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

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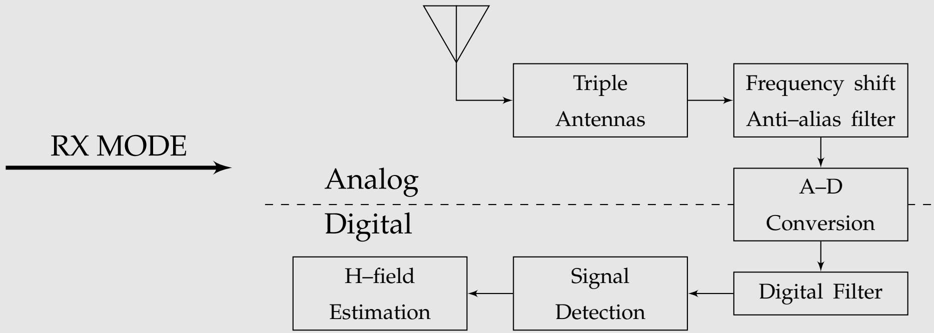
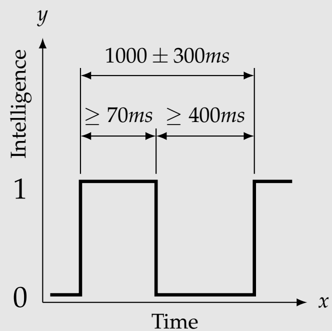
ARTVA Beacons Overview



TX MODE

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



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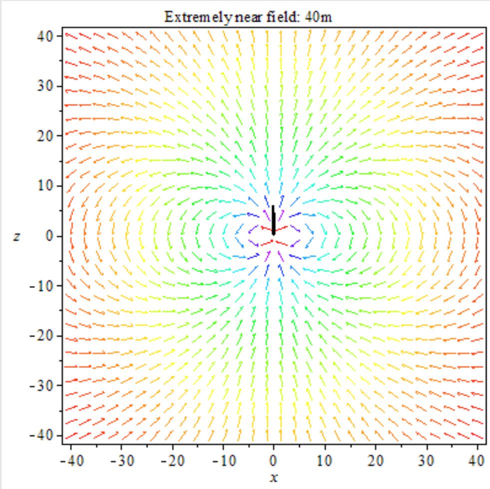
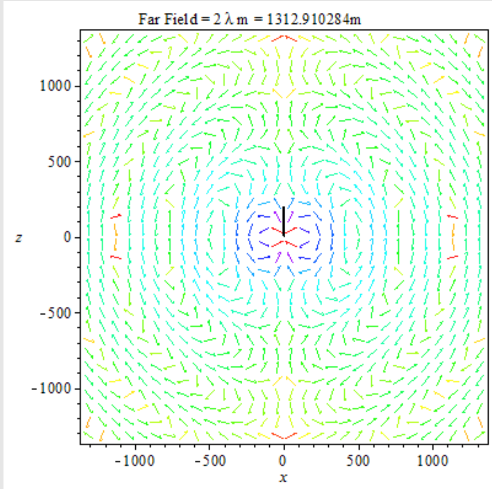
H–Field in Transmission

Field Complexity



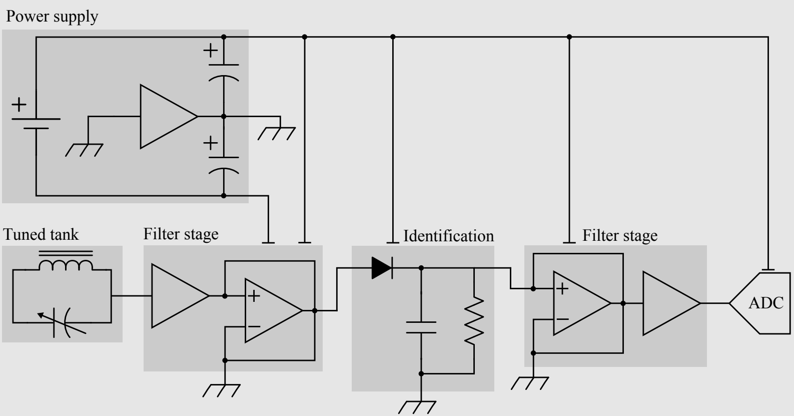


Simplified Equations for H–field

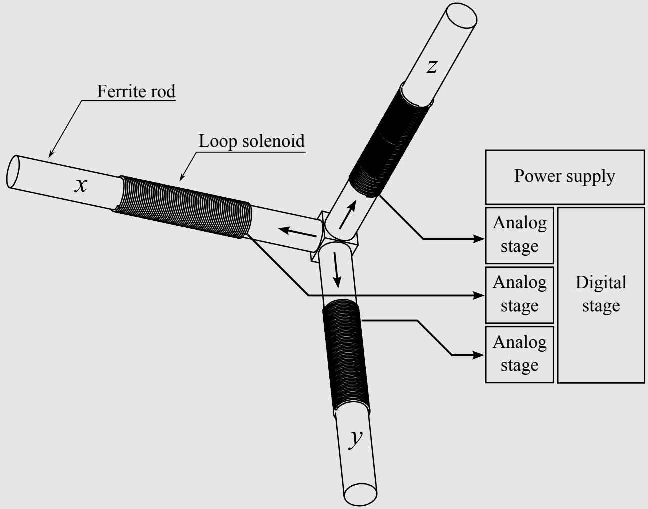
$$\mathbf{B}(\mathbf{r},\mathbf{m}) = \frac{\mu_0}{4\pi r^5}\begin{bmatrix} 2x^2-y^2-z^2 & 3xy & 3xz \\ 3xy & 2y^2-x^2-z^2 & 3yz \\ 3xz & 3yz & 2z^2-x^2-y^2 \end{bmatrix}$$

Design of a Digital ARTVA

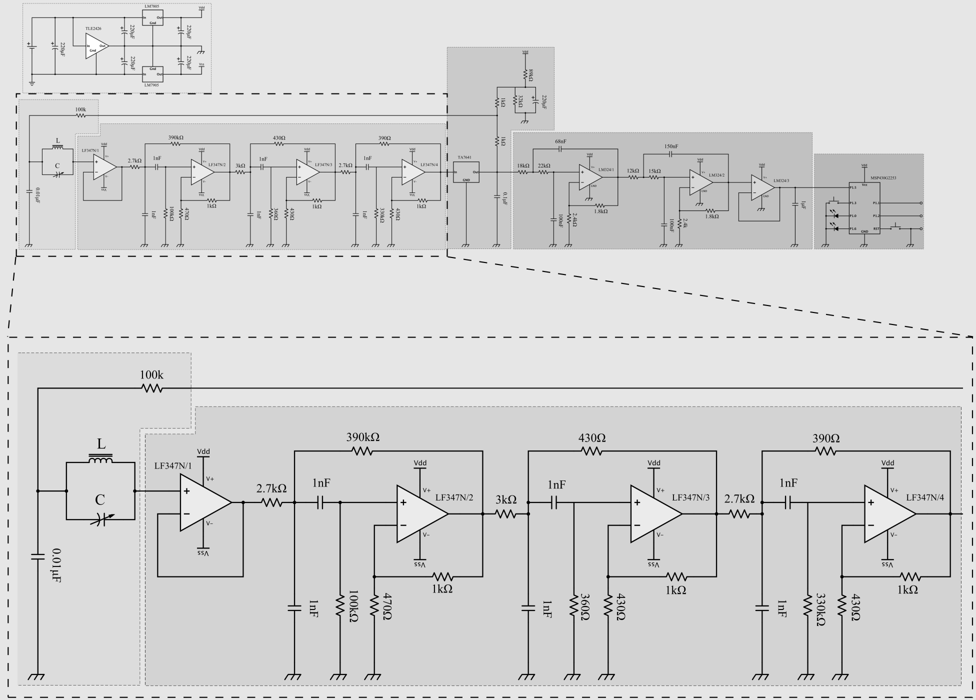
General Overview



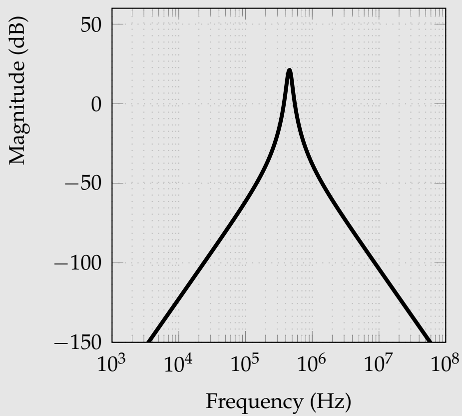
Triple antennas



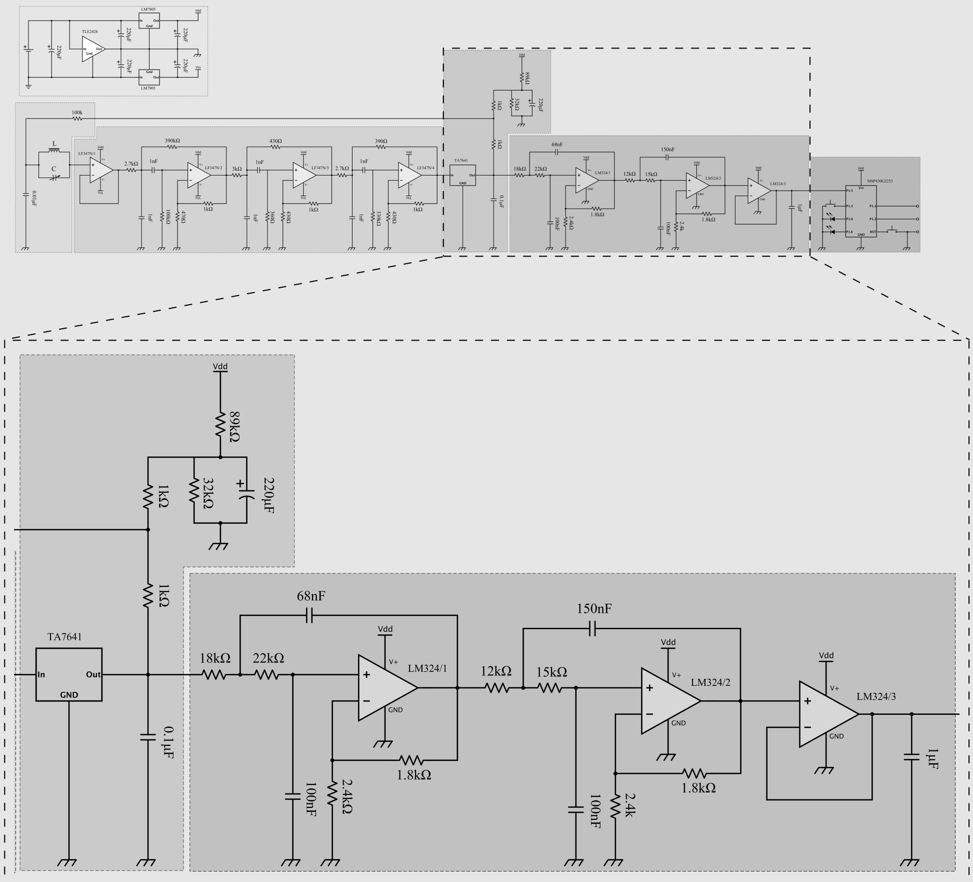
Schematics – Antenna and PreAmplifier



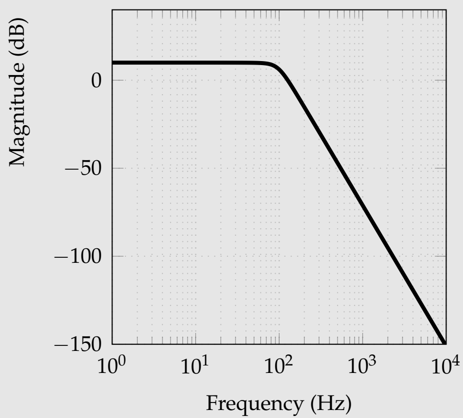
PreAmplifier Characteristic



Schematics – Identification and Amplifier



Amplifier Characteristic



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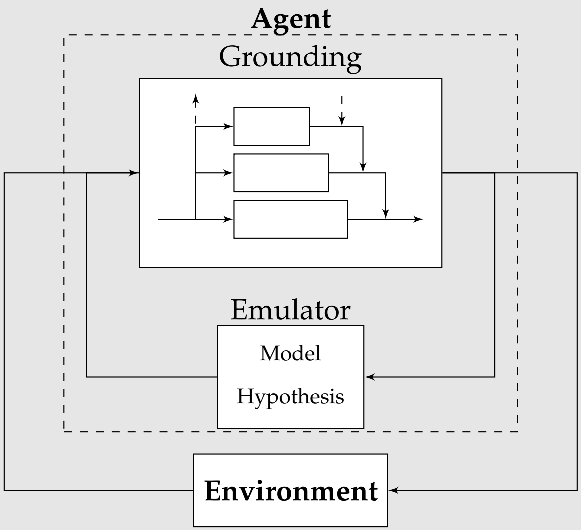
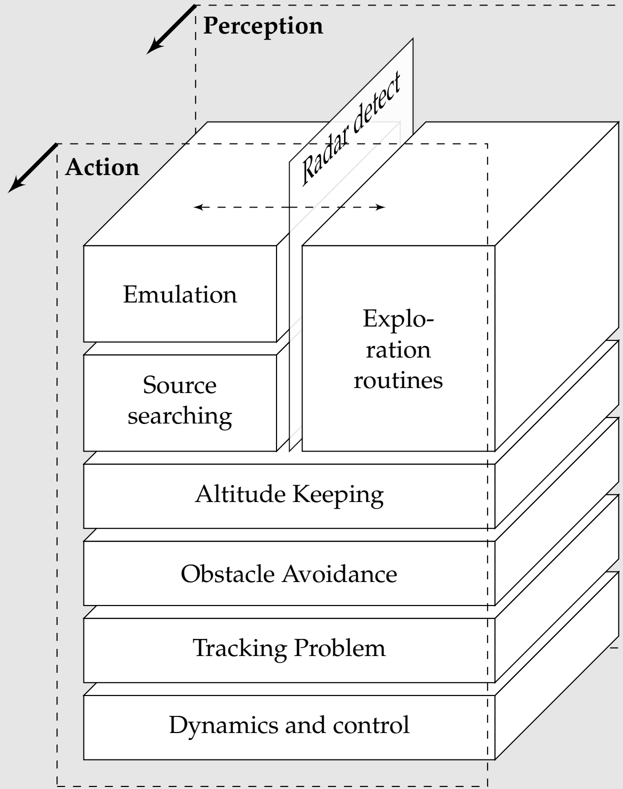
Perception–Action Map

Litterature overview...

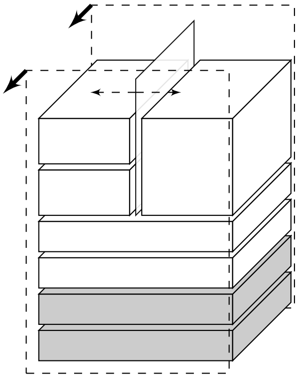


- Subsumption and grounding
- Emulation

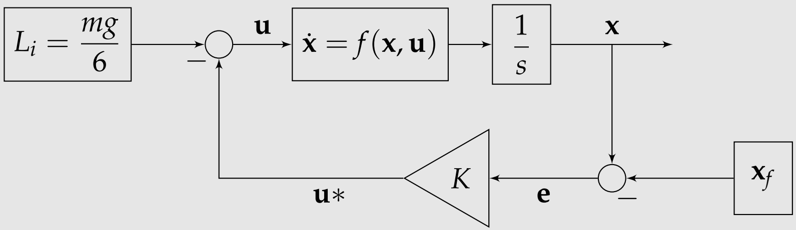
... applied to our agent



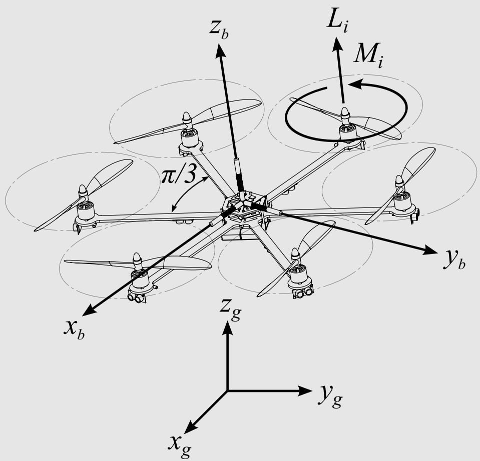
Dynamics, control and tracking



LQR Control

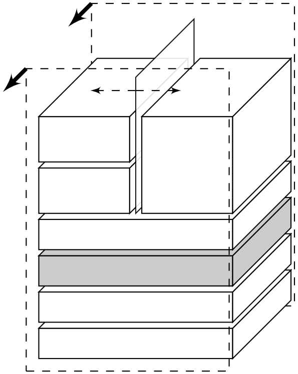


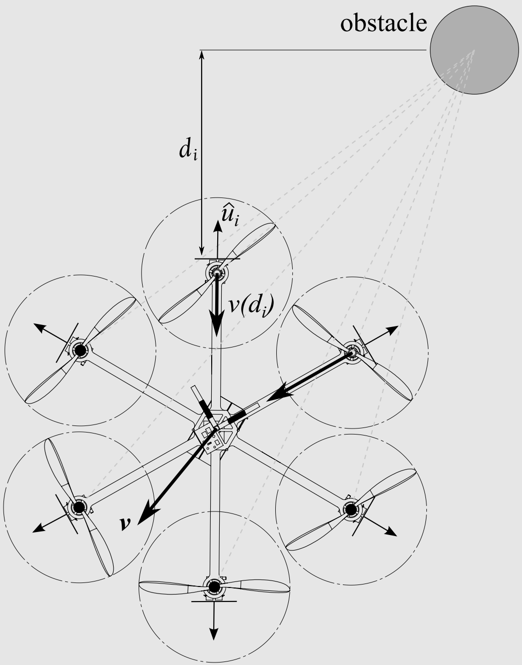
Newton–Euler Equations



$$
\begin{aligned}
\mathbf{x} &= [x, y, z, \phi, \theta, \psi, u, v, w, p, q, r]^T \\
\mathbf{u} &= [L_i : i = 1..6] \\
\dot{\mathbf{x}} &= f(\mathbf{x}, \mathbf{u})
\end{aligned}
$$

Obstacle Avoidance





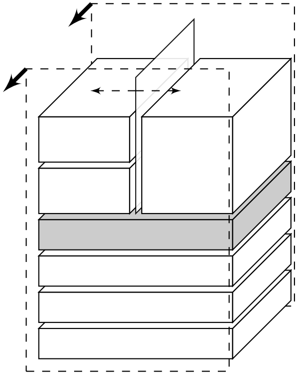
$$\mathbf{v} = \mathcal{R}(\phi,\psi,\theta)\sum_{i=1}^{6} v(d_i)\begin{bmatrix}\cos\left((i-1)\frac{\pi}{3}\right)\\ -\sin\left((i-1)\frac{\pi}{3}\right)\\ 0\end{bmatrix}$$

- Advantages
  - low computation needed
  - minor constraint on upper layers
  - fit QFD constraints
- Drawbacks
  - non–optimal paths
  - limited reliability

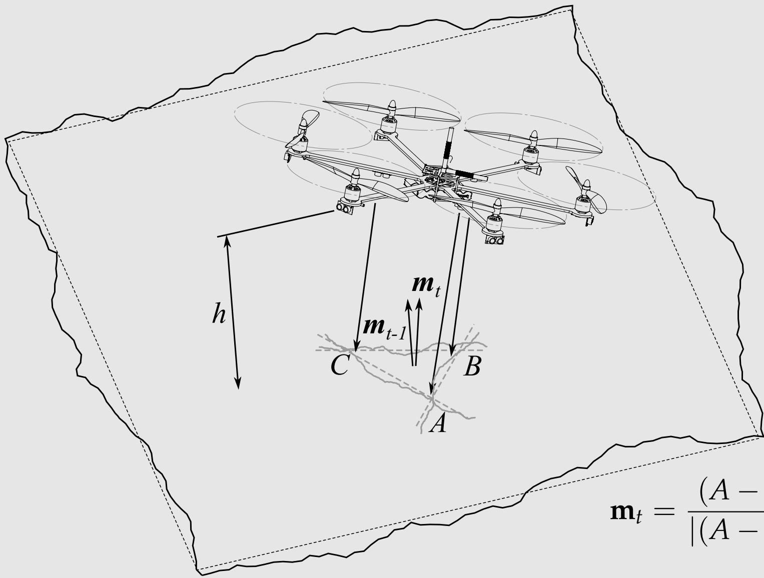
Speed function example:

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

Altitude Keeping



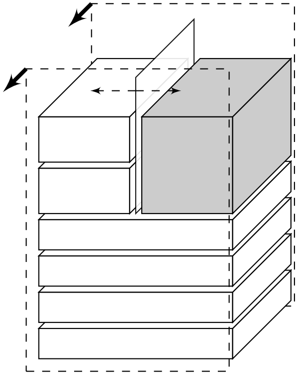
Identification of the surface normal $\mathbf{m} \longrightarrow$ S.L.A.M. Problem $\begin{bmatrix} \mathbf{x} \\ \mathbf{m} \end{bmatrix}$



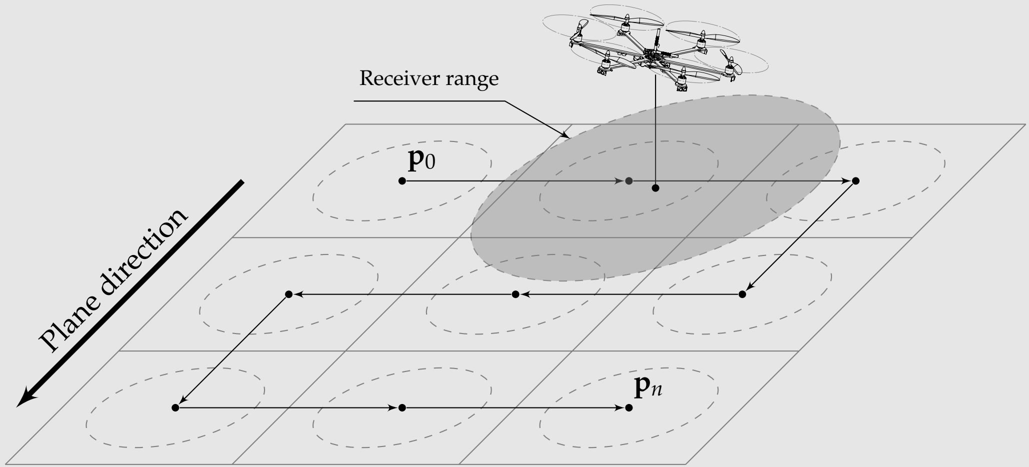
$$\mathbf{m}_t = \frac{(A - B) \times (B - C)}{|(A - B) \times (B - C)|}$$

Keep the VTOL at costant distance h along exstimated plane normal $\mathbf{m}_t$

Exploring and Searching Signal Presence

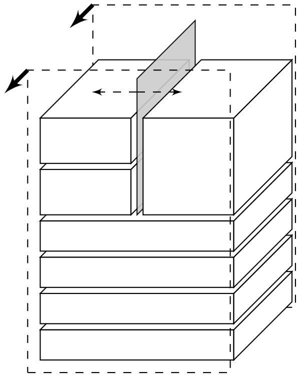


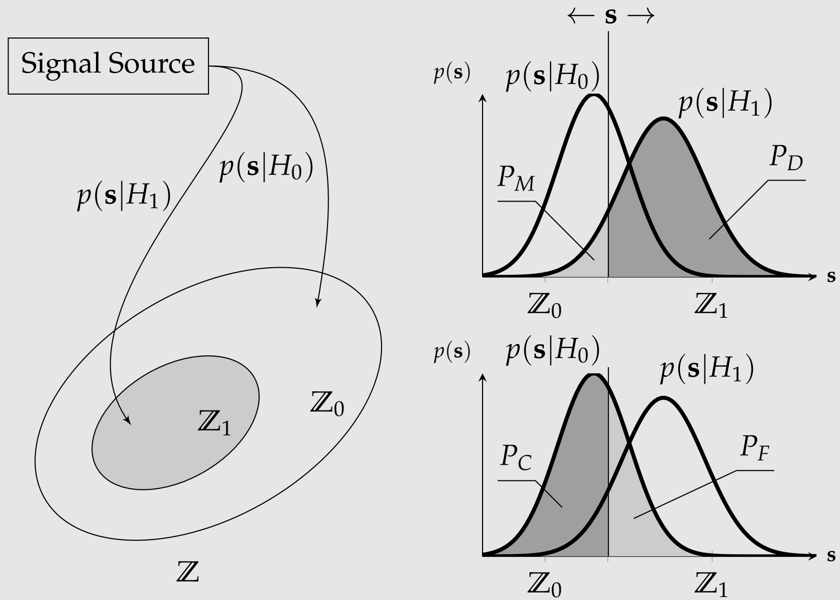
Explore the surface, starting from point $\mathbf{p}_0$, to the point $\mathbf{p}_n$



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

Radar Detection Problem for Signal Presence

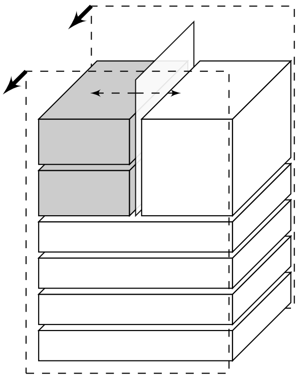




Minimize the risk incurred due to **erroneous decisions**

$$\min R = R(c_{i,j}, P_X) \quad \rightarrow \quad \begin{aligned} \mathbb{Z}_0 &= \{\mathbf{s} \in \mathbb{Z} : \Delta(\mathbf{s}) < \eta\} \\ \mathbb{Z}_1 &= \{\mathbf{s} \in \mathbb{Z} : \Delta(\mathbf{s}) > \eta\} \end{aligned}$$

Pinpointing Signal Source



Searching the Maximum H–field

Data: $|\mathbf{H}|_{k-1}$, ψ_{k-1}, $\mathbf{v}_{k-1}$, w_1, w_2, Δ, δ

```
/* 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 */
```

$|\mathbf{v}_k| = (1 - w_2)|\mathbf{v}_{k-1}| + w_2 v(|\mathbf{H}_k|);$

```
/* 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 stimated position is given by the solution of the **optimization problem**:

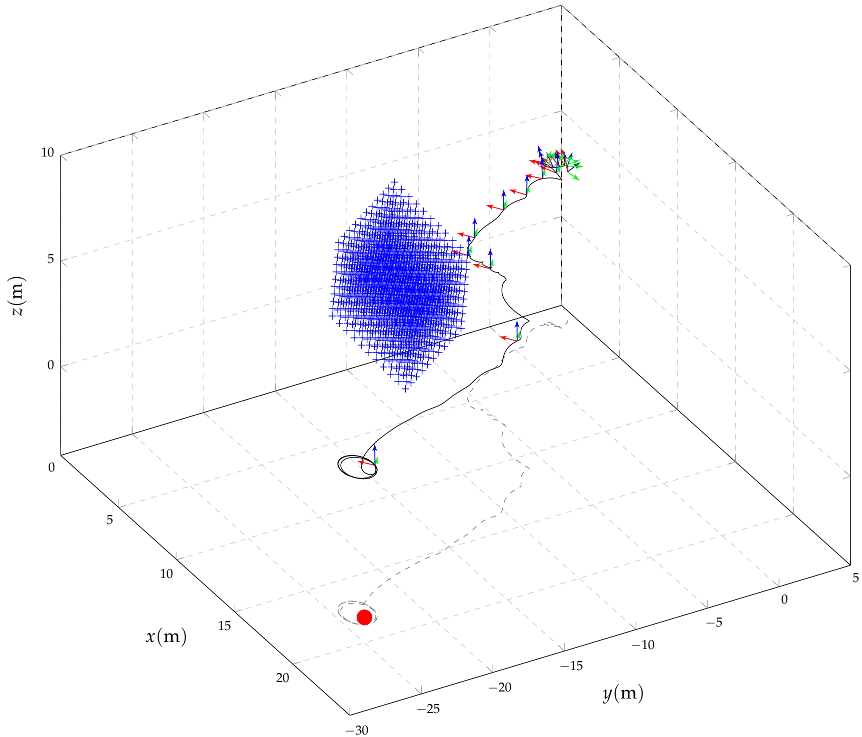
$$\begin{cases} \min \delta = \left(\hat{\mathbf{H}} - \mathbf{H}(\mathbf{p}_t, \mathbf{m}, \mathbf{x})\right)^2 \\ (\mathbf{p}_T - \mathbf{x})^2 \leq \mathbf{r}_{\max} \end{cases}$$

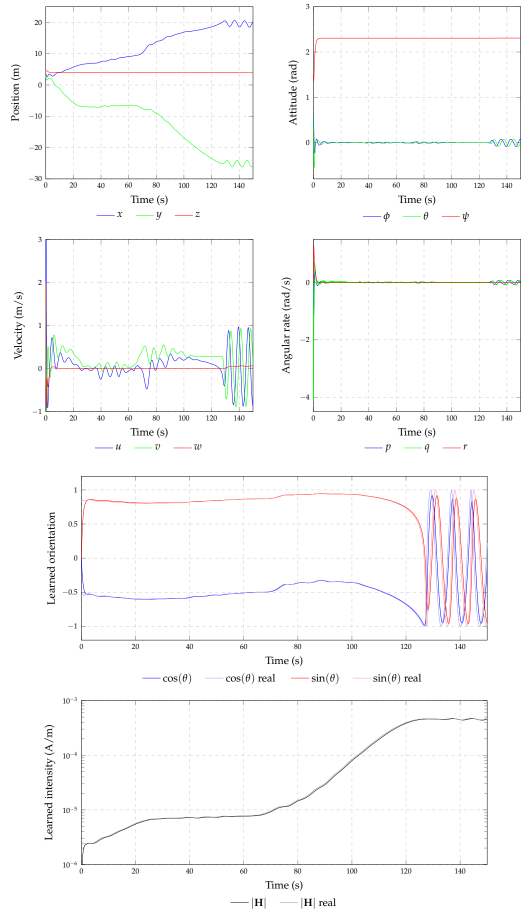
and treated as a **stochastic variable**

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

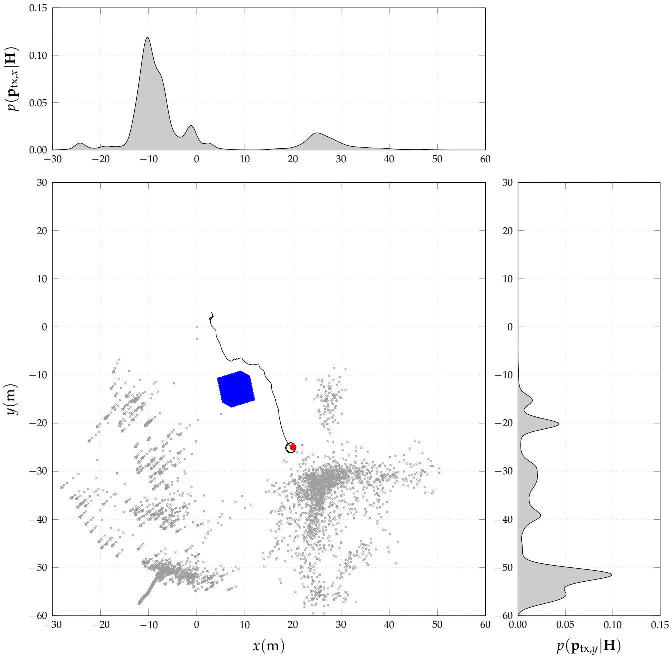
from $\hat{p}(\mathbf{p})$ we extract **mean** and **covariance**!

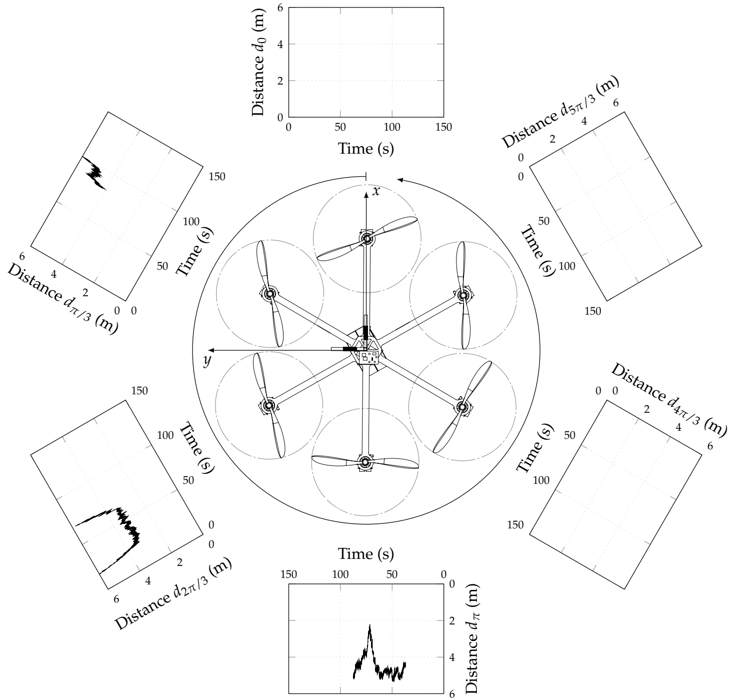
Simulation Results (1)





Simulation Results (2)





Questions?

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

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.

$$\left\{\begin{aligned} \nabla\cdot\mathbf{B} &= 0\\ \nabla\times\mathbf{E} &= -\frac{\partial}{\partial t}\mathbf{B}\\ \nabla\cdot\mathbf{E} &= \frac{\rho}{\varepsilon_0}\\ \nabla\times\mathbf{B} &= \mu_0\left(\mathbf{J}+\varepsilon_0\frac{\partial}{\partial t}\mathbf{E}\right)\end{aligned}\right. \xrightarrow[\left\{\begin{aligned}\mathbf{A}' &\mapsto \mathbf{A}+\nabla\psi\\ \phi' &\mapsto \phi-\frac{\partial\psi}{\partial t}\\ \nabla\cdot\mathbf{A}' &= -\frac{1}{c^2}\frac{\partial^2\psi'}{\partial t^2}\end{aligned}\right.]{\left\{\begin{aligned}\mathbf{B} &= \nabla\times\mathbf{A}\\ \mathbf{E} &= -\nabla\phi-\frac{\partial\mathbf{A}}{\partial t}\end{aligned}\right.} \left\{\begin{aligned}\nabla^2\phi-\frac{1}{c^2}\frac{\partial^2\phi}{\partial t^2} &= -\frac{\rho}{\varepsilon_0}\\ \nabla^2\mathbf{A}-\frac{1}{c^2}\frac{\partial^2\mathbf{A}}{\partial t^2} &= -\mu_0\mathbf{J}\end{aligned}\right.$$

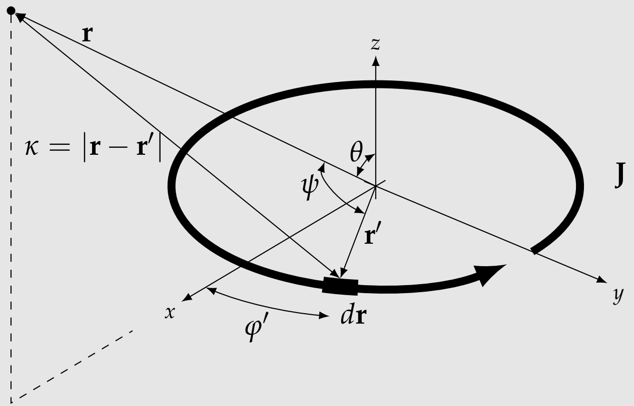
Application to our problem: integral formulation

$$\begin{aligned}\phi(\mathbf{r},t) &= \frac{1}{4\pi\varepsilon_0}\int_\Omega \frac{1}{|\mathbf{r}-\mathbf{r}'|}\rho\left(\mathbf{r}',t-\frac{|\mathbf{r}-\mathbf{r}'|}{c}\right)d\mathbf{r}\\ \mathbf{A}(\mathbf{r},t) &= \frac{\mu_0}{4\pi}\int_\Omega \frac{1}{|\mathbf{r}-\mathbf{r}'|}\mathbf{J}\left(\mathbf{r}',t-\frac{|\mathbf{r}-\mathbf{r}'|}{c}\right)d\mathbf{r}\end{aligned}$$

Magnetic dipole problem

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

Solution for boundary condition problem



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

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

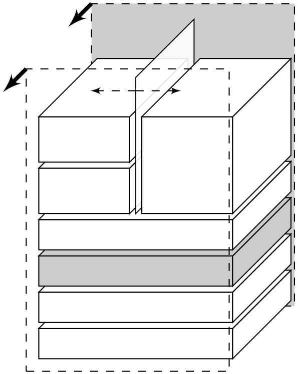
B–Field solution

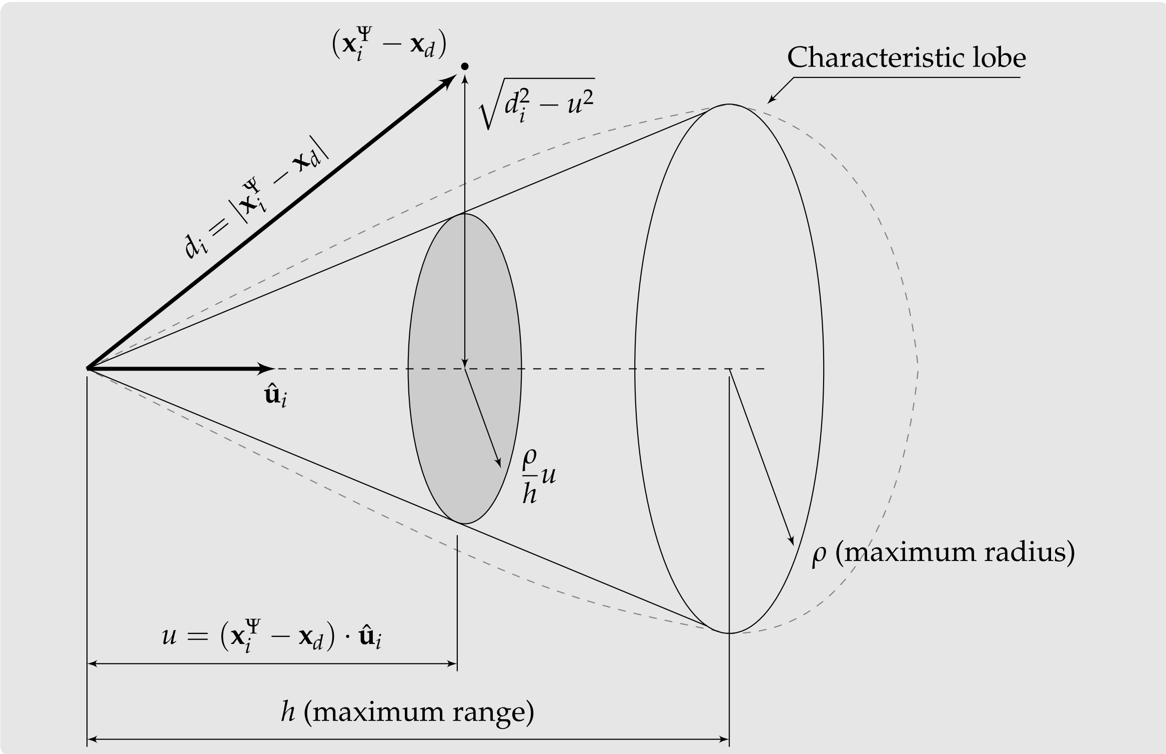
$$\tau = t - \frac{r}{c}$$

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

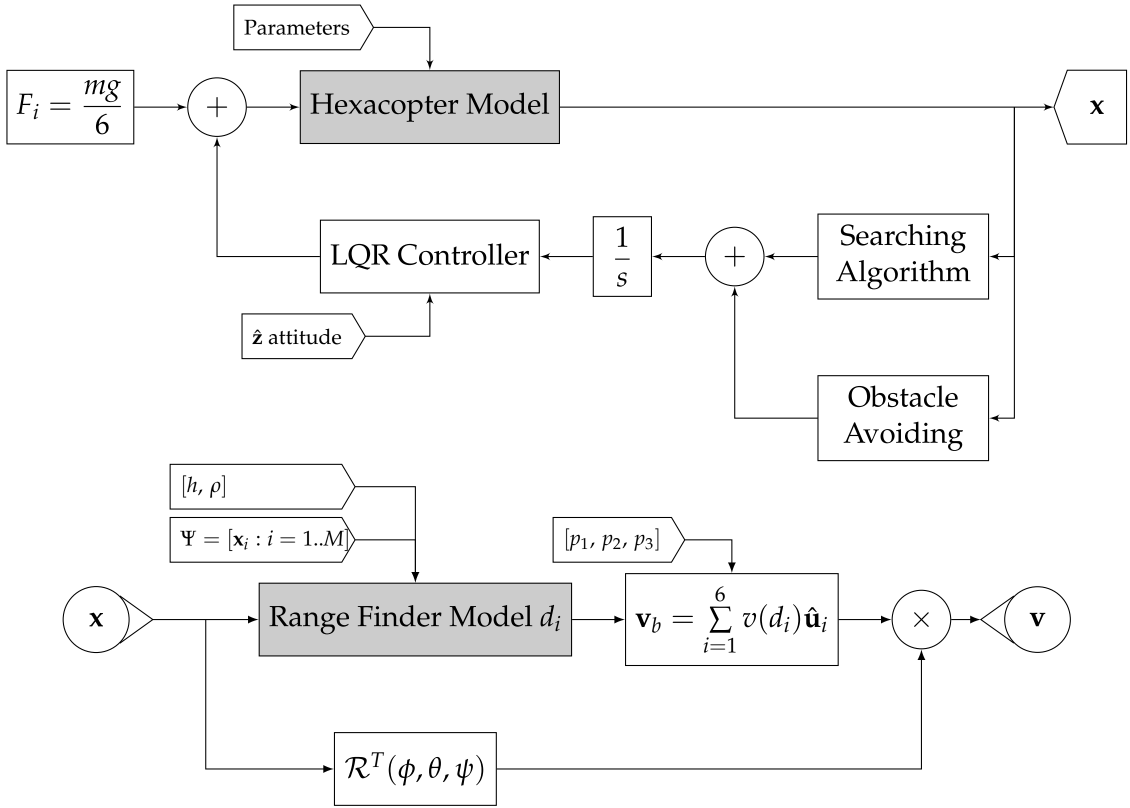
$$B_r = \frac{\mu_0 m_0}{4\pi r^3 c} \sin(\theta) \left((c^2 - \omega_0^2 r^2) \cos(\omega_0 \tau) - \omega_0 r c \sin(\omega_0 \tau) \right)$$

Simulating a Range Finder





Simulink Implementations (1)



Simulink Implementations (2)