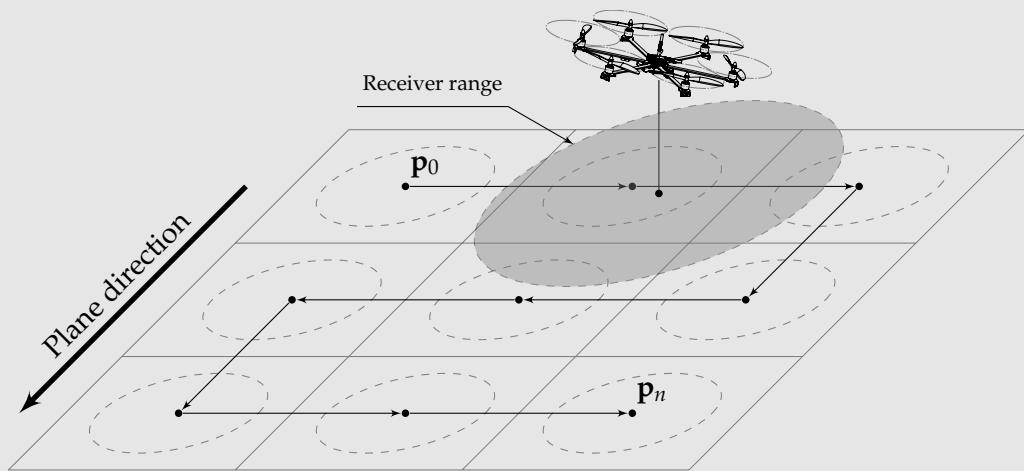


Keep the VTOL at constant distance h along estimated plane normal \mathbf{m}_t

Exploring and Searching Signal Presence

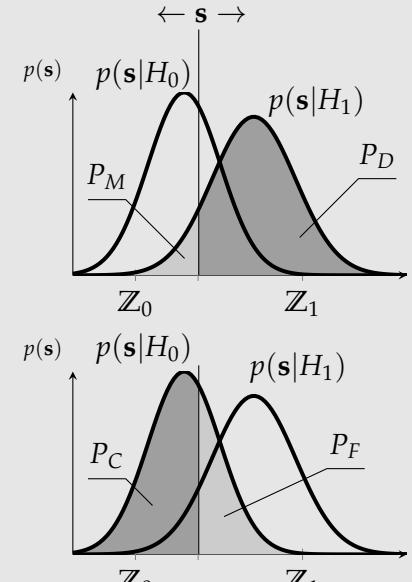
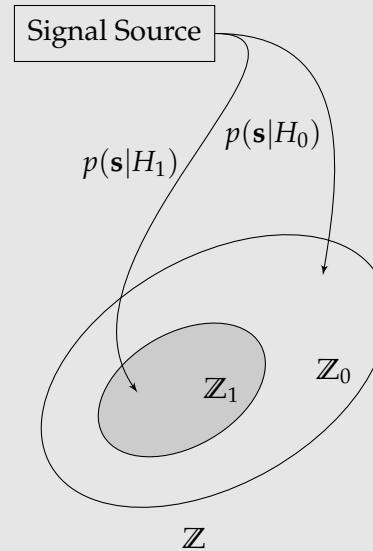
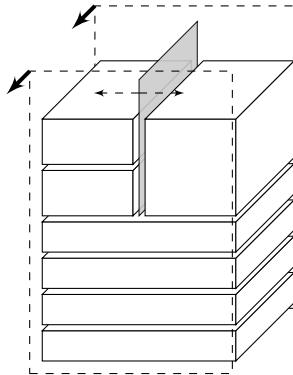


Explore the surface, starting from point p_0 , to the point p_n



We need a strategy to understand if **there is a signal**

Radar Detection Problem for Signal Presence



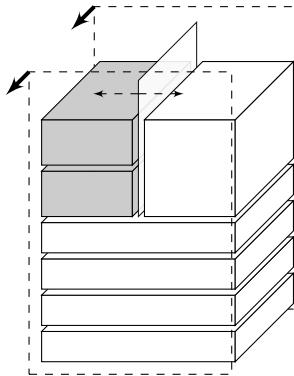
Minimize the risk incurred due to **erroneous decisions**

$$\min R = R(c_{ij}, P_X) \quad \rightarrow$$

$$\mathbb{Z}_0 = \{\mathbf{s} \in \mathbb{Z} : \Delta(\mathbf{s}) < \eta\}$$

$$\mathbb{Z}_1 = \{\mathbf{s} \in \mathbb{Z} : \Delta(\mathbf{s}) > \eta\}$$

Pinpointing Signal Source



Searching the Maximum H-field

Data: $|\mathbf{H}|_{k-1}, \psi_{k-1}, \mathbf{v}_{k-1}, w_1, w_2, \Delta, \delta$

```

/* Steer in direction of greater intensity */
if  $\left( \frac{|\mathbf{H}|_k}{|\mathbf{H}|_{k-1}} - 1 \right) \leq \Delta$  then
     $\psi_k = (1 - w_1)\psi_{k-1} + w_1\delta;$ 
else if  $\left( \frac{|\mathbf{H}|_k}{|\mathbf{H}|_{k-1}} - 1 \right) \geq \Delta$  then
     $\psi_k = (1 - w_1)\psi_{k-1} - w_1\delta;$ 
/* Set speed magnitude
 $|\mathbf{v}_k| = (1 - w_2)|\mathbf{v}_{k-1}| + w_2v(|\mathbf{H}_k|);$ 
/* Steer in direction of flux lines
 $\cos(\psi)_k = (1 - w_1)\cos(\theta) + w_1\cos(\psi)_{k-1};$ 
 $\sin(\psi)_k = (1 - w_1)\sin(\theta) + w_1\sin(\psi)_{k-1};$ 
/* Defines speed
 $\mathbf{v}_k = [|\mathbf{v}_k| \cos(\psi)_k, |\mathbf{v}_k| \sin(\psi)_k, 0];$ 
return  $\mathbf{v}_k$ 

```

Emulation of an H-field

The estimated position is given by the solution of the **optimization problem**:

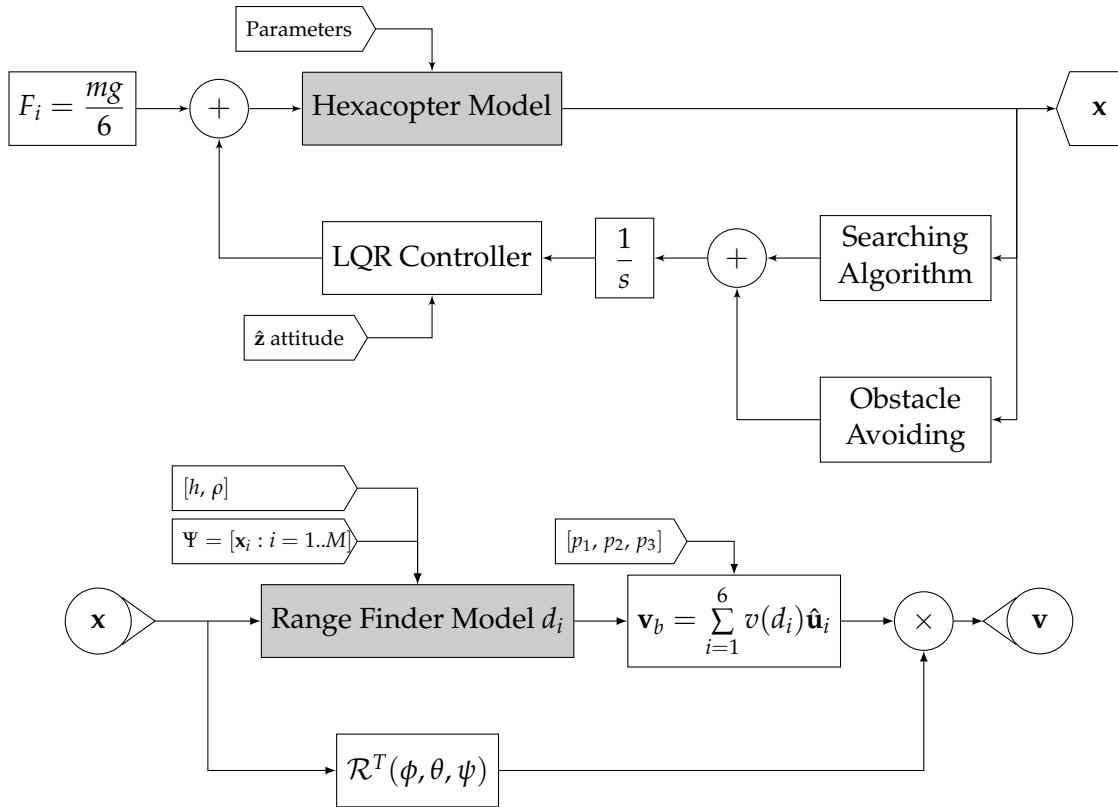
$$\begin{cases} \min \delta = (\hat{\mathbf{H}} - \mathbf{H}(\mathbf{p}_t, \mathbf{m}, \mathbf{x}))^2 \\ (\mathbf{p}_T - \mathbf{x})^2 \leq r_{\max} \end{cases}$$

and treated as a **stochastic variable**

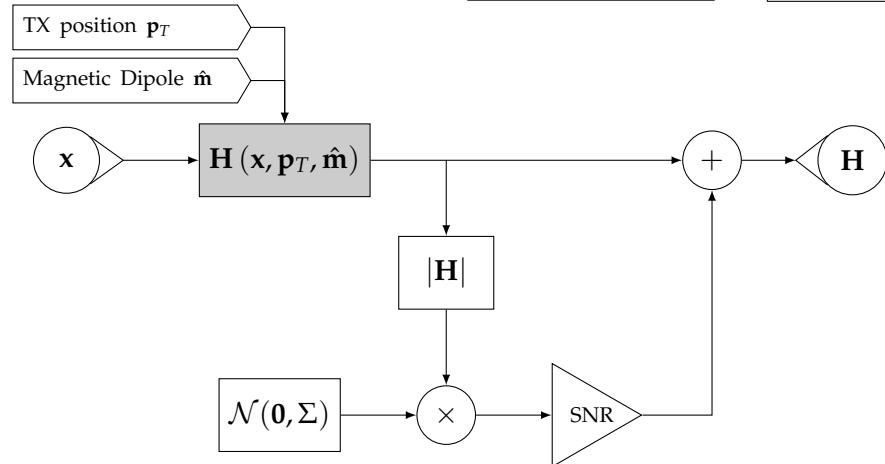
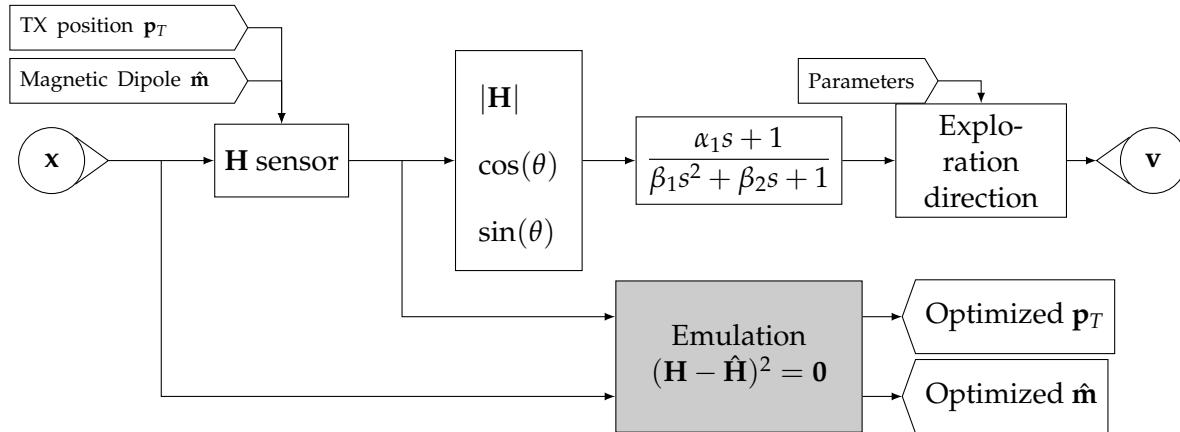
$$\hat{p}(\mathbf{p}) = \frac{1}{N} \sum_{k=1}^N \frac{\gamma(\mathbf{p} - \mathbf{p}_k, h)}{V(h)}$$

from $\hat{p}(\mathbf{p})$ we extract **mean** and **covariance**!

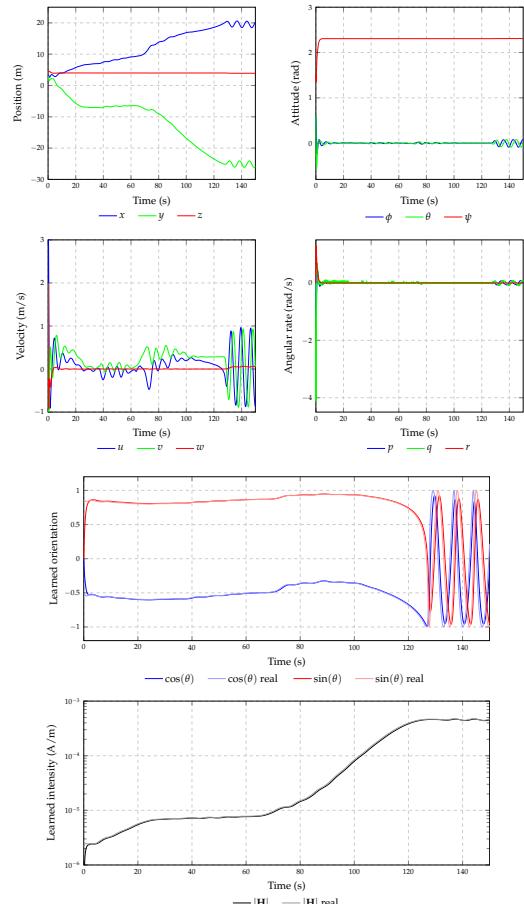
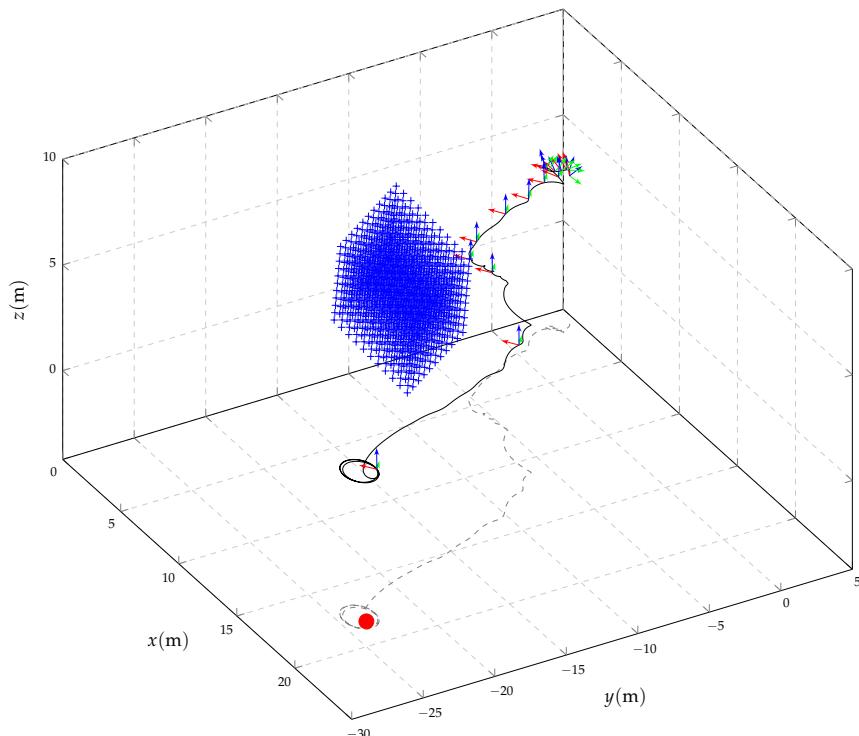
Simulink Implementations (1)



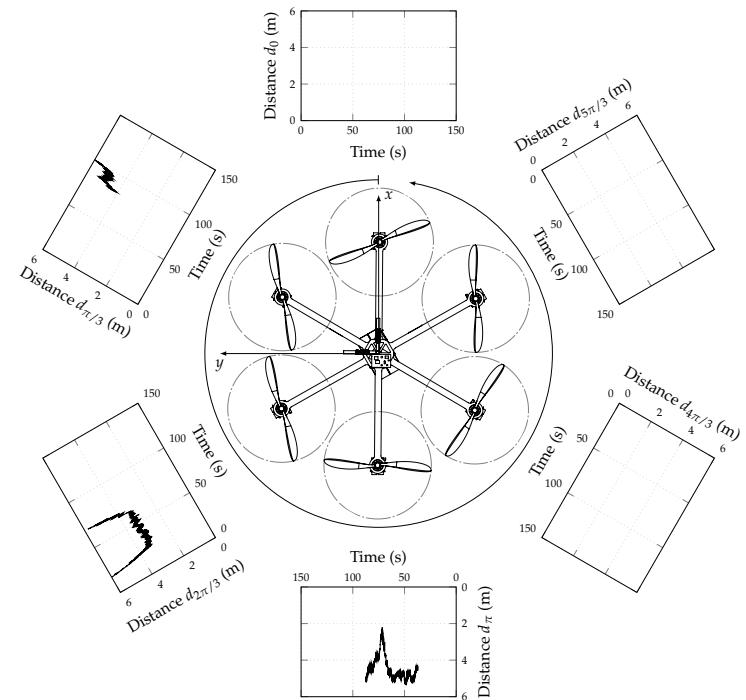
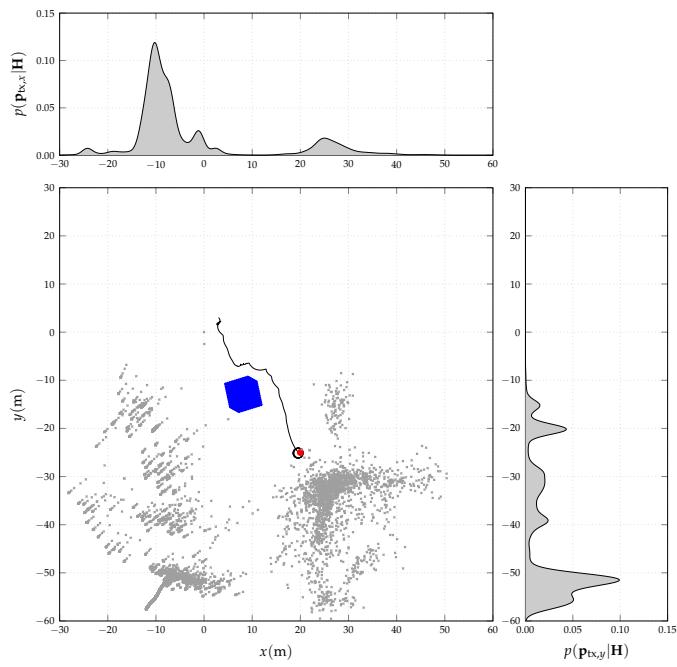
Simulink Implementations (2)



Simulation Results (1)



Simulation Results (2)



Questions?