Blade
Runner

Developing and testing intelligent autonomous aircraft

In *Do Androids Dream of Electric Sheep?*, a science fiction story by Philip K. Dick and later the action film *Blade Runner*, a central question is whether autonomous, high-tech machines are capable of dreaming. If they are, what do the German Aerospace Center's unmanned research aircraft ARTIS and Prometheus dream of? They dream of their experimental flight environment, of possible missions and, even more exciting, of missions yet impossible.

Prometheus, the newest member of the Institute of Flight Systems' research fleet.

30 cm

Anntena | Magnetometer | Remote control | Sonar | Current supply | GPS | Flight control processor | IMU | Antenna | Image processing | Stereo camera

DLR's research UAVs (like ARTIS here) contain numerous onboard systems. These are used for stabilization, flying preset trajectories, automatic take-off and landing, and so on.

Mission Impossible

The missions under investigation by researchers at the German Aerospace Center's (DLR) Institute of Flight Systems are dangerous, dirty, and dull. Only missions like these justify the expense of developing unmanned aircraft. For all other missions, the hand on the control stick has always been, and will always be, human. But wherever someone – or something – has to enter an obstacle-ridden scenario, investigate a disaster site, fly at high risk under extreme conditions, or make tedious relay or inspection flights, unmanned aerial vehicles (UAV) come into their own. In theory. And to some extent in practice: Modern UAVs can fly along pre-planned waypoints, and some can take off and land automatically. However, there is not a single UAV that is allowed or even able to operate in Germany's general airspace, because at the moment, they quite simply lack the ability to "see" their environment and react to it appropriately.

Artificial Sensory Organs

This is where the research begins. To perceive its environment, a UAV needs additional equipment such as image sensors for a two-dimensional, or even better, three-dimensional view of its surroundings. Cameras, radar and laser scanners can all be used. The captured sensor data must then be processed in real time so that the results can be used for flight control. A decision system or mission manager also has to be developed; this will receive environmental data and UAV-specific data and use it to assess options, make decisions, and if necessary even change the route or abort the mission in an emergency. The flight controller also has to meet tougher requirements, especially with regard to its precision and its ability to utilize the aircraft's maximum flight performance.

Flying Research Platform

But before even beginning to tackle these demanding tasks, a suitable research platform and infrastructure have to be set up. Looking round the market to find a suitable experiment platform, one very quickly realizes that an off-the-shelf system will never fulfill these very particular research needs. Only a custom development can provide the necessary combination of special, powerful, modular sensors and processors, open interfaces and easy programmability to meet the need for a large payload and good usability. It also covers certification aspects and customer expectations, and ensures that the basic system, measuring equipment, onboard electronics and flight control processor are optimally coordinated.

Technical Components

The research platforms that were developed consist of flight control computers, different data commu-

World modeling and mapping in real time during fully automated flight over unknown terrain.

ARTIS, the Autonomous UAV

At the DLR's Institute of Flight Systems in Braunschweig, Germany, researchers are using small unmanned helicopters to develop an experimental aerial vehicle called ARTIS (Autonomous Rotorcraft Testbed for Intelligent Systems). The project aims to investigate new kinds of systems and algorithms for autonomous, intelligent functions and evaluate them in experiments. In addition to an onboard computer and data link, ARTIS has a variety of sensors such as satellite navigation (GPS), an inertial measurement platform and a magnetometer. Imaging sensors (such as video cameras) are extremely important. Functions for machine decision-making, collision avoidance, and cooperation between several flight systems are major research focuses, in addition to advanced flight control and flight guidance concepts. Real-time image processing systems are also used for experiments on optically supported navigation and world modeling.

nication devices, a high-precision GPS receiver system, a three-axis acceleration and rotation speed sensor, and a sonar device for measuring the altitude above ground. A three-axis magnetometer is also included. These modules are all needed to stabilize the UAV, to fly it on preset trajectories, and to have it take off and land automatically. The individual vehicles are all fitted with the same sensors and control processors. Each of the three ARTIS helicopters (midiARTIS, meARTIS and maxiARTIS) implements a different drive concept: two-stroke engine, electric drive or turbine. The rotors are between two and three meters in diameter, and the maximum take-off weight is 25 kg. Prometheus, in contrast, is a pusher propeller airplane with a twin-tail unit. Collectively, these aircraft cover tasks that demand highly precise navigation in a confined space, and also tasks that require a long range and high flying speed.
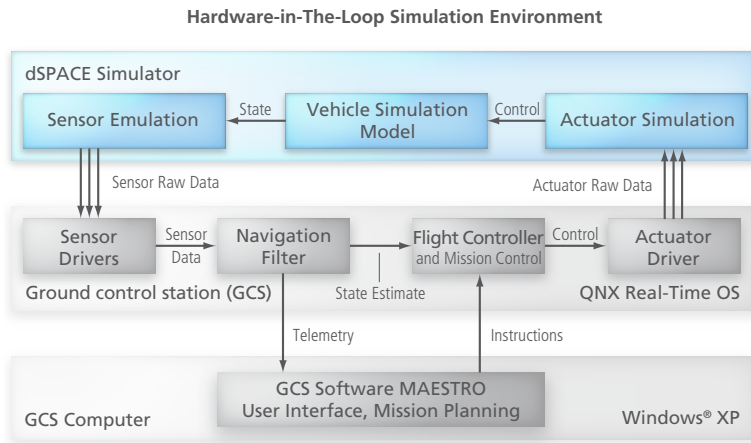
Mathematical Description of Flight Behavior

While the real flying system is being set up, a mathematical description of the system's mechanical flight behavior also has to be developed. This is the basis for setting up a flight controller that will automatically stabilize the aerial vehicle and steer it towards waypoints. Physical relations and captured data (from wind tunnel tests, for example) are combined to create a simulation model of the aerial vehicle. The model's parameters can be determined precisely by applying the same control inputs to the real flying system and to the model, recording the responses of both, and minimizing the differences between their responses by adjusting the model parameters. If the model's behavior and the real behavior are not consistent enough, the model can be extended or refined in an iterative process. The result is a precise, numerically and analytically acces-

sible description of the controlled system.

Developing a Flight Controller Model

This model was implemented in MATLAB®/Simulink® and then immediately used to develop the controller in a desktop simulation. However, to perform its tasks, the flight controller requires precise information on the vehicle's attitude and position, so the navigation algorithms also had

Hardware-in-The-Loop Simulation Environment

dSPACE Simulator		
Sensor Emulation	→State→ Vehicle Simulation Model ←Control←	Actuator Simulation

Sensor Raw Data   Actuator Raw Data

Sensor Drivers	→Sensor Data→ Navigation Filter	Flight Controller and Mission Control	→Control→ Actuator Driver
Ground control station (GCS)	State Estimate		**QNX Real-Time OS**

Telemetry   Instructions

GCS Computer	GCS Software MAESTRO User Interface, Mission Planning	Windows® XP

The dSPACE system simulates all the sensor data, so for the UAVs, the simulated flight in the laboratory is just like a real flight.

to be included in the simulation. Since navigation uses the individual sensors, these were also represented in the simulation with their protocols and their noise and time behavior. These sensor simulations take the data they need from the simulation of flight mechanics. The simulation also includes a wind and gust model,

Real-Time Simulation
This approach cannot be used to investigate the functioning and behavior of the flight control computer, especially with regard to its real-time capability and correct connection to the hardware interfaces. A dSPACE system provided the solution: to partition the simulation, largely

Flights in the Lab
In practical terms, all the sensors are simply disconnected from the flight control computer and substituted by dSPACE-simulated sensor data via compatible connector plugs. The flight control computer processes the serial data with the original drivers and settings, computes a navigation solution, and generates a command. The command is directly executed via the original actuators and also returned to the dSPACE system. The latter uses the command itself, the system dynamics and the environment to calculate a response to the command, and then simulates the corresponding sensor data. To return to the image of the dreaming air-

> "Two factors contribute to the successful development of unmanned aerial vehicles, but they are seldom mentioned and always underestimated: the safety pilot and the dSPACE system for hardware-related simulation. Both of them considerably reduce the 'drop height' of test flights."
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> *Dr.-Ing. Gordon Strickert, German Aerospace Center (DLR)*

plus a ground contact model for take-off and landing. An interface to the UAV's ground control station was set up for easy and realistic handling. Another interface to the outside world allows the position and attitude of the simulated system in its environment to be visualized. All these elements make it possible to plan, fly and observe entire missions in the laboratory. Controller development, parameter tuning, protocol tests, communication tests, and test flight preparation can all be performed within this infrastructure.

using the same function blocks that were developed under Simulink. The navigation and flight controller were taken out of the simulation and performed by the original flight control computer instead. All other functions were ported to the dSPACE system, where they provide real-time simulation of the sensors, the environment, the flight mechanics and the actuator dynamics. Additional conditions such as wind, sensor noise and the failure of entire sensors can easily be set in the dSPACE ControlDesk® experiment software.

craft: The UAV dreams of its mission and reacts accordingly, all the time sitting safely in the laboratory.

System Tests
This kind of hardware-in-the-loop (HIL) simulation has proven to be extremely useful and is being used intensively in development. Subsystem tests, final system tests, algorithm adjustment, interface tests, etc., are always performed in this environment. The simulation is also combined with the powerful visualization environment and used for
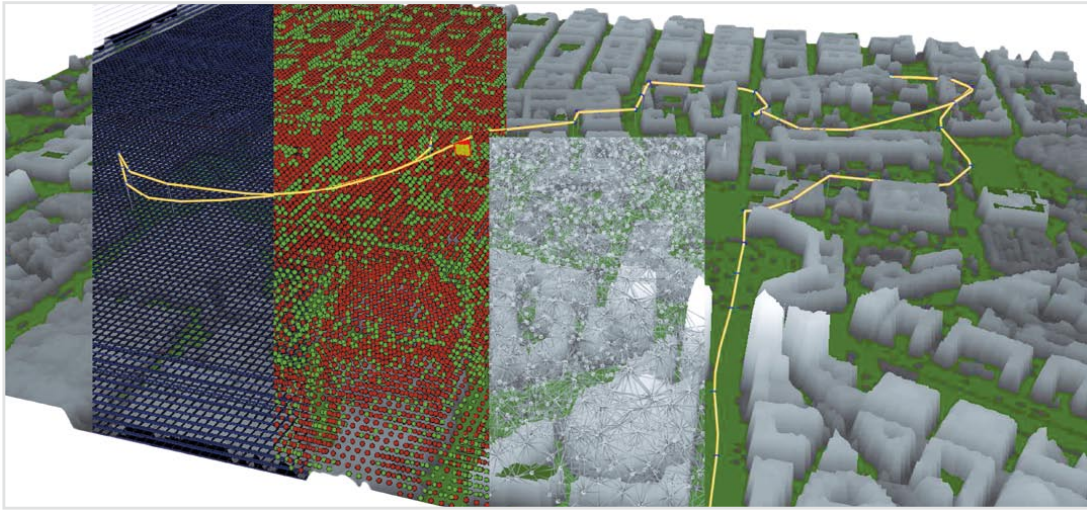
parameter studies, quality management and, last but not least, real-time presentations.

Virtual Flying Class

The UAVs have by now learned to fly in this simulation environment: beginning with careful hovering for the helicopters, then waypoint flight, automatic take-off and landing, and finally even aggressive rapid flight along what are called three-dimensional spline paths. Methods of automatic world modeling and processing, and of three-dimensional map creation, are currently being tested here. This means that the new environment sensors also have to be integrated into the HIL simulator for simulation.

Real Missions

The experimental aerial vehicles regularly have to withstand the test of real flight missions. The cables to the dSPACE system are removed for these, and the normal sensors are connected. Software modifications or reconfiguration are not necessary. Thanks to uncountable hours on the simulator, the system behavior is already known with sufficient precision, and test flights seldom produce surprises. The team can

concentrate fully on real, non-simulated effects and complications.

Autonomous Helicopter

As a result of this work, ARTIS is one of only a few automatic helicopters in the world that can move across unknown terrain, create a map of their environment completely independently, and operate within that environment collision-free. The test flights are turning what were once machine dreams into tangible, measurable realities. ■

Dr.-Ing. Gordon Strickert,
DLR Braunschweig

Automatic route planning in complex low-level flight scenarios.

In Brief

- Developing autonomous unmanned aerial vehicles
- Simulating complex spatial environment models in real time
- Optimizing the controller on the dSPACE Simulator

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