Technische Universität Braunschweig

Institut für Flugführung

Dynamic Route Optimization based on Adverse Weather Data

Dipl.-Ing. Christina Schilke, Institute of Flight Guidance,

Technische Universität Braunschweig, Germany

Agenda

- **Motivation**
- **State of the Art and Associated Problems with Current Situation**
- **Overview of the Concept and System Architecture**
- **Database – Radar Data**
- **Nowcast Function**
  - Creation of Polygons
  - Tracking of Polygons
  - Vector Calculation
  - Nowcasting
- **Route Optimization Function**
- **Validation with Reference Scenario**
- **Summary and Limitations of System**

Motivation

- Continuously growing air traffic requiring a change in current air traffic procedures
- One of the main goals is to preserve or even improve the current safety level

- Environmental and economic aspects are not to be ignored
  - These factors are enabled through an efficient and flexible design of flight trajectories

- A concept for a dynamic flight path optimization by means of spatial and timely changing variables has been developed

- The focus has been laid on
  - Meteorological boundary conditions (through convective weather)

- The goals are
  - The calculation of an optimized route
  - A minimization of detours

Fig. 1: Cumulonimbus Cloud [1]

State of the Art and Associated Problems

- Nowadays, the pilots get weather forecast information mainly before flight
- The flight route is planned under consideration of the weather forecast
- However, flight route planning cannot always consider convective areas, e.g. as the forecast is imprecise and misses convective cells or as the forecasted convective weather covers a large area that cannot be completely flown around
- During flight, pilots get in most cases only restricted information on weather en route
- Mainly, they get information on areas of high reflectivity from their on-board weather radar, information on lightning strikes from their stormscope, additional information on the weather situation at several airports, and sometimes reports from other pilots
- When using the on-board weather radar, there are some limitations such as the restricted range and angle of beam

Overview of the Concept

- The overall research concept envisages a route optimization regarding a minimization of detours under consideration of the current and nowcasted weather situation
- The study focusses on the airborne flight planning considering dynamic in-flight weather information
- Flight crew regularly receives current radar data from ground radar stations (all 5-15 min) via data link during flight
- Radar data provide detailed meteorological information on areas of high reflectivity
- From the movement of the areas of high reflectivity a nowcast can be generated
- The route is optimized based on the nowcast

Fig. 2: Ground Weather Radar Station in Front of a Supercell Thunderstorm [2]

System Architecture

- Three main components:
  - Database management system
  - Nowcast function
  - Route planning and optimization function

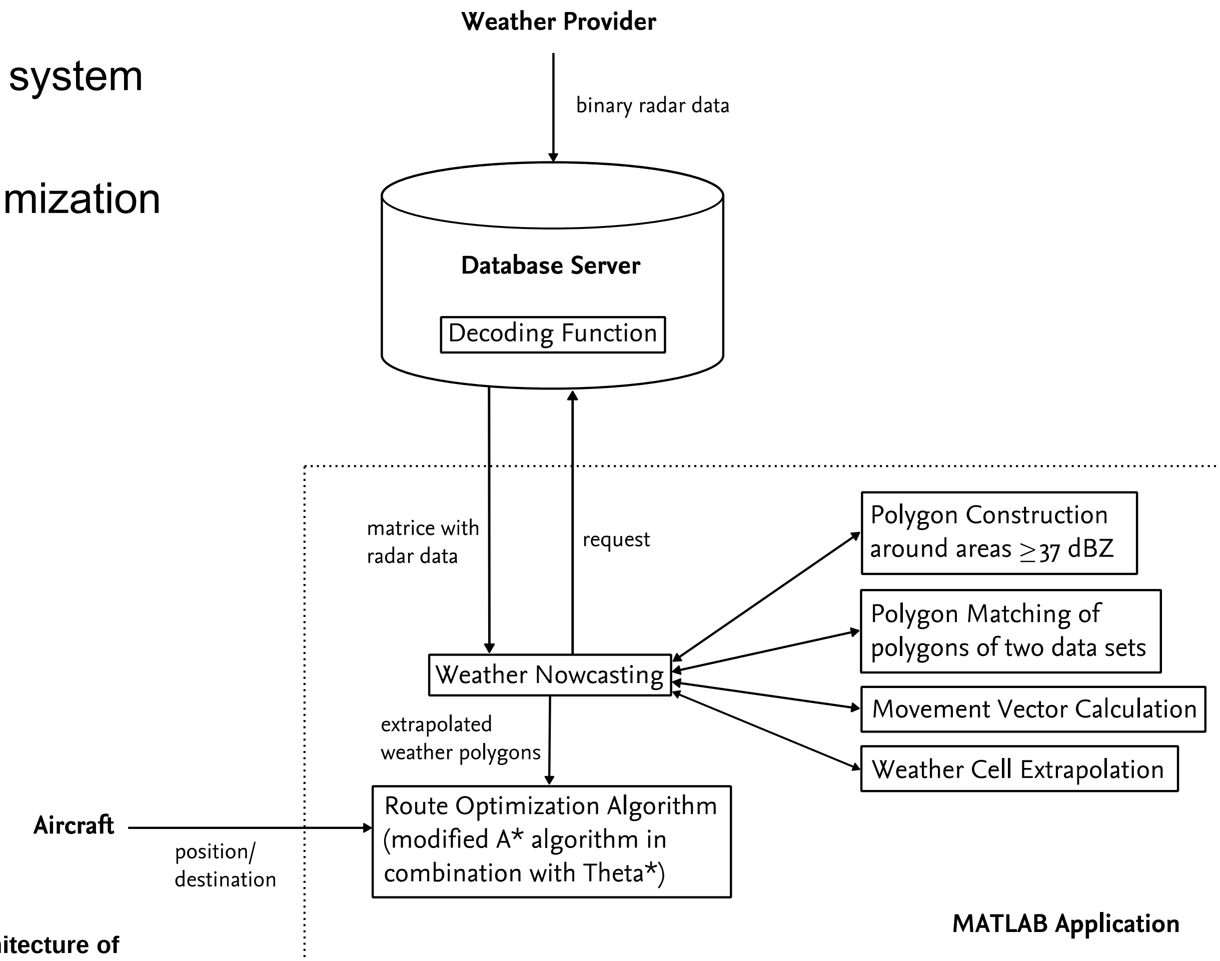

Fig. 3: System Architecture of Route Optimization System

Database – Radar Data

- The database mainly contains volume composite radar data from the German Weather Service (DWD)
- Composite radar data are generated from the output of several weather radar stations
- This data depicts large-scale precipitation areas and is composed of the highest reflectivity from any elevation angle of the radar
- The thicker and wetter the clouds are the higher is the radar reflectivity
- The spatial resolution of the used radar data from the DWD is a 2x2 km grid of Germany
- Every 5 min a new radar data set is generated
- There are small functions in the database in order to decode and store the radar data

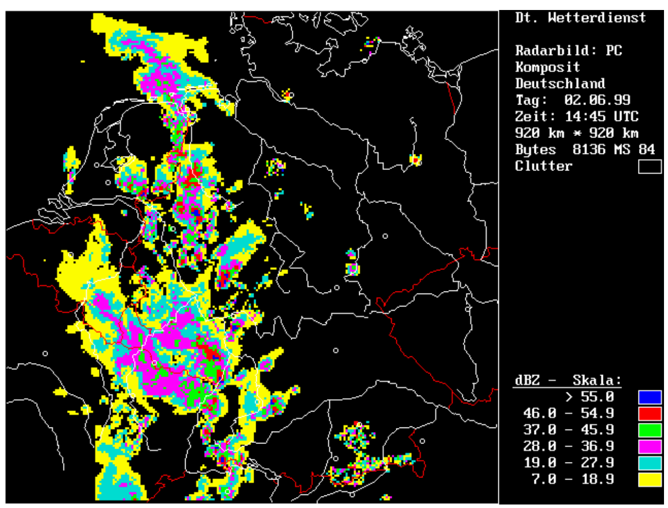

Fig. 4: PC Composite Radar Data from DWD [3]

Nowcast Function

- The nowcast function is composed of different parts
- First, polygons around areas of convective weather are created
- The following algorithms track the polygons from two different radar datasets
- Finally they match the polygons and create a movement vector from the position of both polygons
- Through this movement vector the future position of the storm cell is predicted

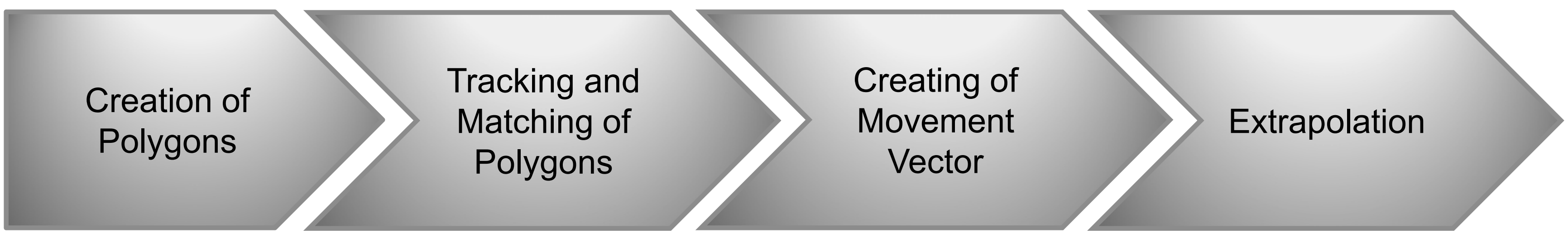

Fig. 5: Parts of Nowcast Function

Nowcast Function – Creation of Polygons

- Thunderstorms can be understood as impermeable objects which have to be circumnavigated
- For convective weather a reflectivity threshold of 37 dBZ can be assumed
- For a reflectivity ≥ 37 dBZ there is in most cases heavy precipitation, severe turbulence, hail, and lightning
- Additionally, experience has shown that pilots often avoid flying through areas of reflectivity ≥ 37 dBZ
- Thus, the algorithm creating the polygons around areas of high reflectivity takes 37 dBZ as threshold

→Every grid point ≥ 37 dBZ is within a contour polygon marking a no-go area

- Finally, the algorithm calculates the centroid and the surface area of each polygon

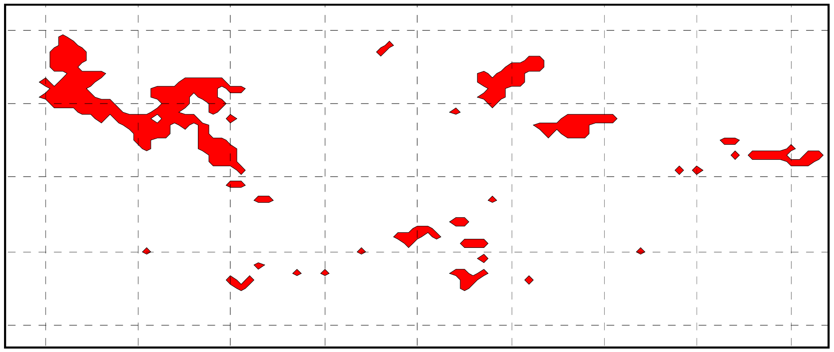

Fig. 6: Contour of Area of High Reflectivity

Nowcast Function – Tracking of Polygons

- In order to match the polygons several characteristics of the current and the previous scan are compared (distance between the centroids of both polygons, difference of the surface area, and overlap of both polygons)
- A convective cell typically moves with maximal 2 km/min
- Thus the matching centroid is searched within a threshold radius concerning a defined time span between both scans
- As well as the searching radius of the centroid is limited, there is also a limit concerning the area difference of the polygons of both scans if the cell does not merge with or split into other cells
- Another characteristic concerning polygon matching is the overlap: if one polygon from the current scan highly overlaps or contains the other from the previous scan, it is probable that the polygons are the same ones

Nowcast Function – Vector Calculation

- For the nowcast, vectors describing the movement of the cells are calculated
- Every polygon from the current scan is associated to a polygon from the previous scan if possible
- So, the movement vector can be calculated from the dislocation of the centroids
- The speed is then the length of the vector in relation to the time span between both radar scans
- If a polygon from the current scan cannot be matched with another from the previous scan, a vector from the mean value of all vectors in the area is calculated

Nowcast Function – Nowcasting

- Concerning the nowcasting, only the motion of the storm cell is considered
- The geometrical form and the size of the different cells stay the same as in the current radar scan
- For the nowcast calculation, the current positions of all centroids are projected to the future with the calculated motion vectors
- In this study, the nowcasting time has been limited to one hour as in most cases the extrapolation accuracy decreases with time
- This decrease of accuracy depends on the considered type of weather phenomenon
  - For individual convective storms, extrapolation nowcasting decreases very rapidly with time (in most cases only useful up to 30 min)
  - However, the extrapolation method may be useful for forecasting the movement of supercell type storms, squall lines, or storm complexes for periods up to several hours

Route Optimization Function – A*- and Theta*-Algorithms

- The path optimization itself is a modified A* search in combination with a Theta* algorithm
- The A* algorithm finds a least-cost path from a given initial node to one goal node
- It follows a path of the lowest expected total cost
- Disadvantage of A*: A* with an octile heuristic creates unrealistic looking paths
- Therefore, A* has been coupled with Theta* which also allows diagonal movements at any angles
- In this study the cost values to fly through an area of convective weather are set very high so that the algorithm avoids planning the route through such areas

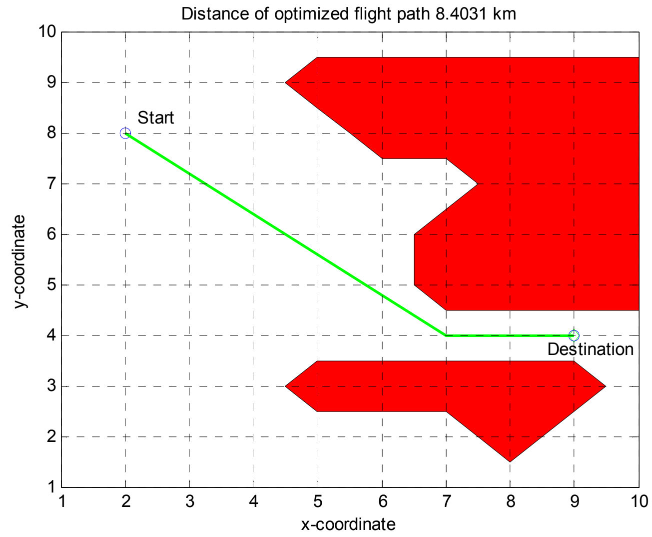

Fig. 7: Path created by A*/Theta*

Technische Universität Braunschweig

Institut für Flugführung

Route Optimization Function

- The initial route calculation based on two input radar sets is a first approach to the generation of the flight path that could be flown
- All grid points where the radar reflectivity is ≥ 37 dBZ are inside red polygons marking the no-go areas
- The shortest distance from the starting point to each grid point is calculated
- A constant flight velocity is assumed and based on this the imaginary flight time to each grid point is calculated
- For each grid point, a calculation of the extrapolation function is done in order to find out how the meteorological situation would be at the time the aircraft would pass this point
- As this initial calculation assumes the direct and shortest path to the target point, several optimizing calculations are done in defined distance steps

Example of a Route Optimization

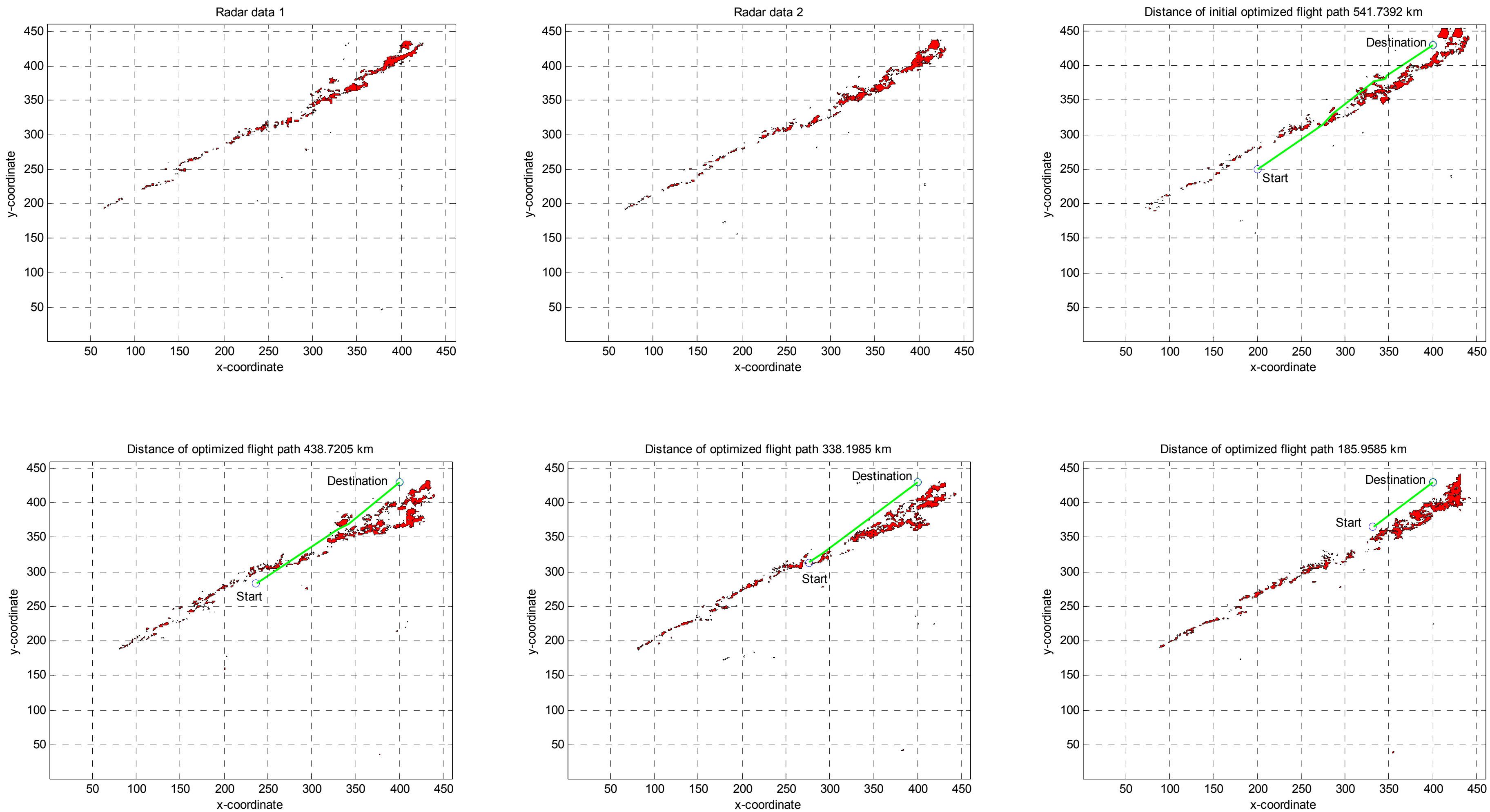

Fig. 8: Input data and several optimization steps

Technische Universität Braunschweig

Institut für Flugführung

Validation with Reference Scenario

- The reference scenario for the validation of the system is loosely based on the current way of circumnavigating around weather hazards
- A case where pilots have to tactically avoid convective cells with on-board weather radar support will be examined
- We assume a radar field of view with a horizontal circular sector described by the two parameters aperture (115° to 360°) and range (80 to 160 NM)
- Concerning the route, a flexible trajectory concept will be presumed and the safety distance to keep to the storm cell will be neglected
- As soon as the track crosses a convective weather cell, the obstacle avoidance maneuver will be simulated
- As the weather hazards are moving during flight, the radar scans have to be regularly updated

Summary and Limitations of System

- Goal of study: creation of an application with which detours can be reduced
- The database for this study and the route optimization algorithms have already been set up
- The development of the reference scenario is ongoing
- The distances of the deviation routes of the developed concept are compared to those ones of the reference scenario in order to analyze in how far detours can be reduced
- This application only considers storm-cell-related circumnavigation
- The nowcasts are based on a simple extrapolation technique, so the development and the decay of cells are not considered
- Furthermore, trajectories of constant speed and with no limitation on the turn rates are created and thus, the aircraft performance has not been considered so far

Acknowledgements

- Parts of the presented work have been funded as a project on the frame of the program Aeronautical Research IV – Aircraft, ATM, and Atmosphere
- This project itself is funded by the German Federal Ministry of Economy and Technology (BMWi) with a co-funding by Airbus Group Innovations
- The weather radar data are provided by the German Weather Service (Deutscher Wetterdienst, DWD)

Thank you!

Technische
Universität
Braunschweig

Institut für
Flugführung

Sources for Figures

1. Fulcrum Safety International, http://fulcrumsafety.com (Last access: September 9 2013)
2. Wikipedia, Wetterradar, http://de.wikipedia.org/wiki/Wetterradar (Last access: November 12 2014)
3. Radar-Verständnis: Grundlagen, DWD-Netzwerk, Produkte, February 22 2003, http://www.wetterzentrale.de (Last access: November 11 2014)