Context & Objective

- Demand for civilian UAV operations increases (fire detection, river bed surveillance, parcel delivery...)
- Most UAVs operate at low altitudes, interfering with traffic in TMAs

Our solution
- A geometrical detect & avoid algorithm
- Validated by intensive simulation
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How to ensure separation between UAVs and traffic?

- Managed by ANSPs
- Delegated to both aircraft and UAV (TCAS-like)
- Handled by the UAV only
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Geometrical algorithm

Based on [van den Berg et al., 2011]
n-body collision avoidance algorithm for robotics

... with a few substantial differences

- only the UAV handles the avoidance maneuver
- only heading changes are considered
- speed ratio between aircraft and UAV might be high:
  Aircraft from 200 kn up to 450 kn
  UAV from 80 kn to 160 kn
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Conflict detection

$\tau$ is the anticipation time.
Conflict detection

\[ d/\tau \]

\( d \) is the anticipation time

\[ \mathbf{v}_A \]

\[ \mathbf{v}_B \]
Conflict detection

\[ d = \tau \]

\( \tau \) is the anticipation time
Conflict detection

$d$ is the anticipation time.

$\mathbf{V}_r$, $\mathbf{V}_A$, $\mathbf{V}_B$, $d$
Conflicts detection

$\tau$ is the anticipation time
\( \tau \) is the anticipation time
Resolution principle

\[ \vec{v}_r \]

\[ \vec{v}_A \]

\[ \vec{v}_B \]

C is the "escape vector"
Resolution principle

\[ \vec{s}_C \] is the “escape vector”
Resolution principle

$\vec{s}_c$ is the “escape vector”
$\overrightarrow{s_C}$ is the "escape vector"
$\vec{s}_C$ is the “escape vector”
Model

\[ \mathbf{V}_A \]

\[ \mathbf{V}_B \]

\[ \mathbf{V}_B' \]
Multiple constraints
Multiple constraints
Multiple constraints

\[ \vec{v}_A \]

\[ \vec{v}_B \]

\[ \vec{v}_C \]
Multiple constraints
Multiple constraints

\[ \vec{v}_C \]

\[ \vec{v}_A' \]

\[ \vec{v}_B \]
Resolution strategies

Closest

- Try to stay as close as possible to planned trajectory
Resolution strategies

Closest

- Try to stay as close as possible to planned trajectory
- Saturates the constraint
Resolution strategies

Safest

Try to keep the most room for maneuver
Resolution strategies

Safest

- Try to keep the most room for maneuver
Resolution strategies

Safest

- Try to keep the most room for maneuver
Resolution strategies

Safest

- Try to keep the most room for maneuver
- Longer-term view

\[ \overrightarrow{V_{\text{safest}}} \]

\[ \overrightarrow{V_{\text{target}}} \]

\[ \overrightarrow{V_A} \]
Contents

1 Model

2 Experimental Setup

3 Results

4 Conclusion & Further Work
Experimental Setup

Traffic

- Terminal Maneuvering Areas in Bordeaux FIR, France
- 475 recorded trajectories

Simulations

- Scenarios are built so that if no maneuver is issued, there is a collision
- Target separation distance: $d = 3$ NM
- Many sets of parameters for more than 200,000 simulations
UAV
Experimental Setup

- Speed: 80 kn & 160 kn
- Turn rate: 3°/s to 7°/s
- Six different missions

- Anticipation time: $\tau = 5$ min
- Resolution every 10 s
Resolution Example

Scenario

Closest

Safest
Comparison of strategies

The graph compares the number of scenarios for the closest and safest distances of approach (NM). The x-axis represents the closest distance of approach, ranging from 0 to 40 NM, while the y-axis shows the number of scenarios, ranging from 0 to 400.

The blue bars represent the closest scenarios, with a peak at around 10 NM, decreasing as the distance increases. The pink bars represent the safest scenarios, with a distribution similar to the closest scenarios but shifted to the right, indicating a higher number of scenarios at greater distances.

The graph provides insights into the distribution of scenarios based on the closest and safest distances, which is crucial for assessing the effectiveness of detect & avoid systems for UAV integration.
Comparison of strategies

- Closest
- Safest

- Closest distance of approach (NM)
- Number of scenarios

Allignol, Barnier, Durand & Blond
Detect & Avoid for UAV Integration
ICRAT 2016, Philadelphia
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Influence of UAV maneuverability

![Graph showing the relationship between UAV turn rate and number of airprox. The graph compares different scenarios for closest and safest distances.](image-url)
Influence of UAV maneuverability

UAV turn rate (°/s)

Mean angle deviation (°)

80 kn closest
80 kn safest
160 kn closest
160 kn safest

UAV turn rate (°/s)
Conclusion

- Detect & Avoid geometrical algorithm
  - Intended to UAVs avoiding surrounding aircraft
  - Heading change maneuvers at constant speed

- Validated through intensive fast time simulation against recorded traffic in TMAs

- Two different strategies
  - Trying to stay as close as possible to mission trajectory
  - Providing a better safety level

- Maneuverability (speed and then turning capacity) is the key for an efficient collision avoidance

- Still a few conflicts remain (mainly with the least maneuverable configurations) that need analysis
Further Work
Strategies Hybridization

![Graph showing the number of scenarios for Closest, Safest, and Hybrid strategies with respect to the closest distance of approach (NM).]
Further Work

Strategies Hybridization

![Graph showing the distribution of scenarios based on the closest distance of approach (NM). The graph displays three categories: Closest, Safest, and Hybrid. The x-axis represents the closest distance of approach in NM, ranging from 0 to 40. The y-axis represents the number of scenarios. The bars indicate the frequency of scenarios for each category at different distance intervals.]
Further Work
Strategies Hybridization

Allignol, Barnier, Durand & Blond Detect & Avoid for UAV Integration ICRAT 2016, Philadelphia 20 / 24
Maneuvers might lead the UAV far from its mission
Need to compute a route back to mission
How to detect end of conflict?
Further Work
Aircraft Trajectory Prediction

\[ \vec{V}_A \]

\[ \vec{V}_B \]
Further Work

Aircraft Trajectory Prediction

\[
\vec{V}_A
\]

\[
\vec{V}_B
\]
Further Work

Aircraft Trajectory Prediction

\[ \vec{V}_A, \vec{V}_B \]
Further Work

Aircraft Trajectory Prediction

Resolution over several time steps

V_A

V_B
Further Work
Enhanced strategy to escape “traps”
Further Work
Enhanced strategy to escape “traps”
Further Work
Enhanced strategy to escape “traps”
Further Work
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Enhanced strategy to escape “traps”
Time for questions

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