ALMA MATER STUDIORUM – UNIVERSITA' DI BOLOGNA

SCUOLA DI INGEGNERIA E ARCHITETTURA

Dipartimento di Ingegneria dell'Energia Elettrica e dell'informazione "Guglielmo Marconi"

TESI DI LAUREA
in
Automatic Controls

Agricultural Field Detection and Coverage Path Planning for an Unmanned Aerial Vehicle

CANDIDATO:
Michael Rimondi

RELATORE:
Prof. Lorenzo Marconi

CORRELATORI:
Ing. Nicola Mimmo

Anno Accademico 2017/18 Sessione II

Bambi Project

Wildlife search and rescuing operations over agricultural area made easy and automatic

Bambi Project

Main tasks

- **Georeferencing** the **mission's environment** and **identify** the **field boundary**;
- Calculate the **coverage path**;
- Generate a **timed dependent trajectory** taking into account dynamic constraints of the vehicle;
- Make the drone follow the computed trajectory while **avoiding obstacles**;

Field Detection & Representation

Keyhole Markup Language (KML)

KML is an XML language focused on geographic visualization, including annotation of maps and images.

```xml
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<kml xmlns="http://www.opengis.net/kml/2.2">
  <Document>
    <name>Shapes</name>
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      <LineStyle>
        <width>2.5</width>
      </LineStyle>
    </Style>
    <Style id="transparent50Poly">
      <PolyStyle>
        <color>7fffffff</color>
      </PolyStyle>
    </Style>
    <Placemark>
      <name>Waldpeter Field Boundary</name>
      <description>Field Border</description>
      <LineString>
        <coordinates>
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          11.491755810622863,46.45338389393535,0
          <!-- OMITTED COORDINATES -->
           11.49140555201052,46.45356658266721,0
           11.491609399895651,46.453469568513725,0
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    </Placemark>
  </Document>
</kml>
```
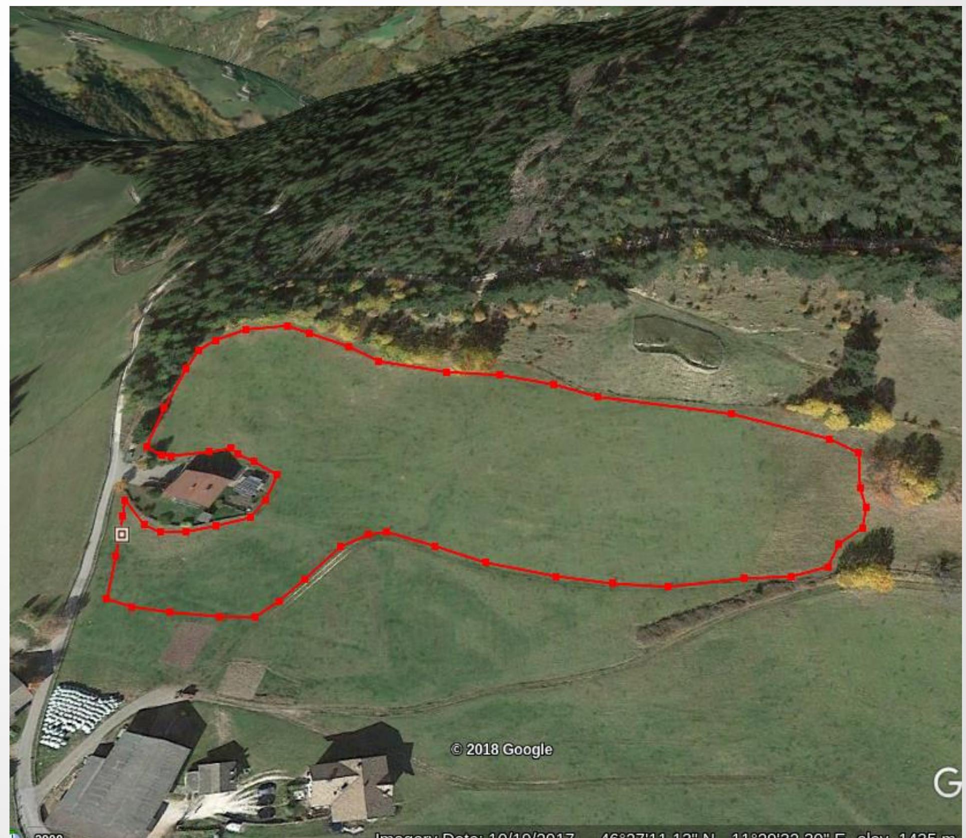
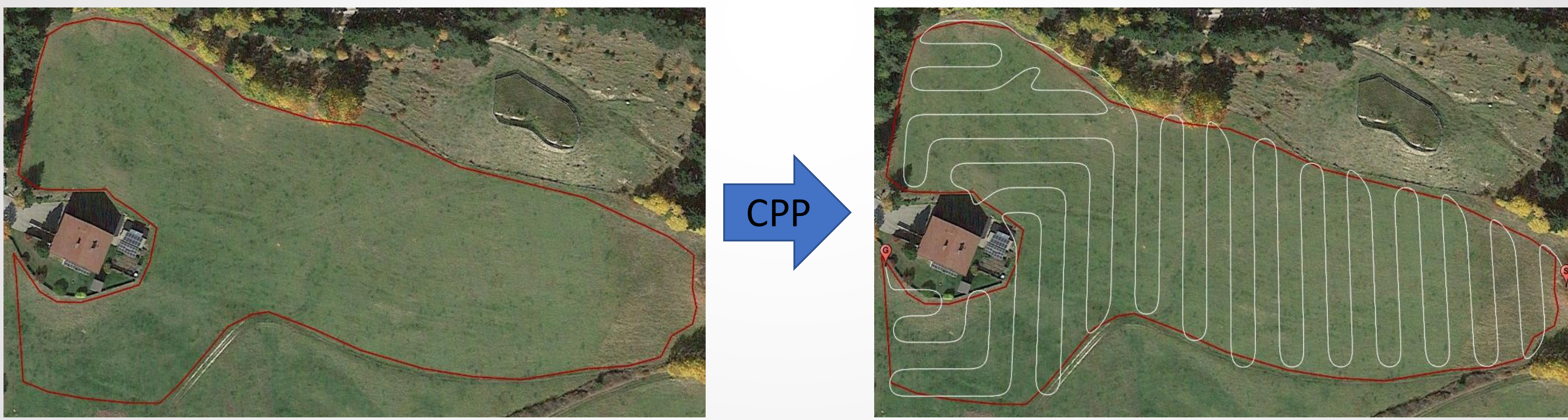



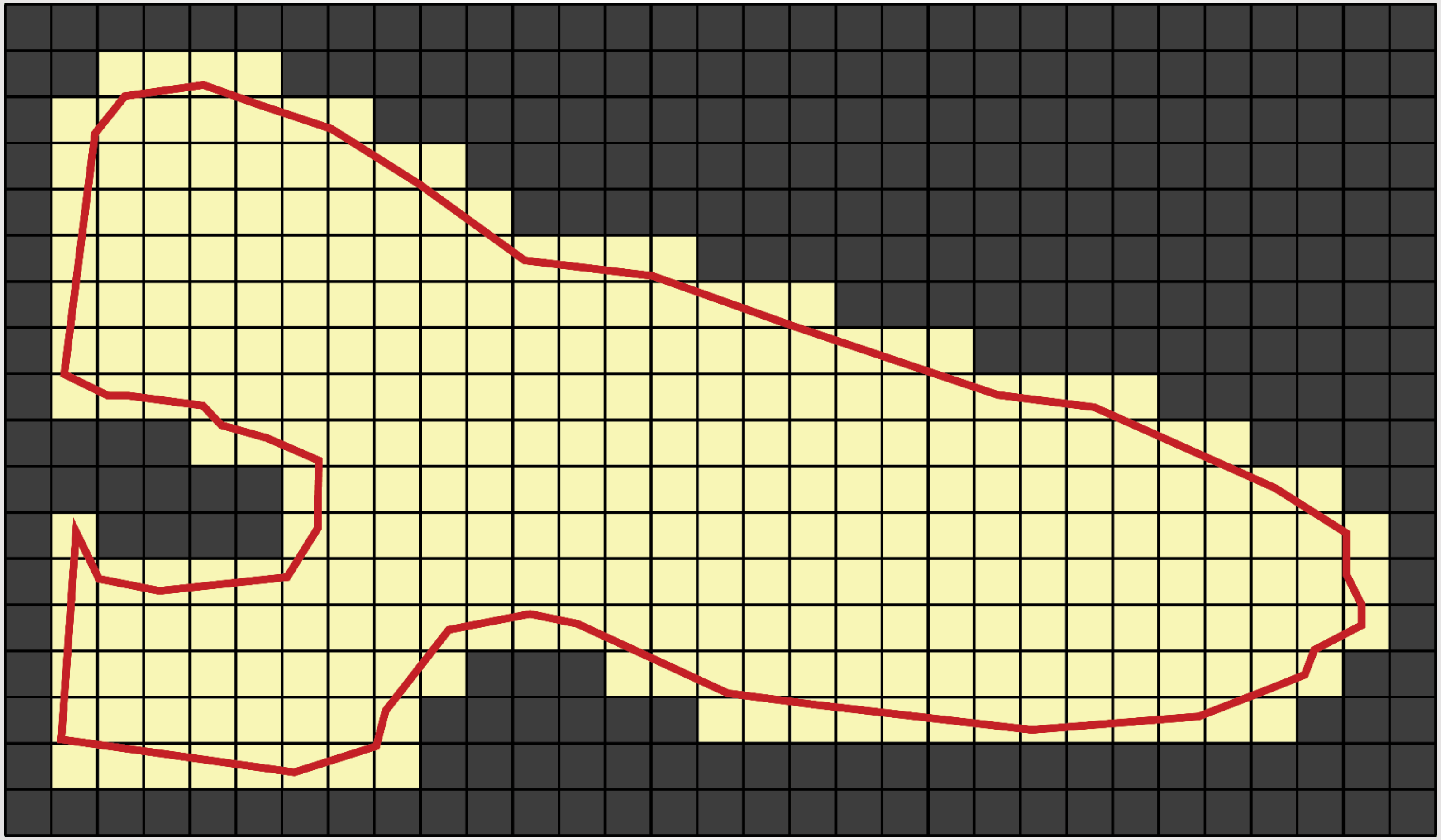
Coverage Path Planning

Coverage Path Planning (CPP) consist of finding a trajectory for a mobile robot such that a target **area** is **completely swept** by the sensor footprint.



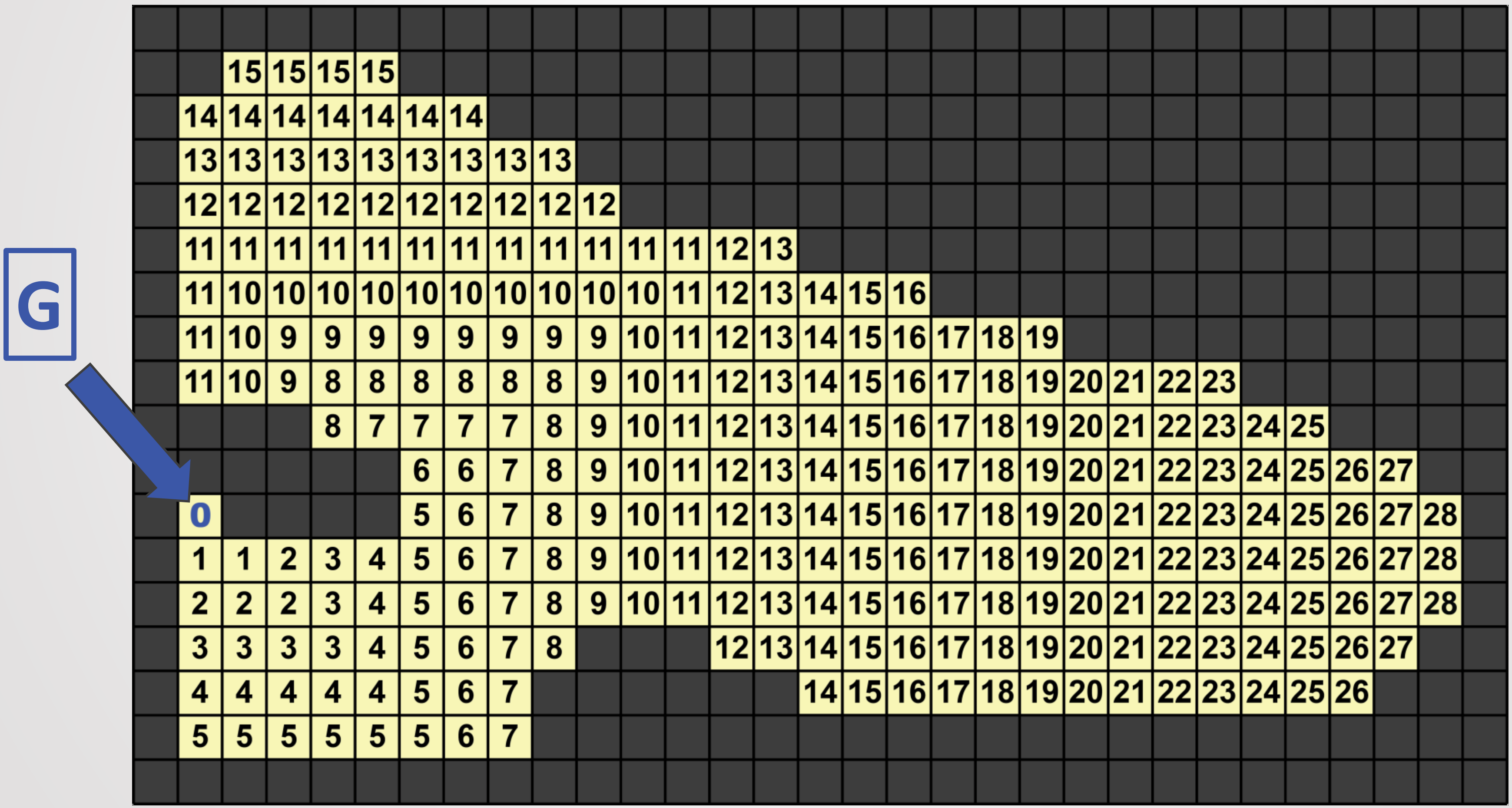
Coverage Path Planning

Approximate Cellular Decomposition



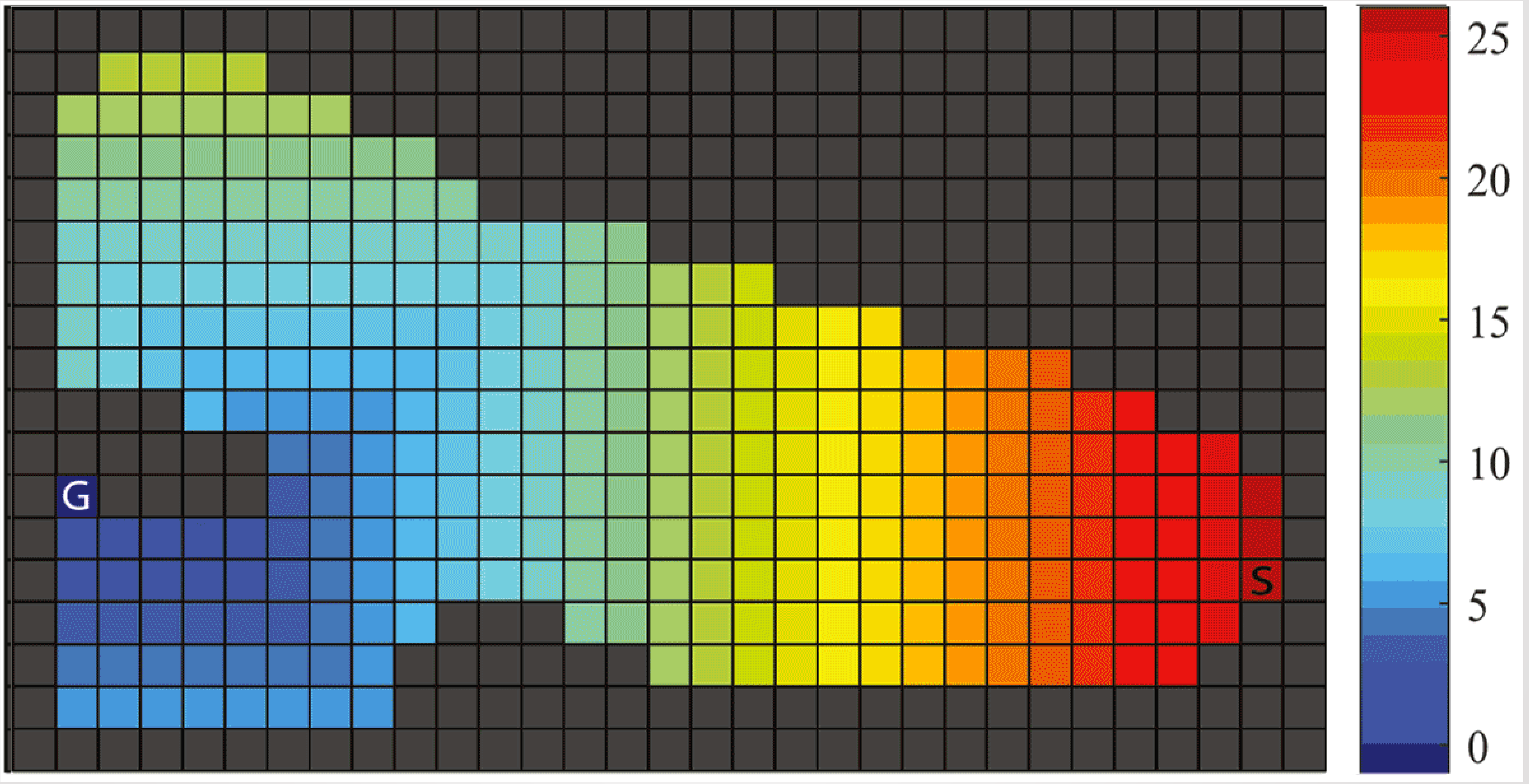
Coverage Path Planning

Wave-front propagation



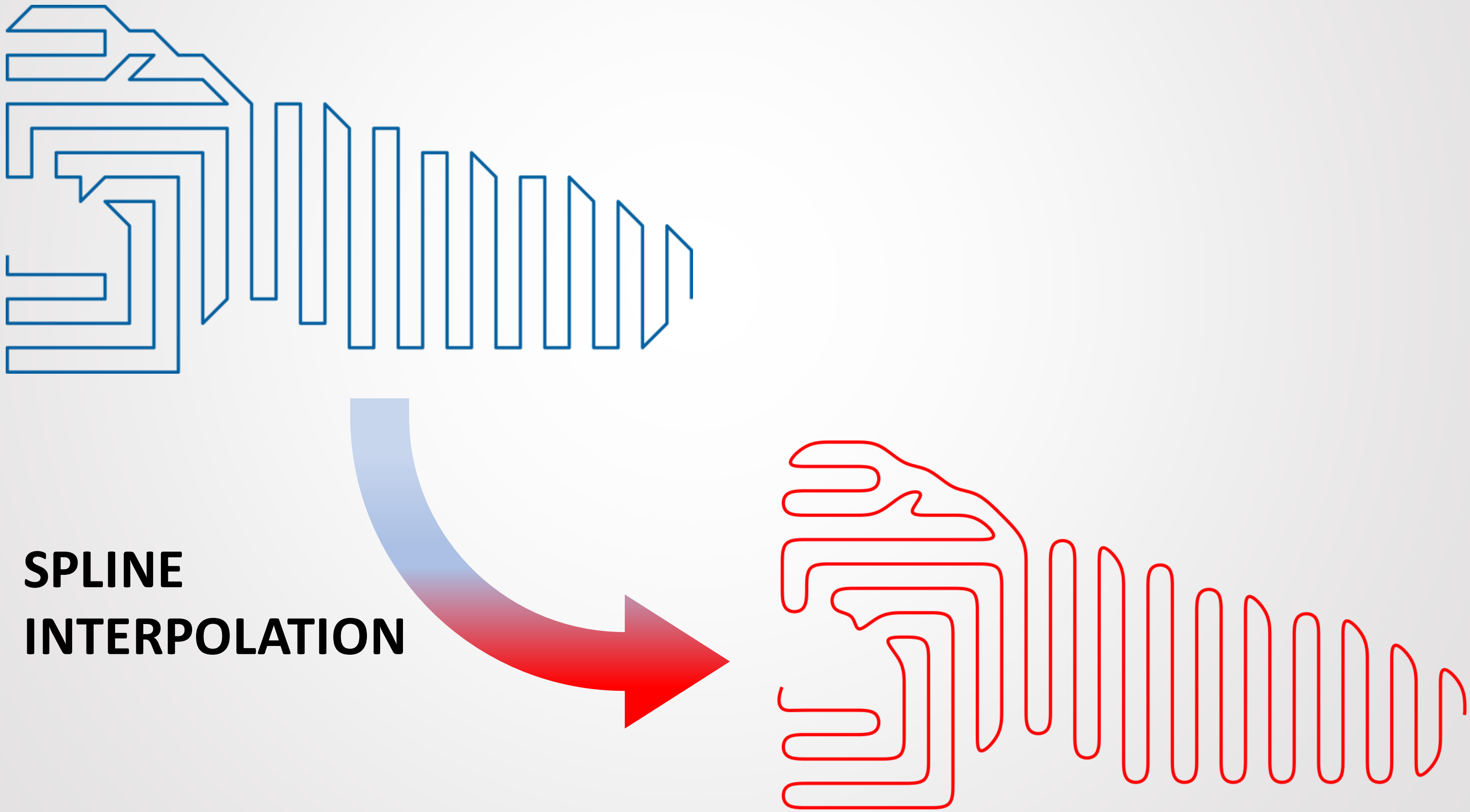
Coverage Path Planning

Coverage Path Generation



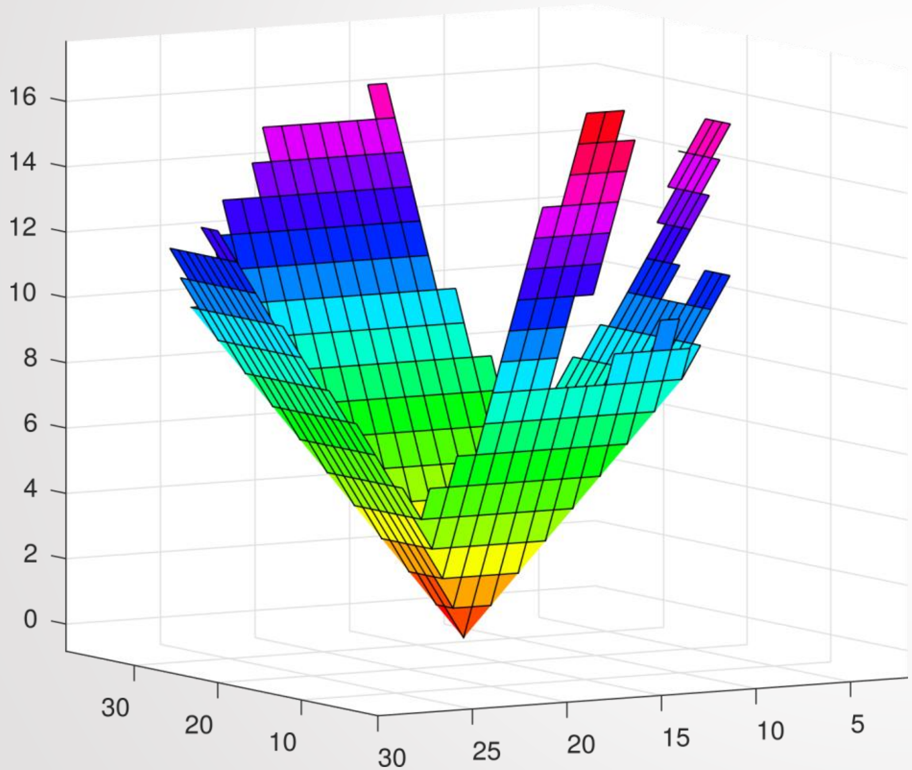
Coverage Path Planning

Path Smoothing



Coverage Path Planning

Different Goal Position

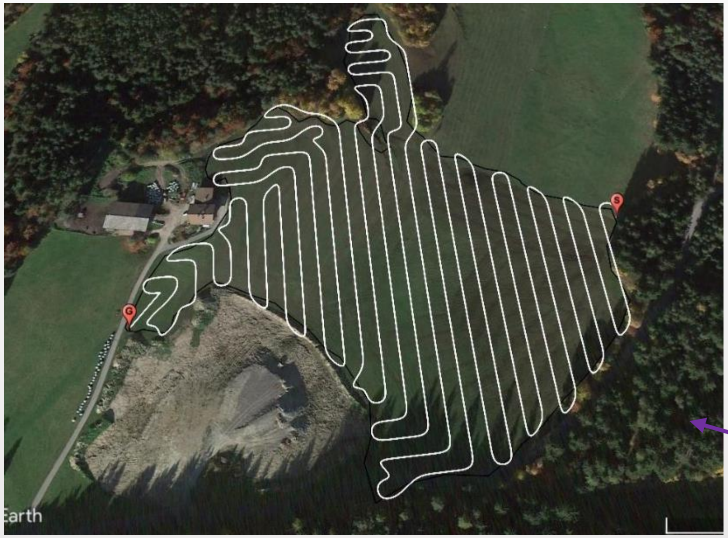


Coverage Path Planning

Simulation Results

Area: *1.544 Ha*
Path *: 2.17 Km*

Area: *5.066 Ha*
Path *: 5.56 Km*



Area: *4.159 Ha*
Path *: 4.66 Km*

Future works

Environment representation:

- **Image recognition** based on AI for field detection

CPP:

- **Consider others cost functions** then the planar distance only (e.g. Terrain elevation profile)

Thank You for the attention!

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TESI DI LAUREA
in
Automatic Controls

Autonomous Navigation Algorithm with Collision Avoidance for an Unmanned Arial Vehicle

CANDIDATO:
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RELATORE:
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CORRELATORI:
Ing. Nicola Mimmo

Anno Accademico 2017/18 Sessione II

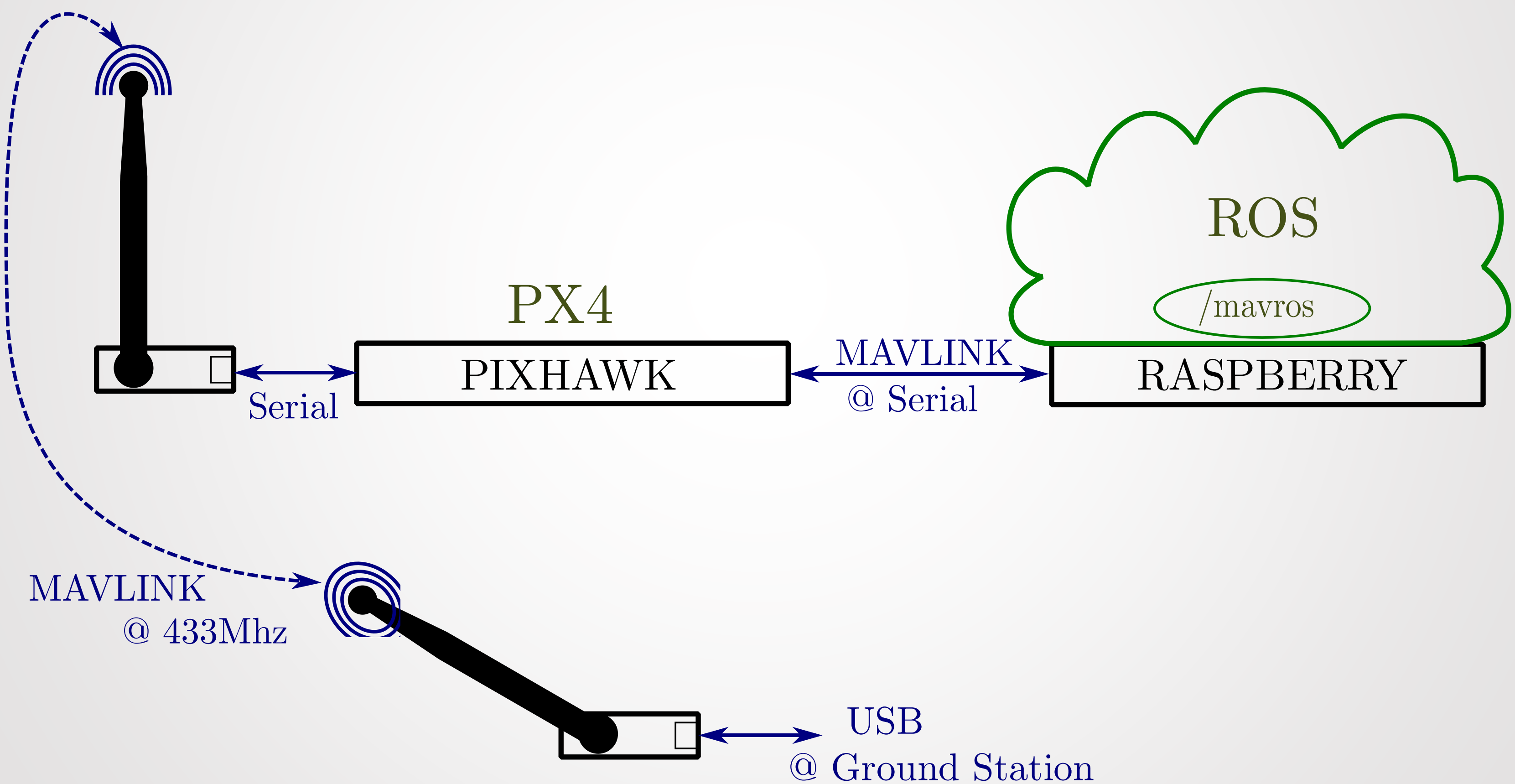
Bambi Project

Main tasks

- **Georeferencing** the **mission's environment** and **identify** the **field boundary**
- Calculate the **coverage path**
- Generate a **timed dependent trajectory** considering dynamic constraints
- Follow the computed trajectory while **avoiding obstacles**

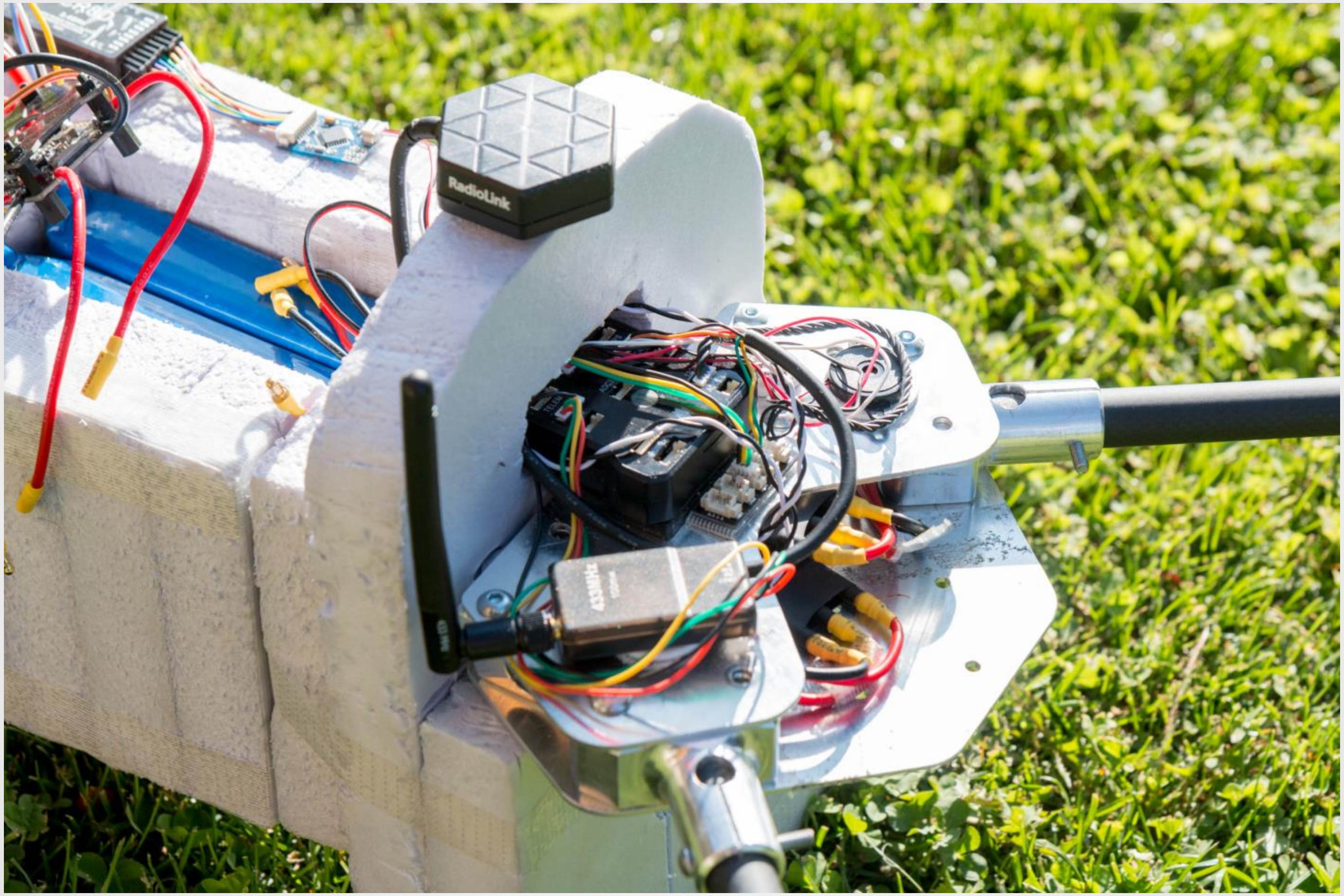
System Architecture

Illustration

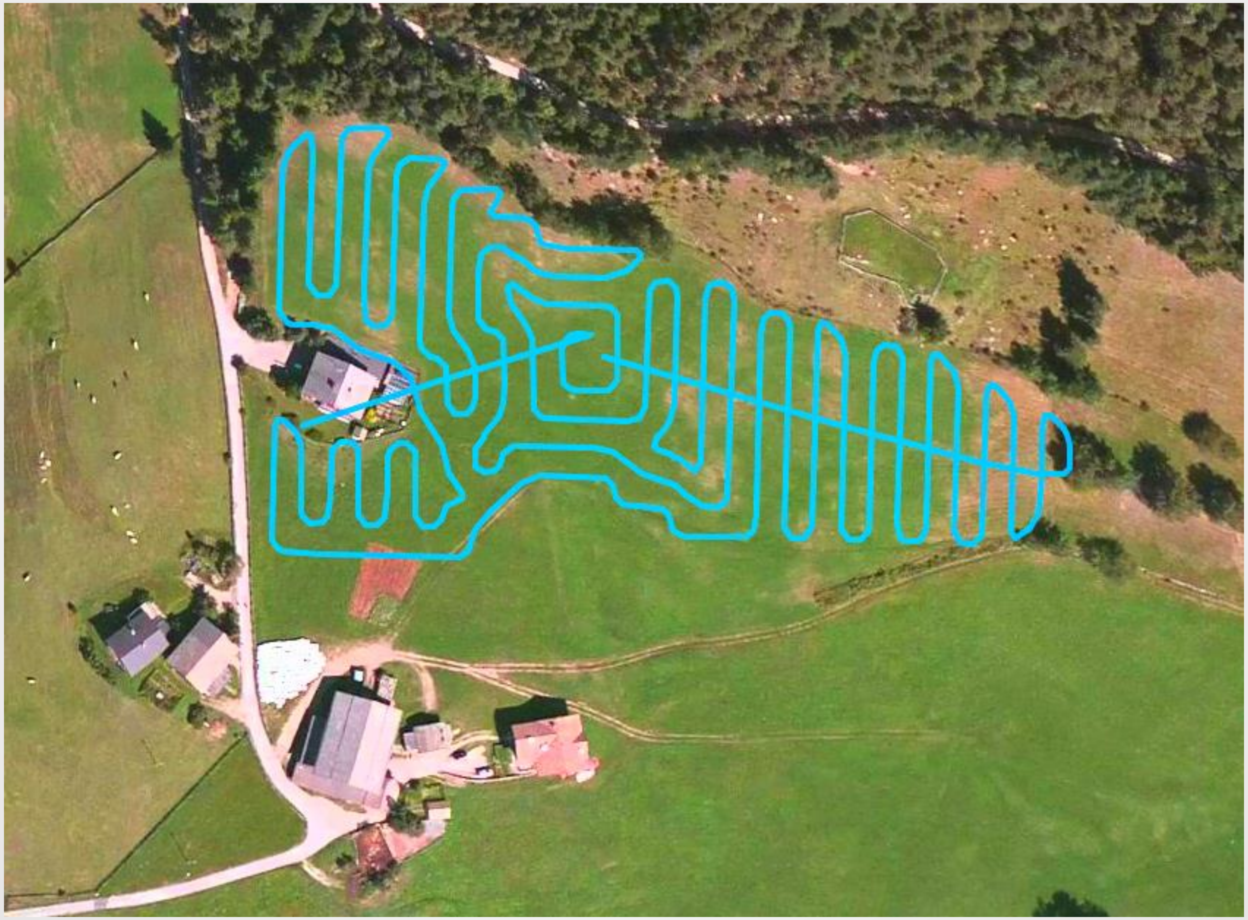


System Architecture

Realization

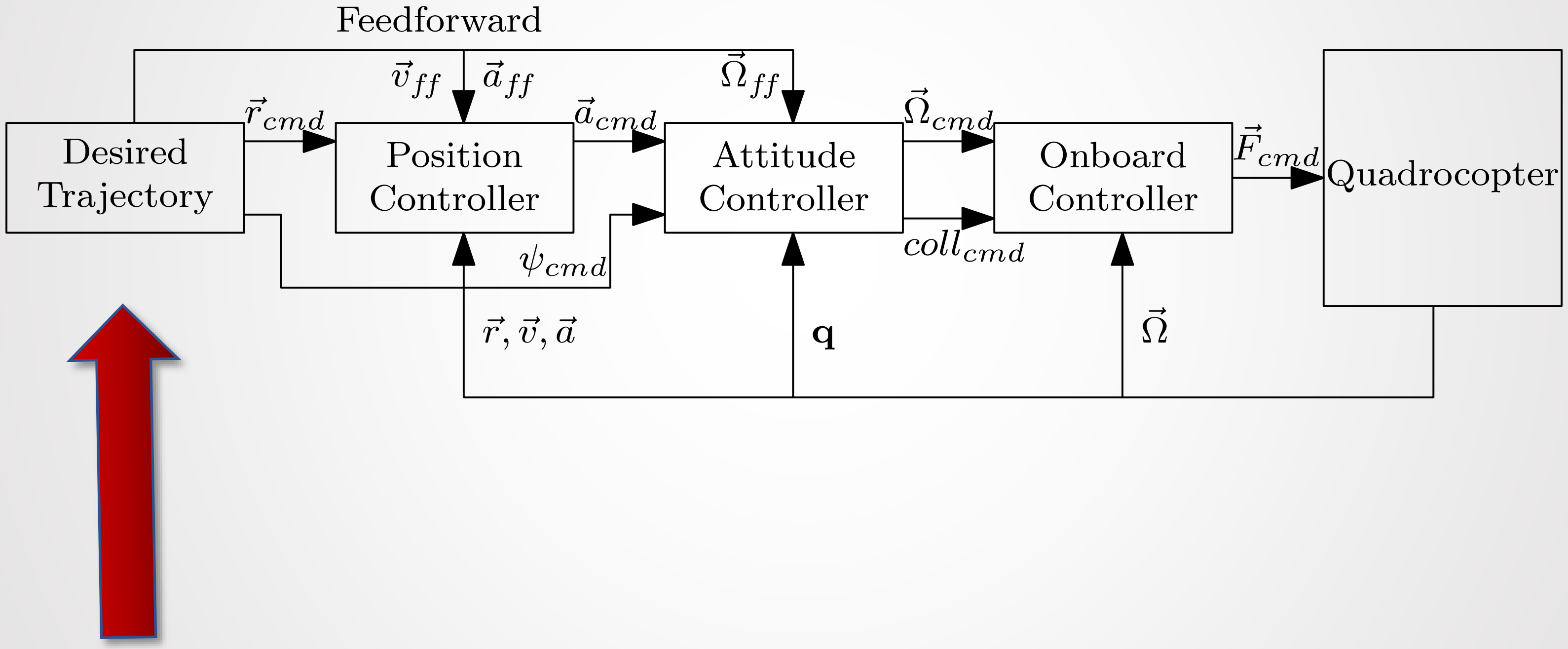


Starting Point
Geometric Trajectory



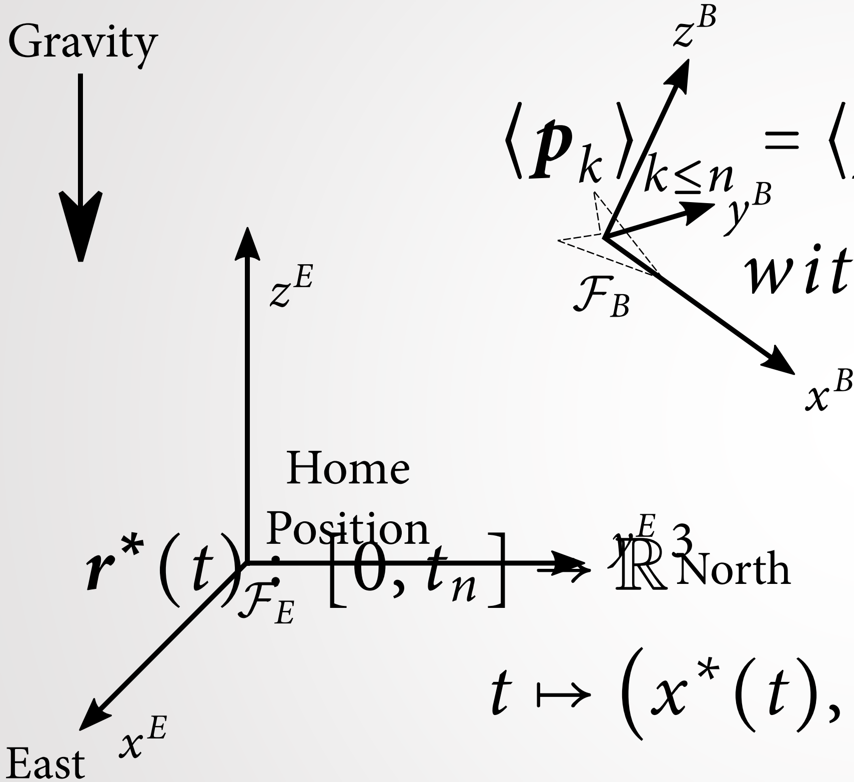
Starting Point

PX4 Flight Controller



Problem Description 1

Trajectory Generation



$$\langle \boldsymbol{p}_k \rangle_{k\le n} = \langle \boldsymbol{p}_1, \boldsymbol{p}_2, \dots, \boldsymbol{p}_n \rangle$$

$$with\ \boldsymbol{p}_k \in \mathbb{R}^3$$

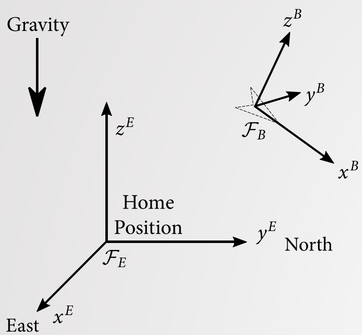
$$\boldsymbol{r}^*(t) : [0, t_n] \to \mathbb{R}^3$$

$$t \mapsto \left(x^*(t), y^*(t), z^*(t)\right)$$

$$\exists \langle t_j \rangle_{j\le n} \mid \boldsymbol{r}^*(t_j) = \boldsymbol{p}_j$$

Problem Description 1

Trajectory Generation



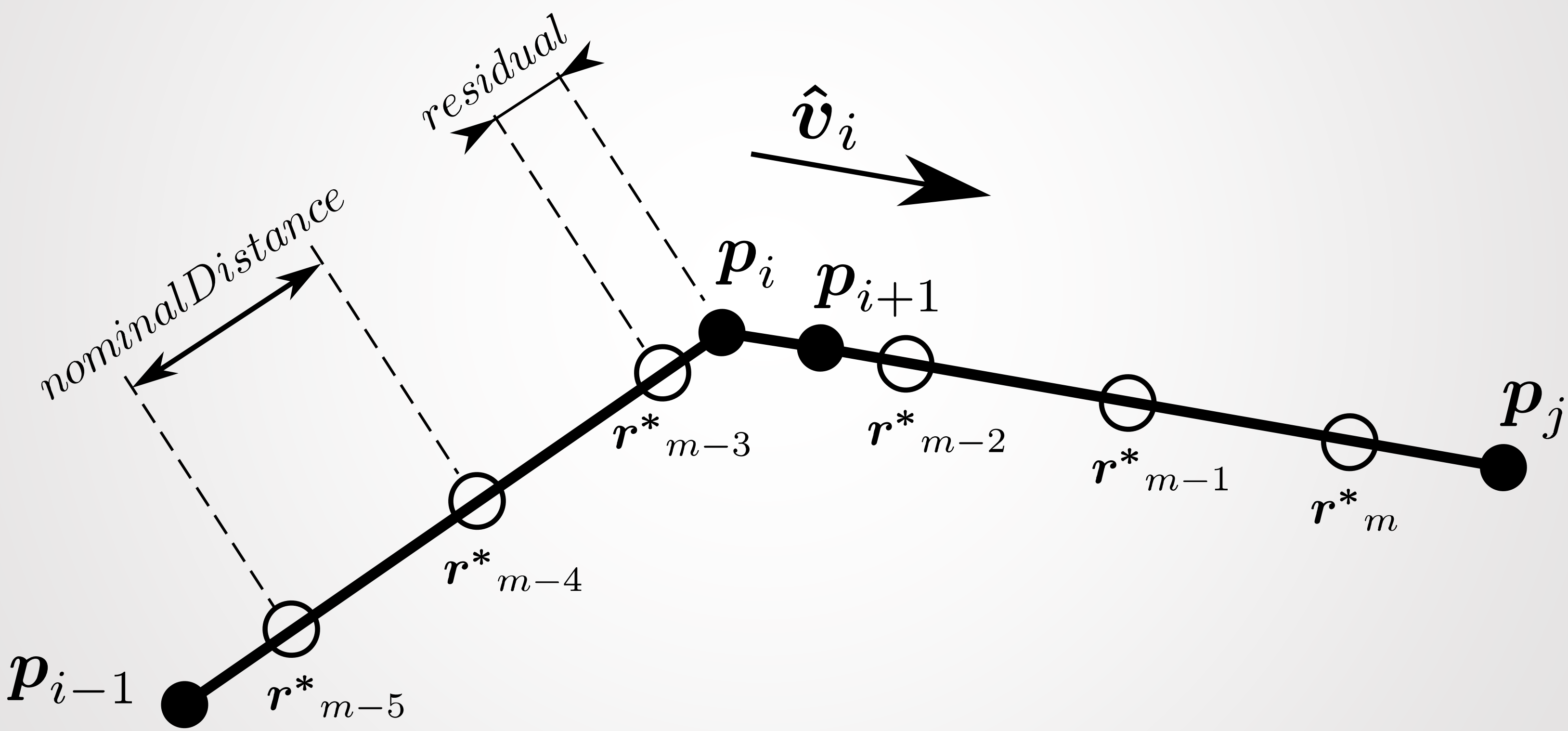
$$\|\dot{\boldsymbol{r}}^*(t)\| \leq v_{max}$$

$$\langle \boldsymbol{r}^*{}_k \rangle_{k<=m} = \langle \boldsymbol{r}^*{}_1, \boldsymbol{r}^*{}_2, \ldots, \boldsymbol{r}^*{}_m \rangle$$

$$\text{with } \boldsymbol{r}^*{}_k = \boldsymbol{r}^*\left(\frac{k}{f_{sp}}\right)$$

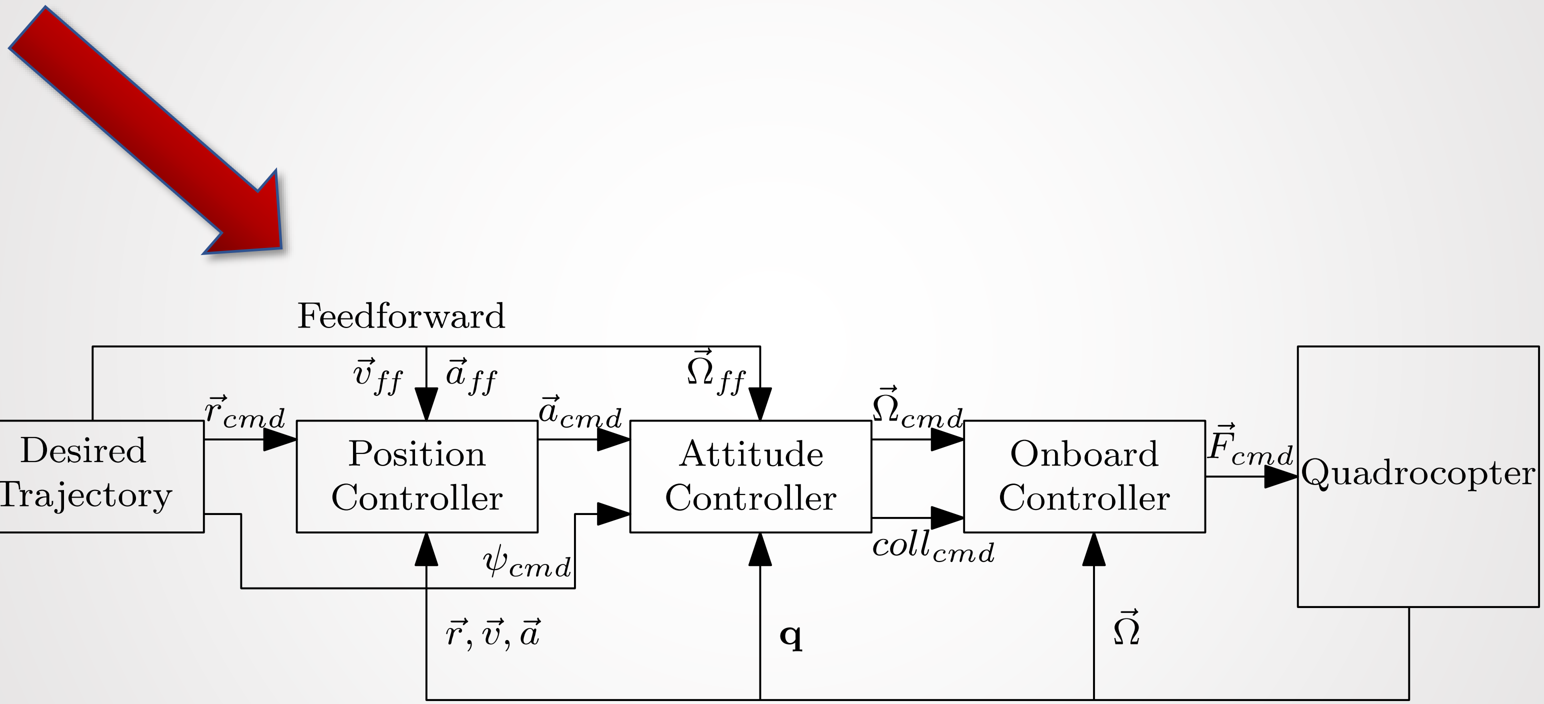
Constant Velocity

Trajectory Generation



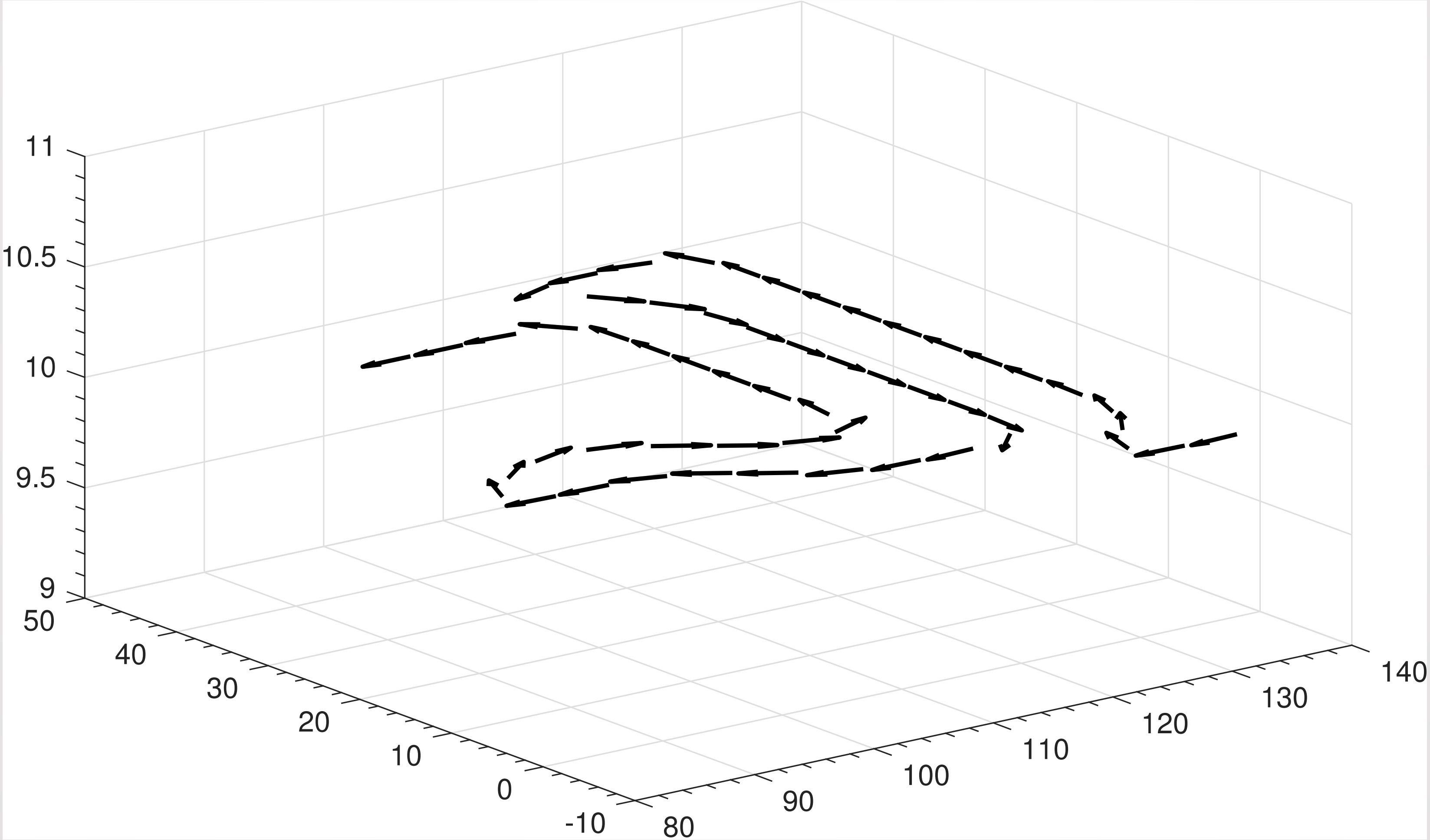
Velocity Feed Forward

PX4 Flight Controller



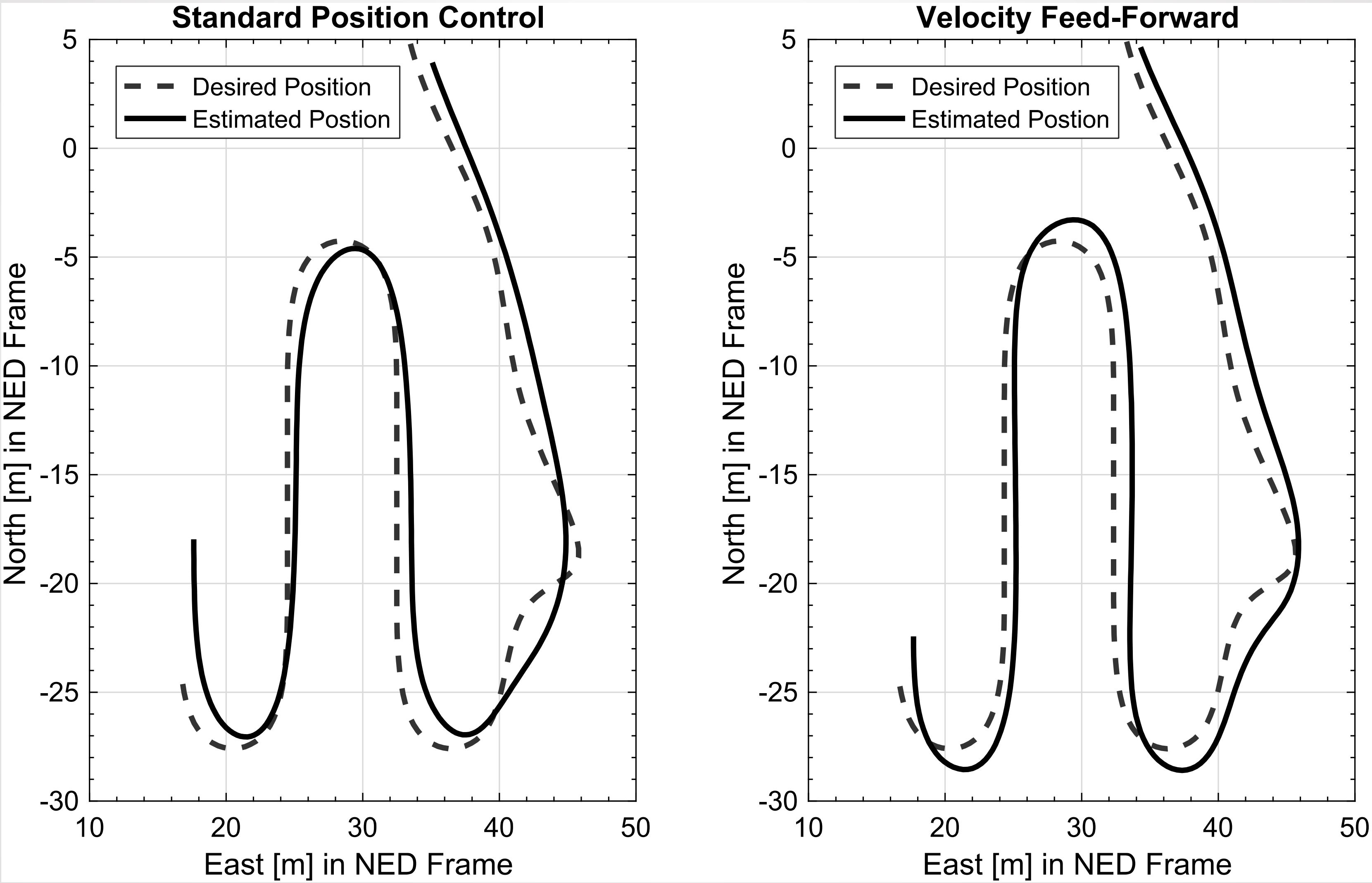
Generated Trajectory

Velocity Vector Plot



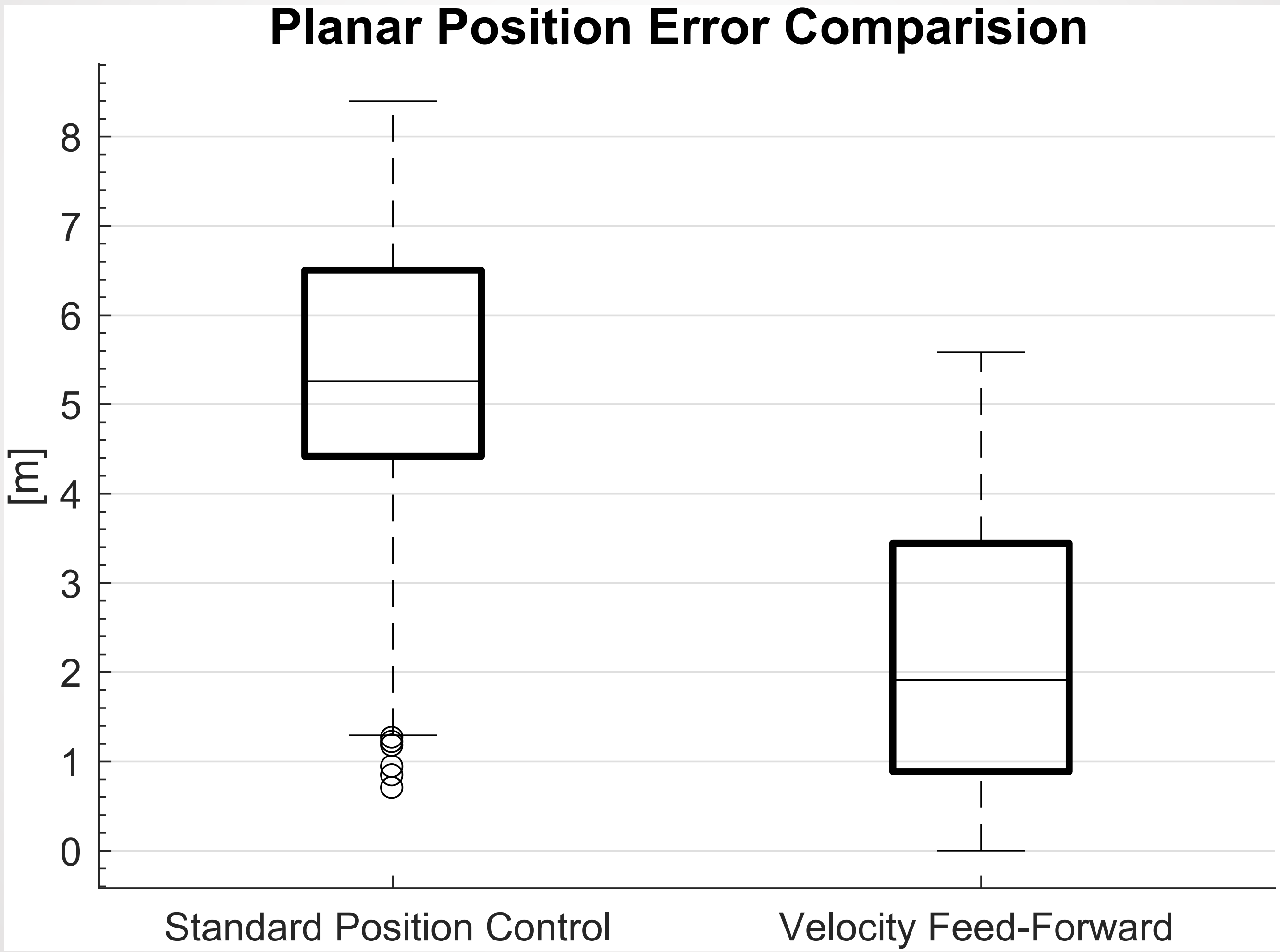
Simulation Results

Standard Position vs Feed Forward Control



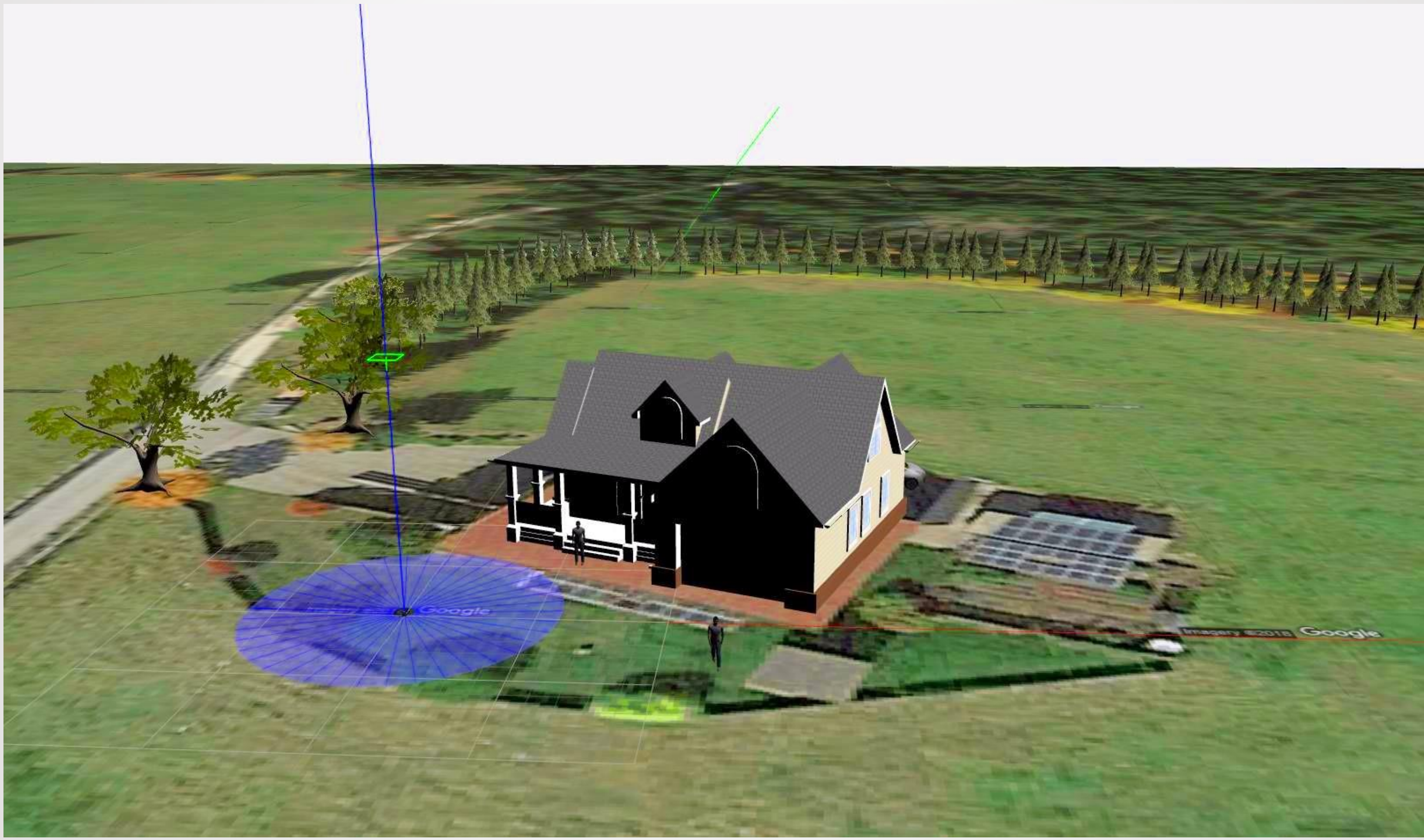
Simulation Results

Standard Position vs Feed Forward Control

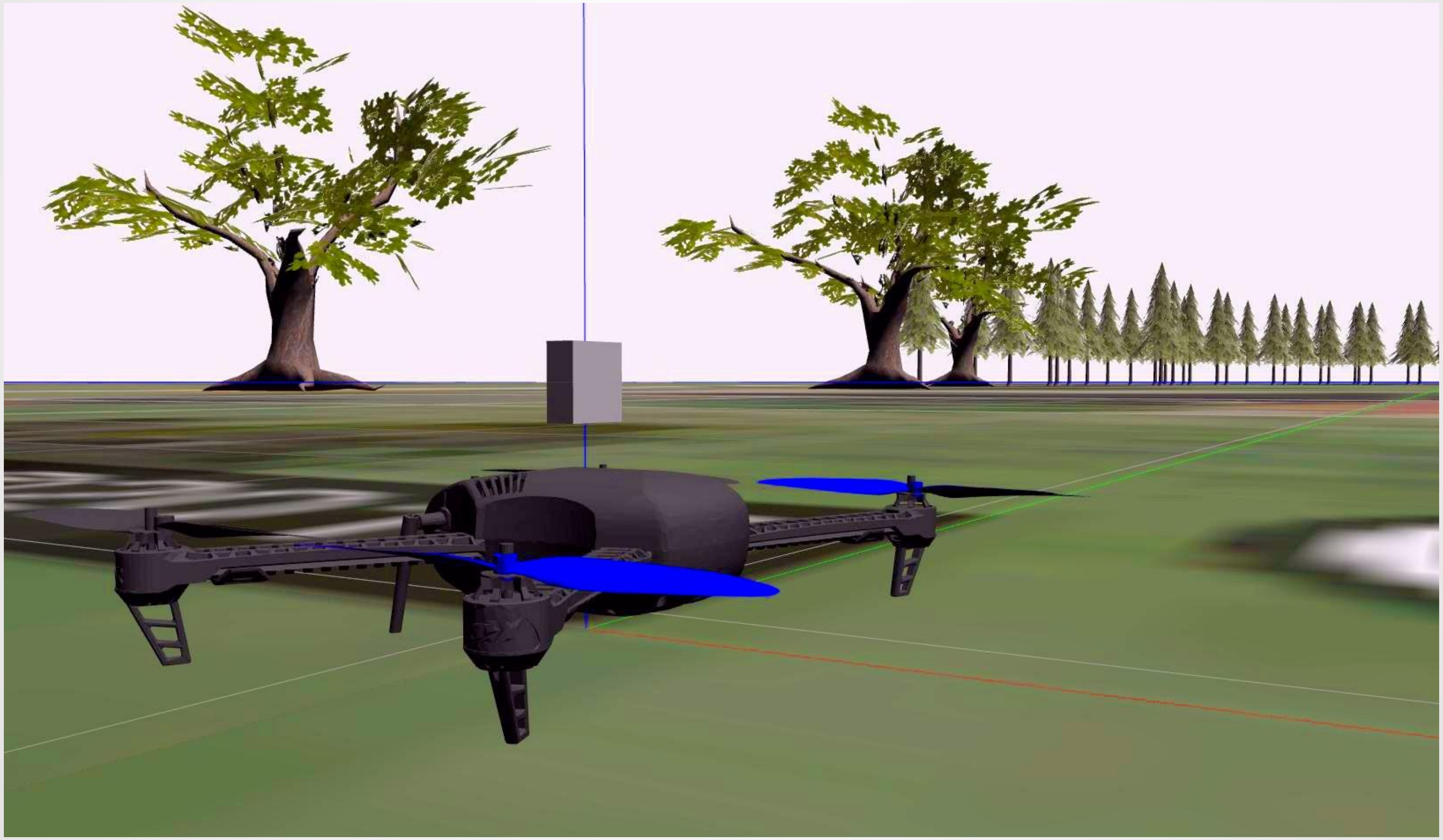


Collision Avoidance

Security Measure

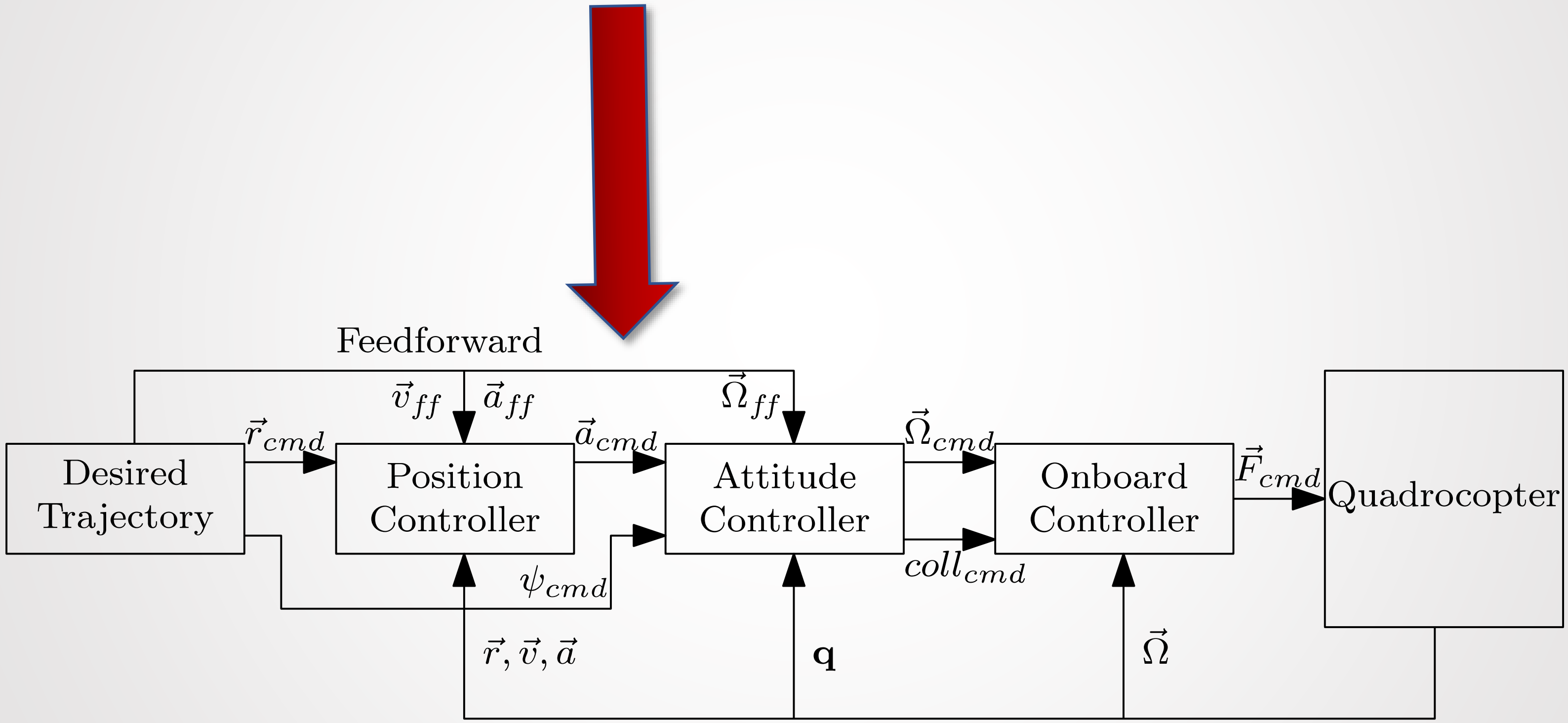


Collision Avoidance
Security Measure



Collision Avoidance

Control Signal



Problem Description 2

Collision Avoidance

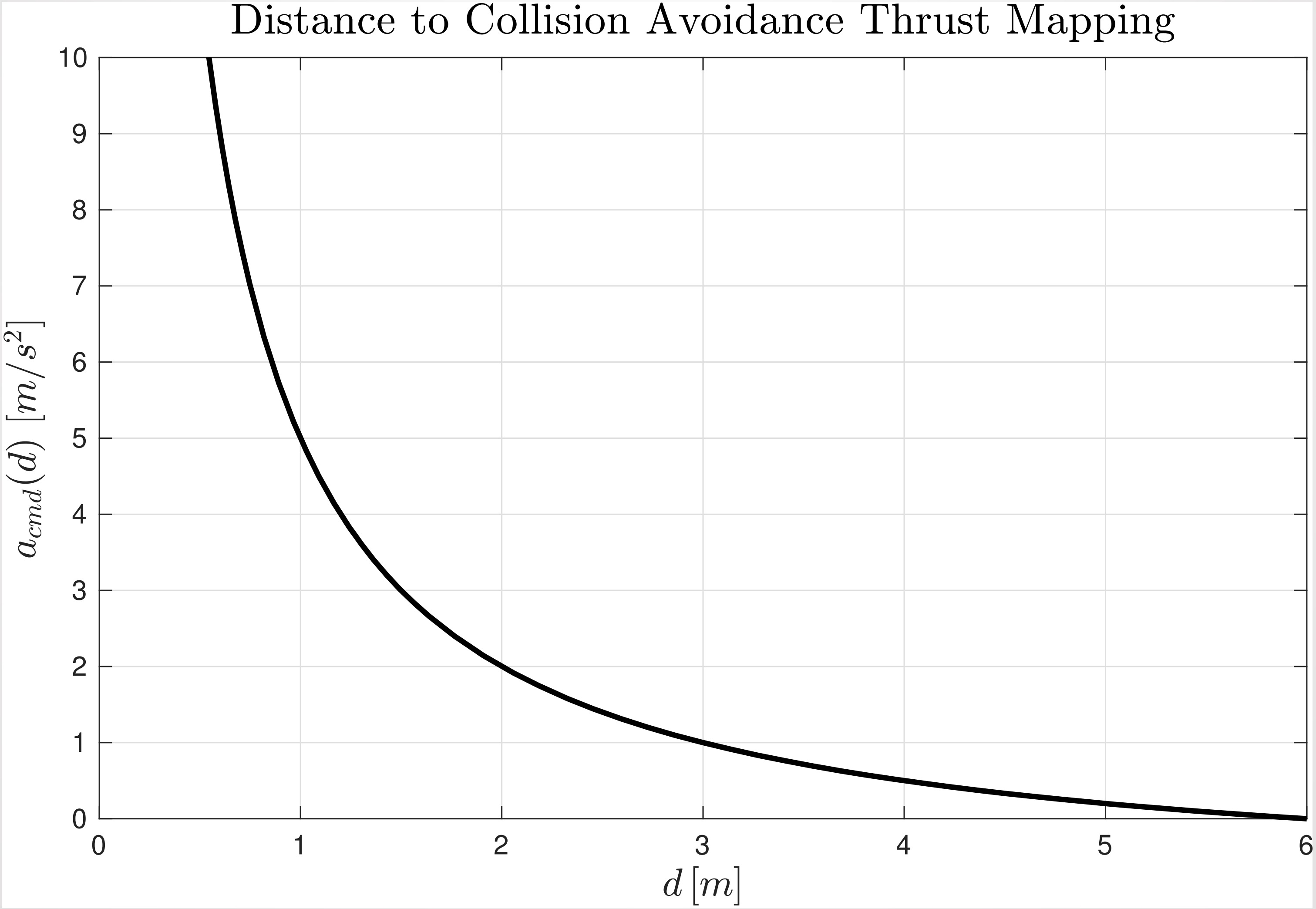
$$\hat{a}_{collision} = \frac{1}{\int_0^{2\pi} w\big(d(\theta)\big) d\theta} \int_0^{2\pi} w\big(d(\theta)\big) \begin{pmatrix} -\cos\theta \\ -\sin\theta \end{pmatrix} d\theta$$

$$x(t) = v_0\, t - \frac{1}{2}\, a_{req}\, t^2$$

$$a_{req} = \frac{v_0^2}{2\, d_{stop}}$$

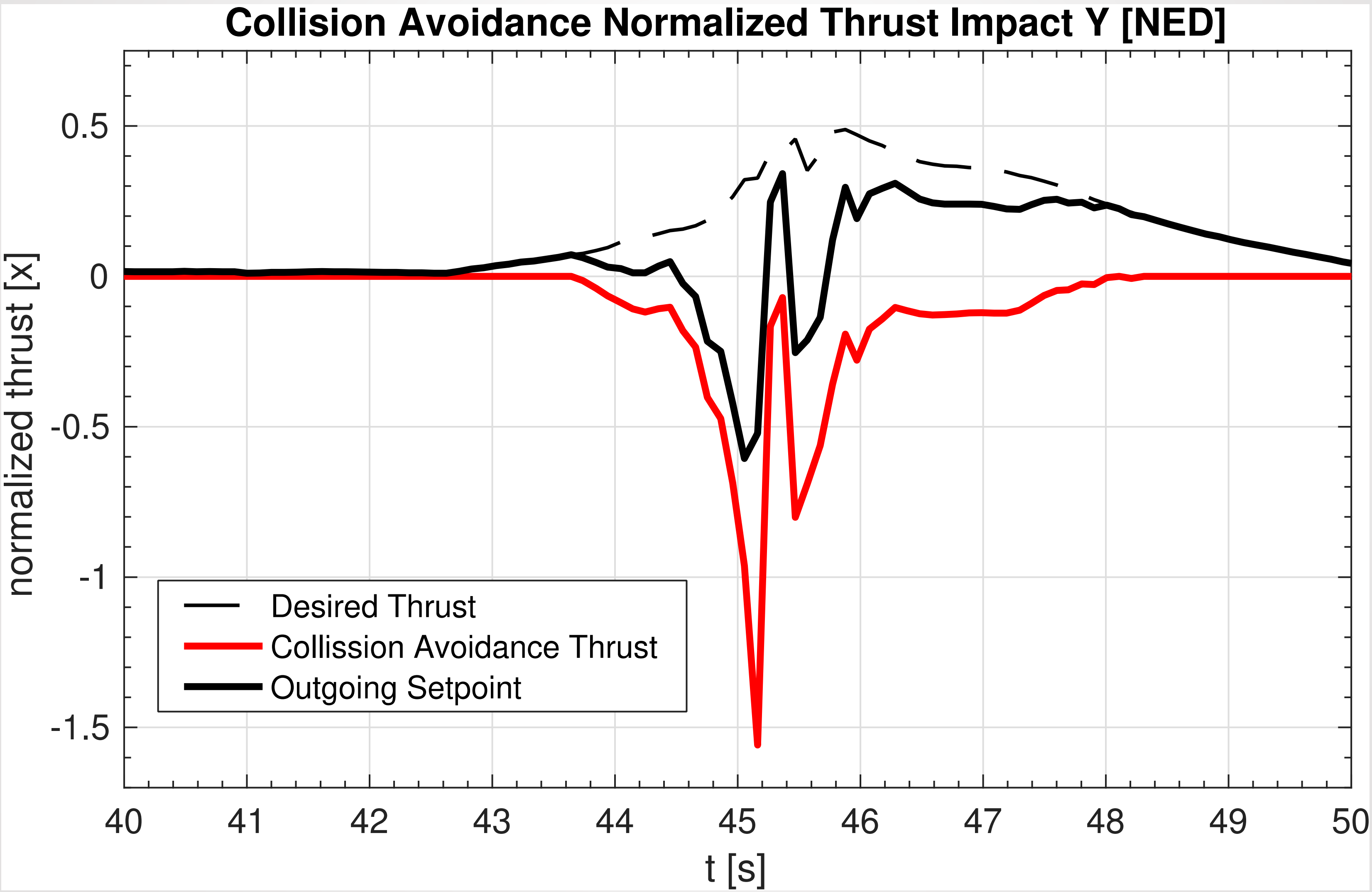
$$\Rightarrow w(d) \propto \frac{1}{d}$$

Weight Function
Control Action



Simulation Results

Thrust Impact



Simulation Results

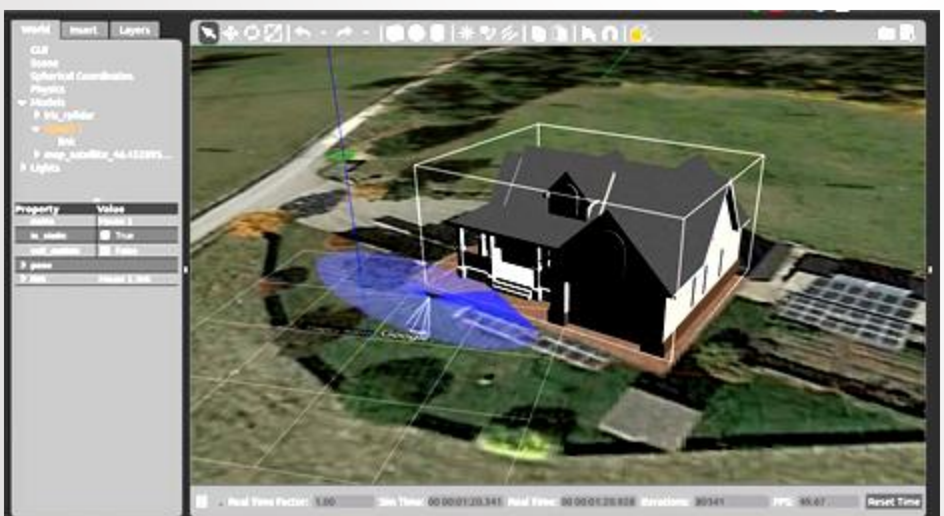
Qualitative Evaluation

Advantages

- Easy implementation
- Low Latency
- Always enabled (Security)

Disadvantages

- Local minima
- No reference trajectory correction
- Reliable measurements needed



Conclusion

Future Works

- Optimal Control
- Field Experiments

Q&A

Thank you for having me