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StraVARIA – Autonomy Considerations for Stratospheric High Altitude Pseudo-Satellites made in Bavaria

Martin Köhler; Andreas Klöckner

In Europe there has been a comprehensive advance on the field of unmanned solar aircrafts during the past years. Improved solar cells and more efficient and lighter aircraft structures enable permanent stationing of solar powered drones, providing a variety of remote sensing capabilities. For this purpose, a combination of an efficient energy system and aircraft configuration is decisive . This is particularly true for the stationing of "High Altitude Pseudo Satellites (HAPS)" in the stratosphere. Within the scope of the collaborative project "Autonomy Considerations for Stratospheric High Altitude Pseudo-Satellites made in Bavaria (StraVARIA)", the DLR Institutes of Atmospheric Pysics and of System Dynamics and Control work on the subproject "Modeling, Control and Weather Detection (StraVARIA-DLR)" in order to increase the autonomy of HAPS platforms. The work encompasses the development of an integrated system model and a weather detection system for instrument flight as well as surveys concerning energy-optimized short-time autonomy. In detail, the involved DLR institutes strive for solutions of three scientific work objectives which are explained in the following: First, a flight control system will be developed which automatically preserves the functionality of a HAPS platform independent of control input from the ground station. Additionally, considerations of the total energy budget will increase safety and use potential. The second scientific objective includes the development of a weather detection system which supports the operator on the ground as well as the automatic control of the platform with distinct and easy to interpret data. This includes for example so called weather-induced "No-Go Areas". A better availability of information about weather hazards will lead to an improvement of the platform safety in manual as well as in automatic mode. The third scientific objective is to realize an integrated simulation which serves to verify the functionality of the developed technologies within the framework of the whole StraVARIA project.

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StraVARIA – Autonomy Considerations for Stratospheric High Altitude Pseudo-Satellites made in Bavaria

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1. Introduction

In Europe there has been a comprehensive advance on the field of unmanned solar aircrafts during the past years. Improved solar cells and more efficient and lighter aircraft structures enable permanent stationing of solar powered drones providing a variety of remote sensing capabilities. For this purpose, a combination of an efficient energy system and aircraft configuration is decisive. This is particularly true for "High Altitude Pseudo Satellites (HAPS)" in the stratosphere. Within the scope of the collaborative project "Autonomy Considerations for Stratospheric High Altitude Pseudo-Satellites made in Bavaria (StraVARIA)", the two DLR institutes of Atmospheric Physics and System Dynamics and Control work on the subproject "Modeling, Control and Weather Detection (StraVARIA-DLR)" in order to increase the autonomy of HAPS platforms. The work encompasses the development of an integrated system model and a weather detection system for instrument flight as well as surveys concerning energy-optimized short-time autonomy. In detail, the involved DLR institutes strive for solutions of three scientific work objectives which are explained in the following: First, a flight control system will be developed which automatically preserves the functionality of a HAPS platform independent of control input from the ground station. The second scientific objective includes the development of a weather detection system which supports the operator on the ground as well as the automatic control of the platform with distinct and easy to interpret data. This includes for example so called weather-induced "No-Go Areas". The third scientific objective is to realize an integrated simulation which serves to verify the functionality of the developed technologies within the framework of the whole StraVARIA project.

2. Weather detection system

At the DLR Institute of Atmospheric Physics we use different algorithms and data sources to detect and nowcast/forecast certain weather hazards like thunderstorms or heavy precipitation cells. These tools, which are explained in the following, plus our meteorological expertise are used within the StraVARIA project.
The two nowcasting algorithms Cb-TRAM [17] and Rad-TRAM [11] are developed at the Institute of Atmospheric Physics. Cb-TRAM (Cumulonimbus TRacking And Monitoring) is a fully automated algorithm to detect, track, and nowcast (= short-range forecast up to 1 hour) intense convective cells (see figure 1) by using satellite data from METEOSAT. Three different development stages of thunderstorms are identified: convection initiation (yellow contours), rapid vertical development (orange contours), and mature thunderstorm (red contours). Instead of satellite data, the Rad-TRAM algorithm (Radar Tracking and Monitoring**)** allows a reliable detection, tracking and nowcasting of heavy precipitation cells

using the European radar composite issued by the DWD (see figure 2). This consists of radar reflectivities given in six dBZ classes with a horizontal resolution of 2 km x 2 km and encompasses an area of 1800 km x 1800 km [16]. The reflectivity values of the radar composite are composed of measurements from 3-dimensional scans of various radars across Central Europe. Due to the fact that the Rad-TRAM domain covers nearly the complete COSMO-DE model area and renders the current storm situation, it can also be applied within the ”Best- Member-Selection” of Cb-LIKE.

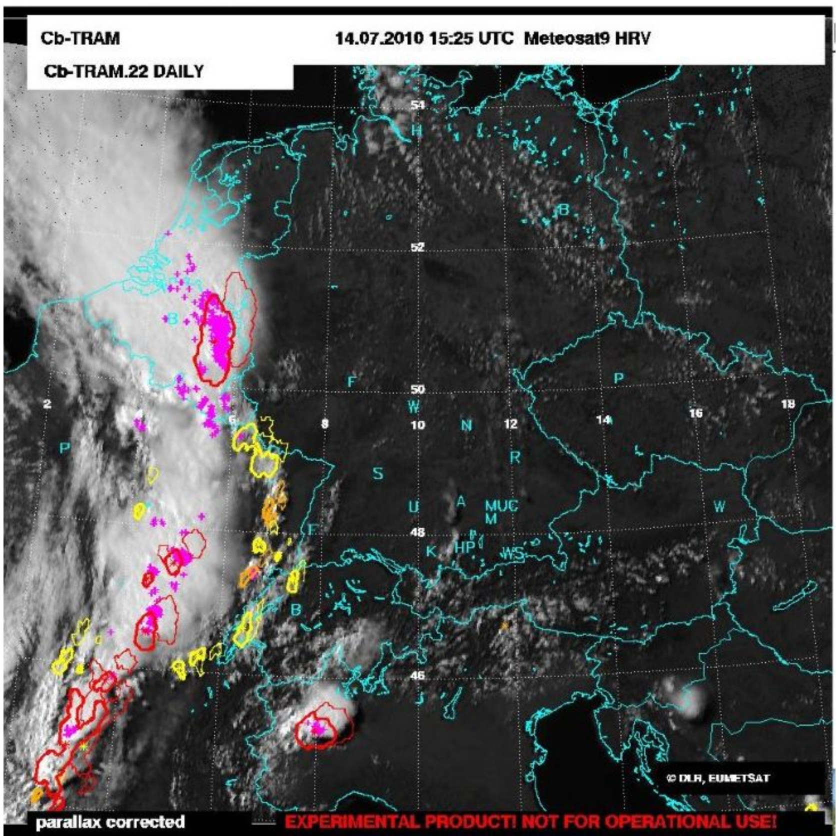

Figure 1: Example of an Cb-TRAM plot with yellow polygons representing stage 1 detections (CI), orange polygons are stage 2 detections (rapid development), and red polygons are stage 3 detections (mature thunderstorms). The dotted lines for each objects show the 60 minute nowcast. The pink crosses represent observed flashes which serve as verification of the detected cells. Source: [15].

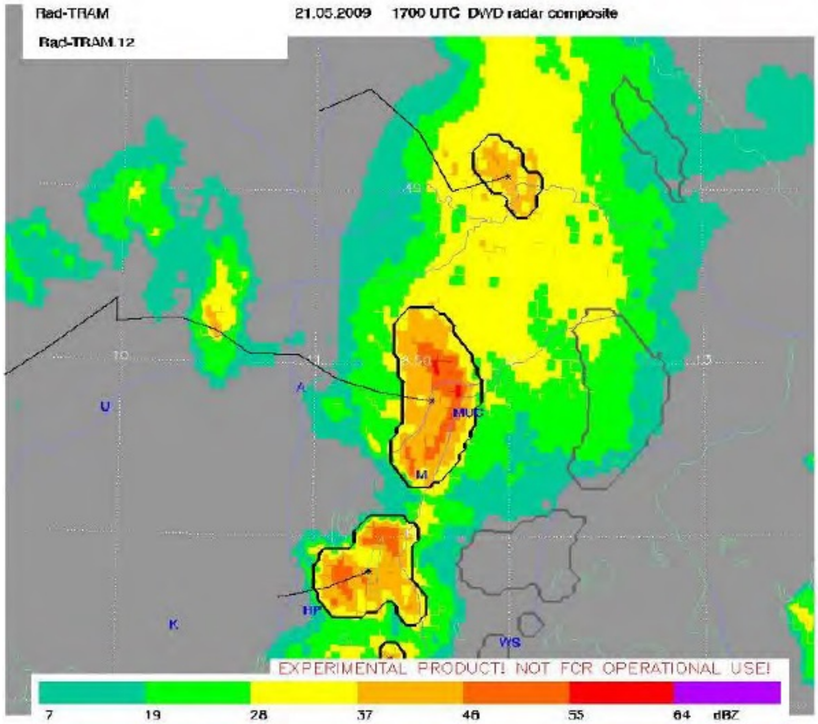

Figure 2: DWD radar composite (colourful shades) over Southern Bavaria overlaid with detected Rad-TRAM cells (black polygons). The grey polygones denote the 1 hour nowcast whereas the black lines represent the recorded tracks of the Rad-TRAM cells. Source: [3].

For the provision of long-term thunderstorm forecasts up to six hours, the algorithm Cb-LIKE (Cumulonimbus-Likelihood) has been developed at the DLR Institute of Atmospheric Physics. Cb-LIKE is an automated system which designates areas with possible thunderstorm development by using output of the COSMO-DE numerical weather prediction model operated by the German Meteorological Service (DWD). The algorithm includes a newly developed "Best-Member-Selection" which allows the automatic selection of that member of a COSMO-DE ensemble that matches best the current weather situation. An innovative fuzzy logic system combines selected model data and calculates a thunderstorm indicator for each grid point of the model domain for the following six hours in one hour intervals. The higher the indicator the more it is likely that a thunderstorm will occur. On figure 3 you can see a four hour forecast of the Cb-LIKE algorithm for Middle Europe. The forecasts are displayed as colored surfaces whereas the blue contour lines represent the observed heavy precipitation cells by Rad-TRAM and serve therefore as verification. As you can see the Cb-LIKE forecasts show a very good performance for this case example. For more information about Cb-LIKE see [12].

Furthermore we use output of the COSMO-DE model of the German Weather Service (DWD) as data source of other important weather data like for example temperature, humidity, or 3d wind. The COSMO-DE model is a nonhydrostatic numerical weather model featuring a resolution of 2.8 km [13]. Within Middle Europe it possesses one of the highest resolutions among all available operational models. It provides forecasts up to 21 hours with a 3 hour update rate between 0000 and 2100 UTC and the domain covers Germany and parts of the neighbouring countries (figure 4). Its grid comprises 421x461 points and 50 vertical height levels. In contrary to its precursors (e.g. COSMO-EU [14]) the COSMO-DE model features a full resolution of large convective phenomena (no parameterization of deep convection) as a result of its high grid resolution [1]. As a consequence it is a logical choice for the application in operational thunderstorm forecasting in Middle Europe (as main data source for Cb-LIKE) and it can be also considered as best data source of further important atmospheric parameters as mentioned before.

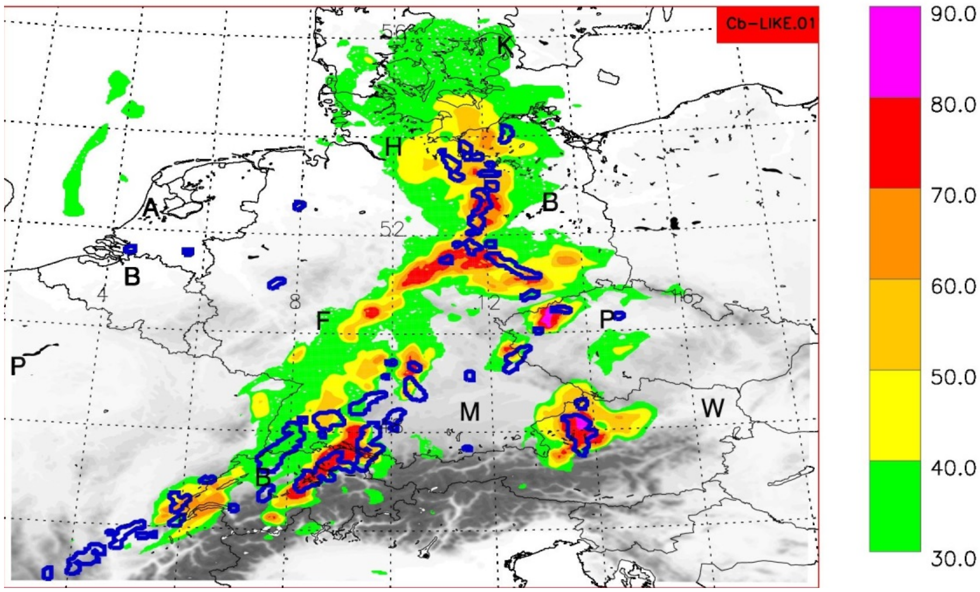

Figure 3: Example of a four hour Cb-LIKE forecast for 1600 UTC (22 June 2011) using the COSMO-DE model run from 1200 UTC. The Cb-LIKE prognoses are displayed as colored surfaces. The blue contour lines represent heavy precipitation cells observed by Rad-TRAM at 1600 UTC and serve therefore as verification of the Cb-LIKE forecasts. Source: [12].

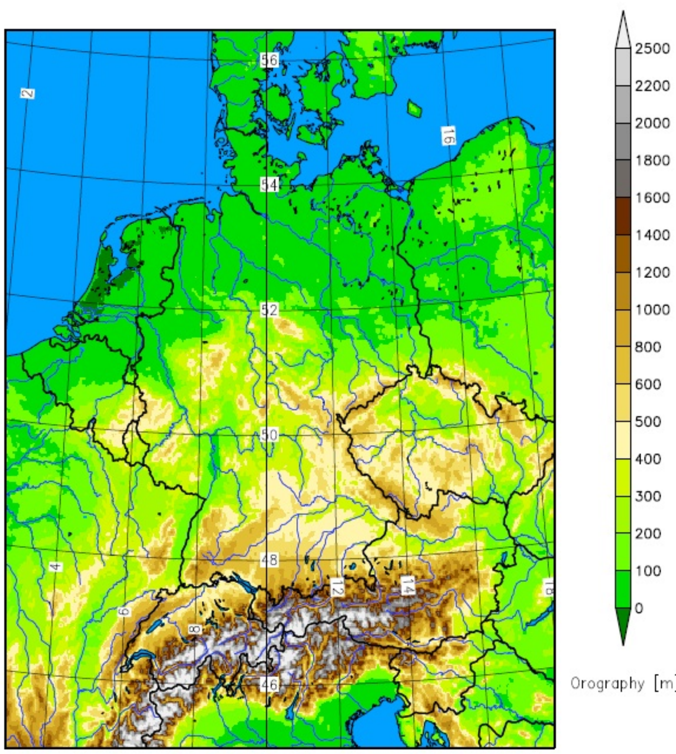

Figure 4: The whole domain covered by the COSMO-DE model which is driven by the German Meteorological Service (DWD). Source: [1].

3. Integrated system model and flight control strategies

In order to validate the results in the total project, a simulation environment is required, which integrates all developed functionalities. To this end, DLR develops an integrated system model, representing the relevant properties of the aircraft (e.g. flight dynamics, energy system), its environment (e.g. solar radiation, wind, turbulence) and the mission objectives and parameters for representative reference scenarios. In cooperation with all partners, the algorithms developed in the various work packages are integrated in an overall simulation and evaluation model [see also [6], [10]].

DLR also develops flight control algorithms as a direct interface to the aircraft model. The flight control converts trajectories into control commands for the aircraft, such as surface deflections and throttle positions. Central limits of the aircraft will be covered in this module, which will be based on non-linear dynamic inversion [2] and total energy control [5].

In addition to the low-level flight control, high level flight strategies are provided. These are accessible by the outer planning layers (developed by the partners) as primitives to be executed aboard the aircraft. Also, safety critical fallback solutions and prerequisites will be implemented in the integrated flight control system.

The contained mission management will receive abstract mission plans from the mission planners (developed by the partners) and execute them according to the aircraft's capabilities. In case of failures, it will automatically react to these events and report the changed circumstances back to the mission planning entities. In this way, critical short-term decisions regarding flight path and payloads can be taken locally aboard the aircraft even under link-loss conditions and without interference by the operator.

Mission management in this context will be implemented in the framework of behavior trees [4] which provide a very natural and modular way to represent the required sequences and alternatives in a state-machine-like execution scheme [[6], [8], [9]].

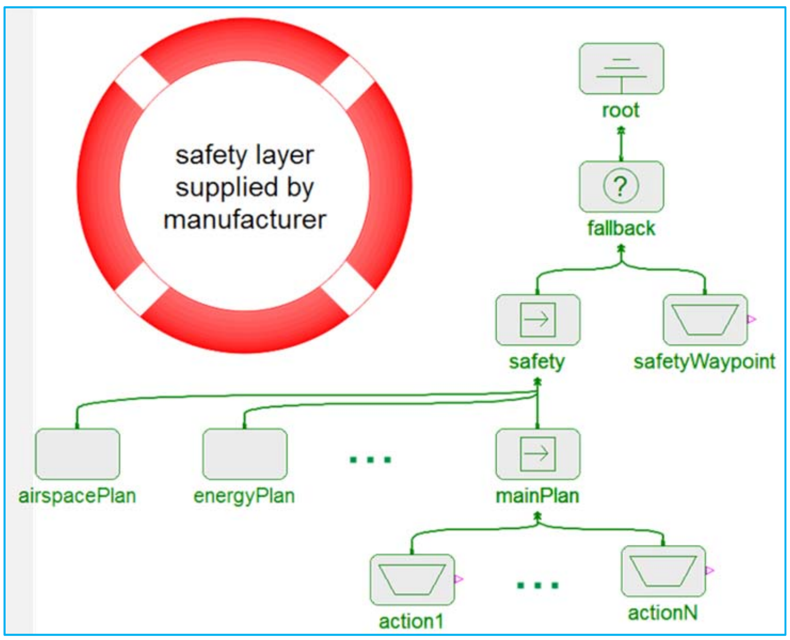

Figure 5: Behavior tree mission management. High-level safety procedures as provided in the mission management module.

4. Conclusion

The application of our tools and expertise within the StraVARIA project will have a positive effect on the framework conditions for remote sensing using HAPS platforms and drones in general. The new flight control system will increase safety and enables a much longer stationing in the stratosphere. In addition, better availability of information about weather hazards will lead to an improvement of the safety in manual as well as in automatic mode and will also enable the application of platforms in situations including high weather activity in the area of operation.

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