Chapter 8

(W) Conclusion and Future Work

To be done here:

- Conclusion of the work (This chapter can not be predicted for now)

8.1 (W) Summary

8.2 (W) Comparison to Other Methods

1. Vector field avoidance [1]
2. Potential field [2]

8.3 (R) Approach Reusability

UTM Services: The constrained *UTM functionality* is outlined in (sec. **??**) including:

1. *Future UTM Communication Architecture* (fig. **??**) as the authority over *airspace segment* (fig. **??**)[3].
2. *Cooperative Conflict Resolution Under UTM Supervision* (fig. **??**) designed as mild/feasible directives (commands) with *constant supervision*.
3. *Rules of the Air Enforcement* (sec. **??**, **??**, **??**) including designs of *Position Notification* (sec. **??**) and *Collision Case Structure/Calculation* (sec. **??**).
4. *Divergence/Convergence Waypoints* concept is showcased in *Overtake Rule* (rule **??**).
5. *Weather Avoidance* (sec. **??**) is using similar concept to *Collision Case*: *Weather Case*. The information are provided by *Local Airspace Authority*.

Emergency Avoidance Functionality: The standard framework implementation (fig. **??**) can handle the situations given in non-cooperative test cases (sec. **??**). The list of threats is given by (tab. **??**).

Event Based Avoidance Functionality: The standard framework implementation (fig. **??**) with active $C2$ link and rules setup (fig. **??**) can handle the situations given in cooperative test cases (**??**). The list of threats is given by (tab. **??**). The *Avoidance Mode Concept* enables to switch between *Event Based Avoidance* (Navigation) and *Emergency Avoidance.*

Note. The emergency Avoidance Functionality is included in *Event Based Avoidance* (Navigation) mode. The prioritization of *threats* may differ (tab. **??**).

Reusability for More Complex Systems: The framework (fig. **??**) with implemented rule engine (fig. **??**) can be used on *any system*, with appropriate *Movement automaton* (sec. **??**) enabling *wave-front* propagation (alg. **??**) for reach set estimation. Following artifacts needs to be delivered for concept reuse:

1. The *Movement Automaton* is used to generate *thick series of waypoints* which guarantees desired degree of safety.
2. The *complex UAS system* is following the *reference trajectory* (sec. **??**).
3. The *Sensor Fusion* (sec. **??**) implementation including classification to *Free*, *Occupied*, *Restricted* space type.
4. The *sensor field* supporting detection of threats. There should be at least one sensor with capability of feeding *Avoidance Grid*. Our implementation was based on LiDAR/ADS-B feeds.
5. The *Information Sources* supporting the online/offline threat processing. This one is completely optional.

Note. On UTM integration: The future UTM system will not giving the extreme commands, the directives are more like constraints, therefore our system can provide the guidance and constraint evaluation

Note. On Safety Margin: The disparity between real flown trajectory (nonlinear dynamics) and planned trajectory (Movement Automaton) needs to be accounted into *Safety Margin.*

Reach Set Approximations: The *wave-front* approach (alg. **??**) can be used with *Constrained expansion function* (sec. **??**) to create own *Reach set Approximation Method.* Existing reach set approximation methods are always following a different goal, they can be reused for other tasks (perf. **??**):

1. *Chaotic* (def. **??**) - high space coverage, ideal for unpredictable and complex avoidance maneuvers.
2. *Harmonic* (def. **??**) - smooth trajectories, medium space coverage, ideal for navigation maneuvers.
3. *Combined* (def. **??**) - combination of the *harmonic* and

   chaotic approximations, the cost function defines preferred trajectories. The procedure is reusable for any reach set approximation types (2^+) combination.
4. *ACAS-X Like* (def. **??**) - following *TCAS/ACAS separation modes*, can be used as alternative for *controlled avoidance* and *navigation.*

8.4 (W) Lessons learned

What can be done differently

- The discretization - euclidian grid vs polar grid
- Intruder modeling ideas, the linear intersection without body volume
- The probabilistic/vs rating approach

8.5 (W) Future Work

1. Adversarial avoidance
2. Real system implementation

Bibliography

[1] Johann Borenstein and Yoram Koren. The vector field histogram-fast obstacle avoidance for mobile robots. *IEEE Transactions on Robotics and Automation*, 7(3):278–288, 1991.

[2] Yoram Koren and Johann Borenstein. Potential field methods and their inherent limitations for mobile robot navigation. In *Robotics and Automation, 1991. Proceedings., 1991 IEEE International Conference on*, pages 1398–1404. IEEE, 1991.

[3] Ingrid Gerdes, Annette Temme, and Michael Schultz. Dynamic airspace sectorization using controller task load. *Sixth SESAR Innovation Days*, 2016.