NDIA 2007

“Real-Time Trajectory Planning (RTTP) for Targets”

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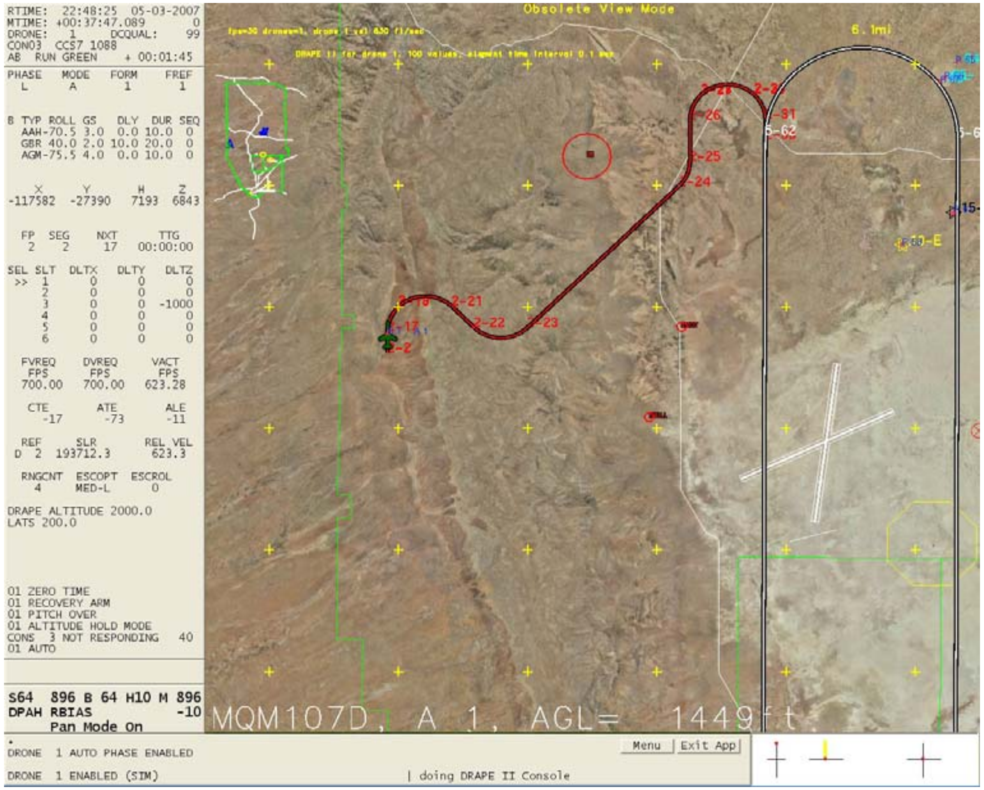
“RTTP in Action-MQM107E Simulation”



Project Description

- Develop a RTTP to safely generate target presentation profiles in real-time.
- Demonstrate application of AI and a high resolution environmental DB to threat presentation management
- Reduce man-hours required to develop flight profiles, reduce RCO workload and increase mission flexibility.
- Brings threat management system closer to allowing project personnel to safely control target presentations.

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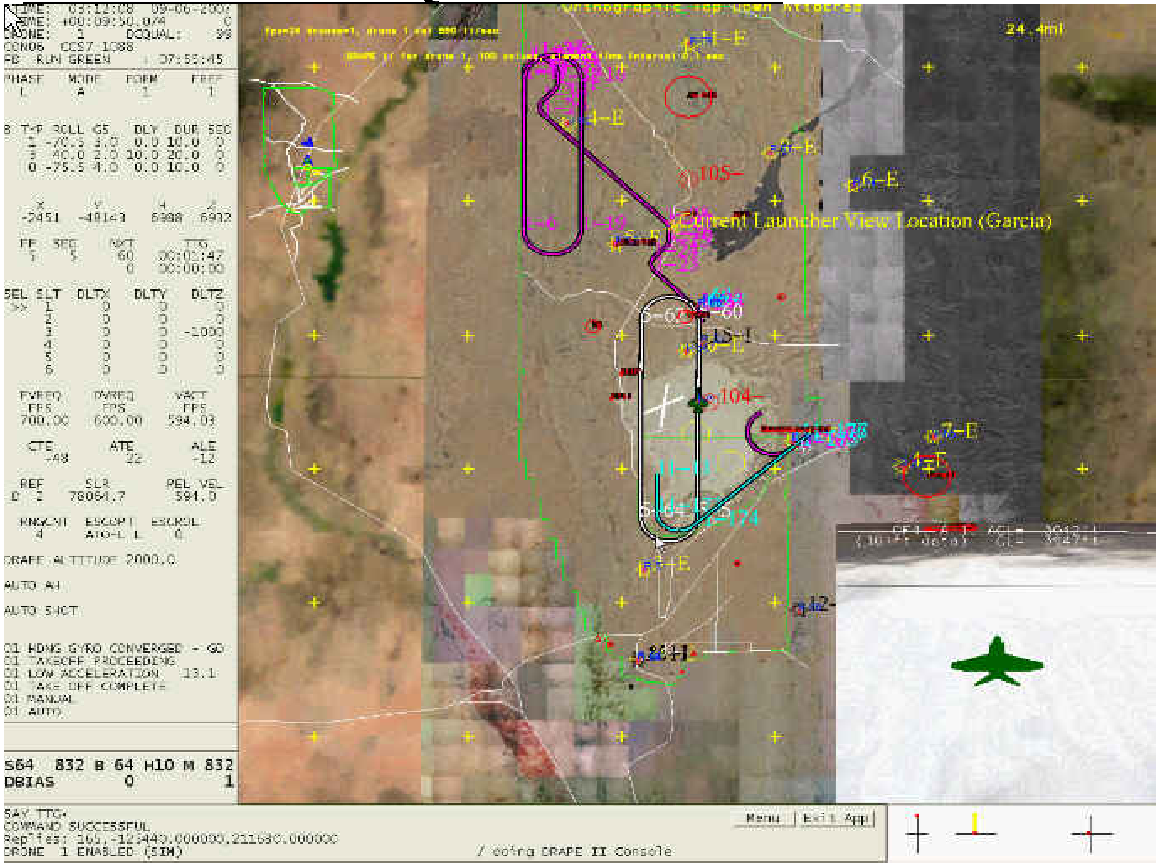
3D Video

NDIA 2007

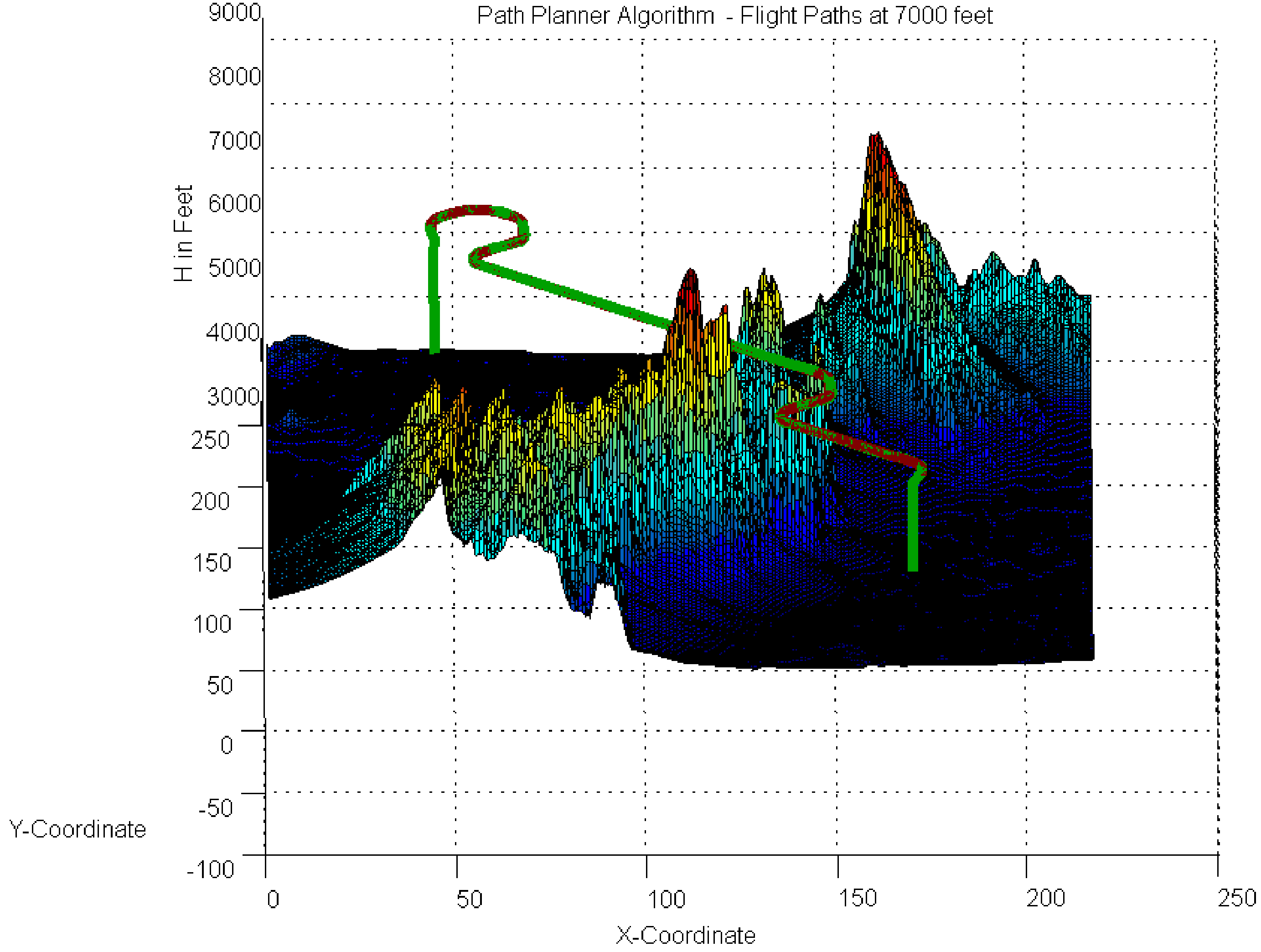
Real-Time Trajectory Planning for Targets

“RTTP in Action-QF4 Simulation”



3D Video

RTTP Trajectory 3D Plot



Briefing Outline

“Real Time Trajectory Planning”

- DFCS
- Problem Statement
- Project Overview
- RTTP Hardware and Software
- Simulation Results
- Future Work
- Questions

DFCS

- The RTTP was integrated into the Drone Formation Control System. The DFCS is a target control system at WSMR. Its mission is to control single and/or multiple unmanned full-scale and sub-scale targets for the Army to test and evaluate new threat systems under different scenarios. DFCS can control the QF-4 full-scale target, the BQM-34A and MQM-107 aerial targets and ground targets such the M-60 and T-72 tanks and the M-812 five ton truck.
  - Simulation – Very accurate 6-DOF models for all aerial targets
  - Navigation
    - Use weighted LSQ filter to process Distance Measuring Equipment (DME) data
    - Use Kalman filter to derive velocity and target accelerations from GPS position data; use target acceleration and telemetry to propagate target position during GPS data link outages.
  - Guidance – Flight Pattern guidance and Waypoint guidance
  - Control – Ground system handles the low frequency loops, the autopilot handles the high frequency control. Both use PID and Non-Linear control techniques.

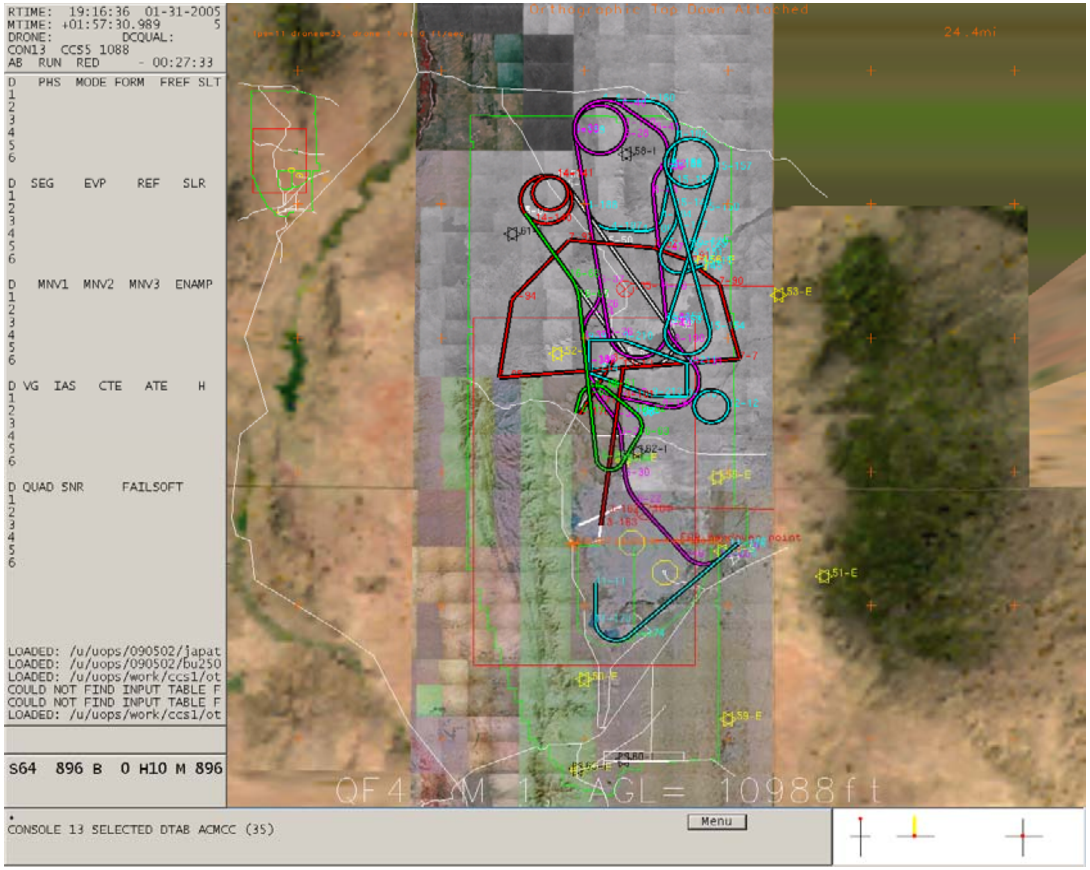
Problem Statement

- The Guidance Algorithms presently used by target control systems utilize flight patterns (FP) composed of circular arc segments and straight segments. These FP must be created prior to the mission. Present target control systems have the capability to translate and rotate these patterns in real time, however changing the geometry and symmetry of these patterns is a very cumbersome process that cannot be safely done in real time.

- These target control systems do not have the capability to automatically generate flight trajectories that are safe to fly at low elevations over mountainous terrain and avoid flying over pre-defined no-fly zone areas.

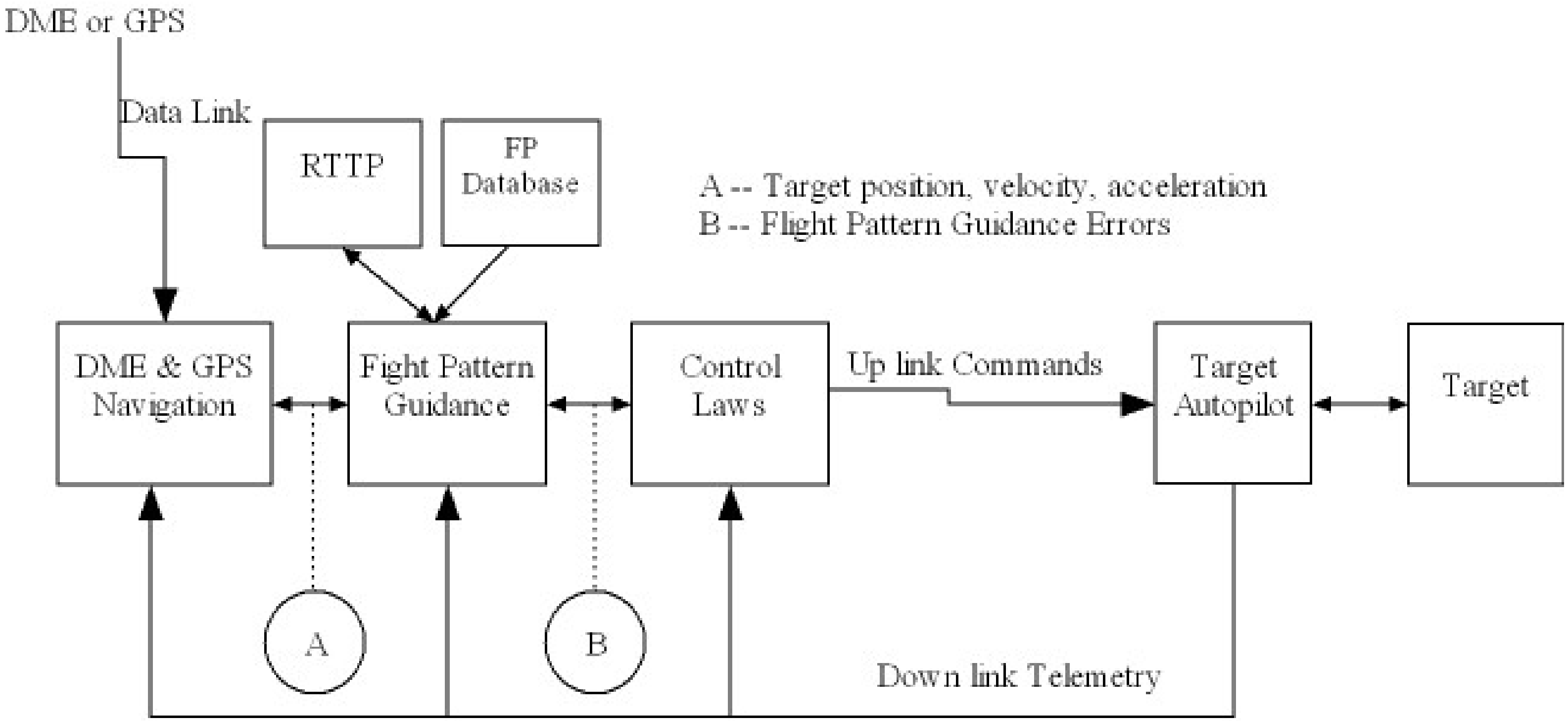
- The mission operator will have the capability to generate flight pattern profiles in real time by simply providing the start and termination coordinates of the desired pattern.

Project Overview
DFCS Typical Man-Made Flight Profiles



Project Overview (cont)
DFCS Controls and Displays

Project Overview
DFCS/RTTP Architecture



Project Overview (cont)

- The DFCS communicates with the RTTP via UDP. The DFCS controller can control RTTP functions via keyboard commands entered at the controller's console.
- Automatically selects the best path given a starting point and the goal. The best path decision is based on a cost function that includes, terrain information, aircraft velocity, and no fly zone areas such as range boundaries and optical sites.
- Uses splines constructed of straight segments and variable size radius arc segments to develop flyable paths. The turn radius (R) is proportional to the target ground speed (Vg) for a given target bank angle (ǿ) and vertical acceleration (Az)
- Uses the A* algorithm to determine best path based on DTED level 2 data and pre-determined no-fly zone areas.

Project Overview (cont)
A* Algorithm

- Search Graph – a 2D plane at elevation h = UAV MSL altitude, partitioned at intervals equal to the UAV turn radius
- Path Returned – NULL or a series of nodes linking the start location and the destination location
- Evaluation function – orders the nodes for expansion (the sum of cost and heuristic functions)
- Cost function – Obstacle Avoidance, Minimum AGL, Start and Destination Headings, Penalizes locations
- Heuristic function – 2D Euclidean distance on h = UAV MSL altitude plane

Project Overview (cont)
Flight Pattern Generation

- Iterative A* Search – Discards A* routes that are not maneuverable by the UAV
- Waypoints – Output processed from maneuverable A* route
- Flight Pattern – Output processed from waypoints

Project Overview
RTTP Commands

PATH ASTAR	Request FP from RTTP with specific attributes: target #, initial route position, initial true heading, FP altitude, final route position and heading, minimum FP AGL allowed, maximum expected target ground speed.
ADD ASTAR	Request FP from RTTP with the following attributes: target #, final route position and heading, minimum FP AGL allowed, maximum expected target ground speed. The start position and flight pattern altitude and initial FP heading are equal to the position, heading and altitude of the target at the time the command is entered.
SEG ASTAR	Request FP from RTTP with the following attributes: target #, final segment number, minimum FP AGL allowed, maximum expected target ground speed. The start position and flight pattern altitude and initial FP heading are equal to the position, heading and altitude of the target at the time the command is entered. The final FP heading is the heading of the start segment on the connecting FP.
ENA ASTAR	Enable UDP communication between RTTP and DFCS
INH ASTAR	Inhibits UDP communication between RTTP and DFCS

Project Overview (cont)

- The generated flight patterns are displayed on the DFCS consoles.
- The operator has the capability to delete unwanted flight patterns and re-generate any other pattern in real time.
- The RTTP can also be used to generate flight patterns in off-line mode; prior to the actual mission. The generated patterns can also be saved into files and retrieved at any point in time per user request.
- The RTTP co-exits with legacy DFCS guidance and control algorithms including with the DFCS nap-of-the earth algorithm named DRAPE. Once the FP is generated by RTTP, the automatic control is done using legacy DFCS control algorithms to control the speed, cross track and the altitude of the target.

Project Overview (cont)

- The operator has the capability to change some of the cost function parameters in real time based on desired mission objectives (i.e. desired target altitude above ground level, maximum target speed, and minimum AGL altitude allowed.

- Presently, the RTTP process resides in a separate Windows based computer. This computer is designed to act as a server for any target control system that uses legacy DFCS flight pattern guidance and control algorithms; TCS, GRDCS and TTCSU.

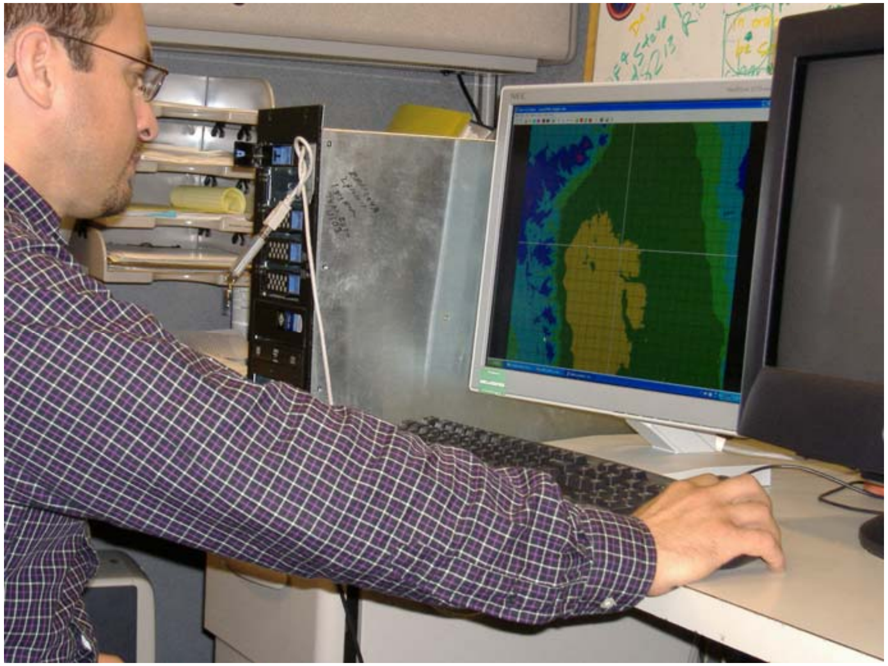
- The RTTP will protect the operator against selecting start and destination points that do not make any sense.

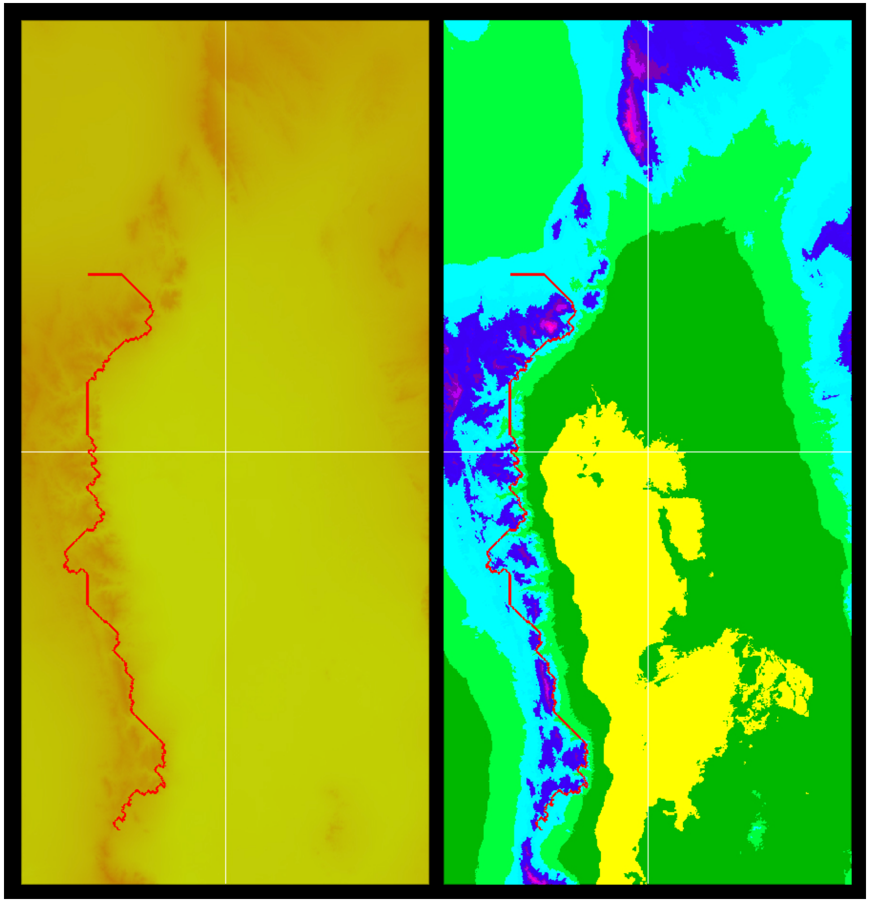
RTTP Hardware and Software

- Dual core 3.5 GHZ Windows based PC, 2 gigabytes of memory
- Windows XP
- C++ OO Design
- DTED Level 2 data
- Applicable to DFCS, TCS, GRDCS or TTCSU

RTTP Test Bed

A* Path generation over WSMR using computer mouse





RTTP Simulation Results

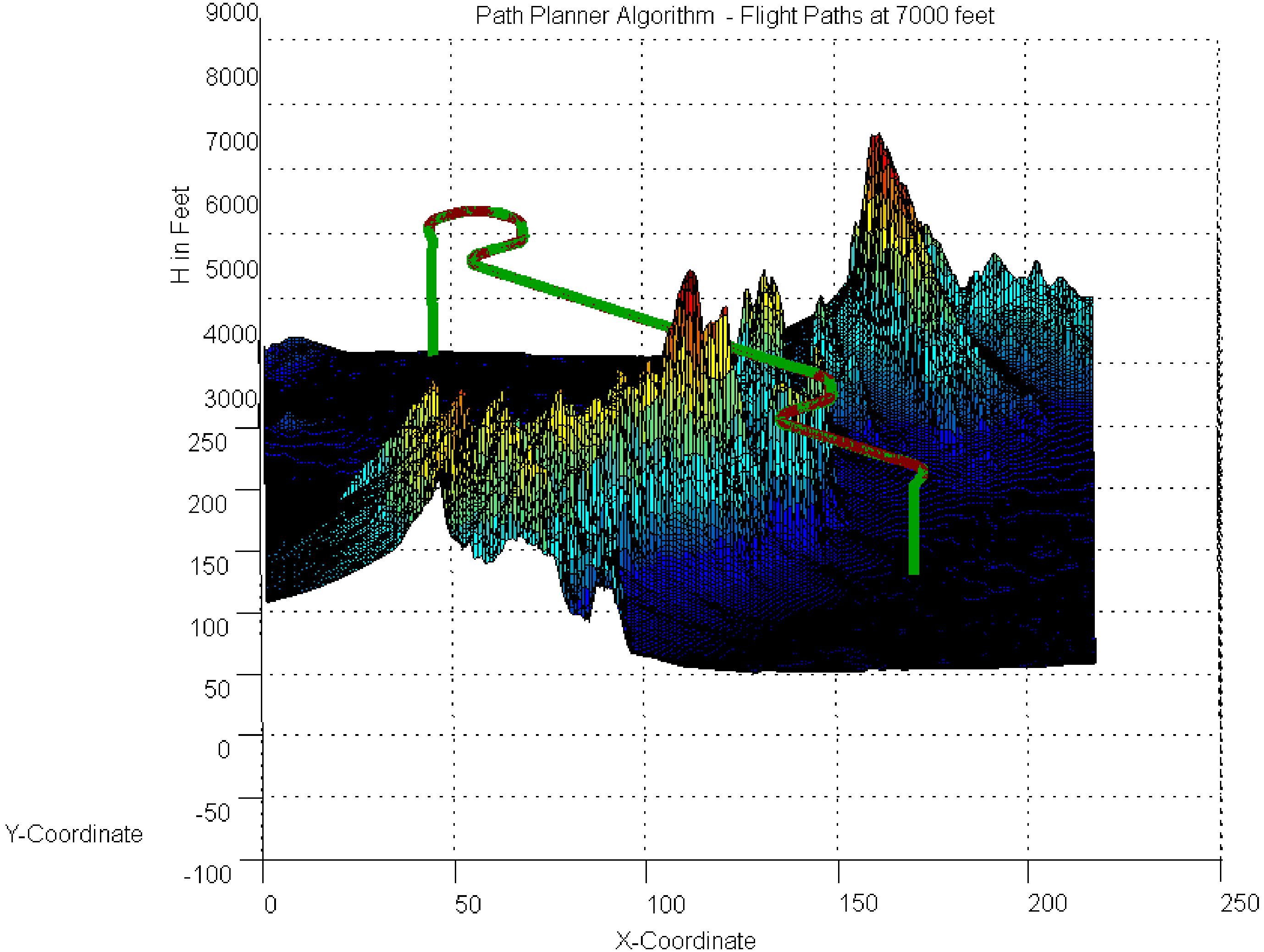
- Plot 1 shows a 3D plot of the path generated by the RTTP algorithm. The SEG ASTAR command was used to generate a path between two existing flight patterns.
- Plot 2, subplot 1, shows terrain underneath pattern below FP altitude
- Plot 2, subplot 2, shows target AGL altitude stayed above the minimum AGL allowed.
- Plot 3 shows the terrain elevations close to the target.
- Plot 4, subplot 1, shows the cross track error during flight. The maximum error was > 500 feet.
- Plot 4, subplot 2, shows the roll command is limited to 60 degrees.
- Plot 4, subplot 3, shows the normal accelerations stayed below 2.5 Gs
- Plot 5, subplot 1, shows the target stay with the rabbit; small along track errors.
- Plot 5, subplot 2, shows slight speed variations from the commanded speed of 600 fps.
- Plot 5, subplot 3, shows good altitude control.

Simulation Results (cont)
Conclusion

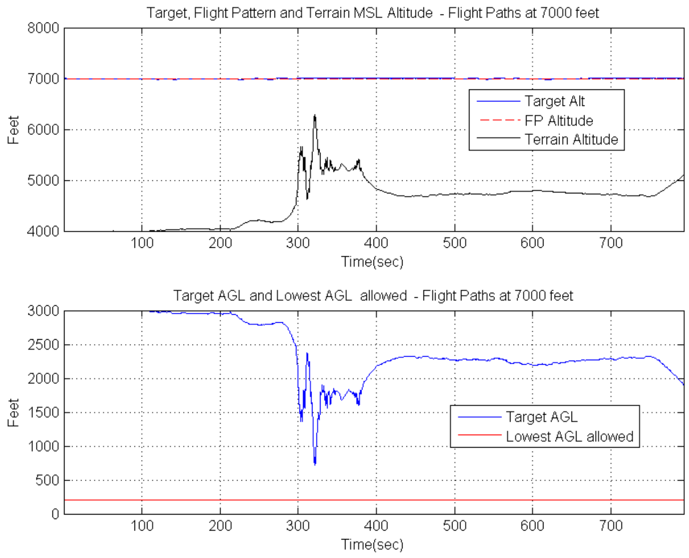
- Cross track can be considerably improved by making the commanded (rabbit) speed at least 10% lower than the expected flight pattern speed used to generate the pattern. This would insure that the flight pattern turn radii are large enough for the target to stay on the pattern during turns.

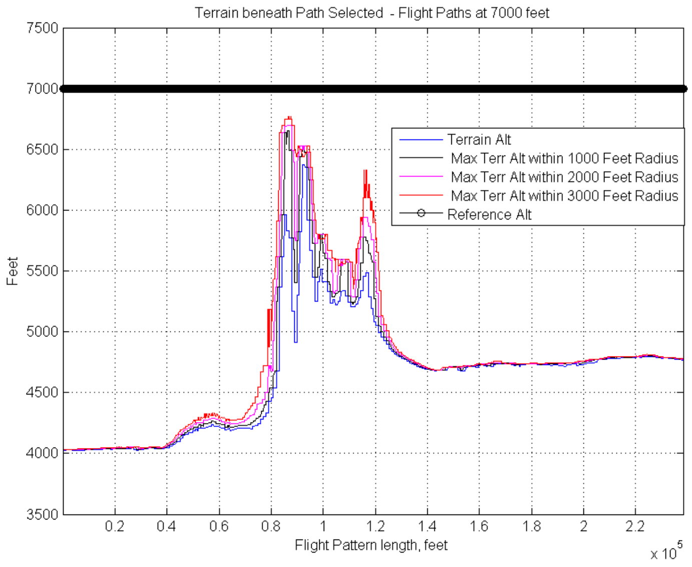
- The patterns generated by the RTTP are flyable and safe

Simulation Results
Plot 1

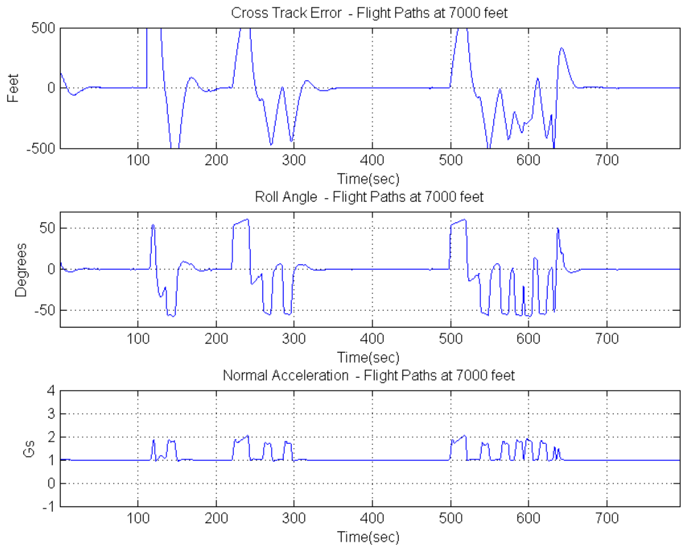


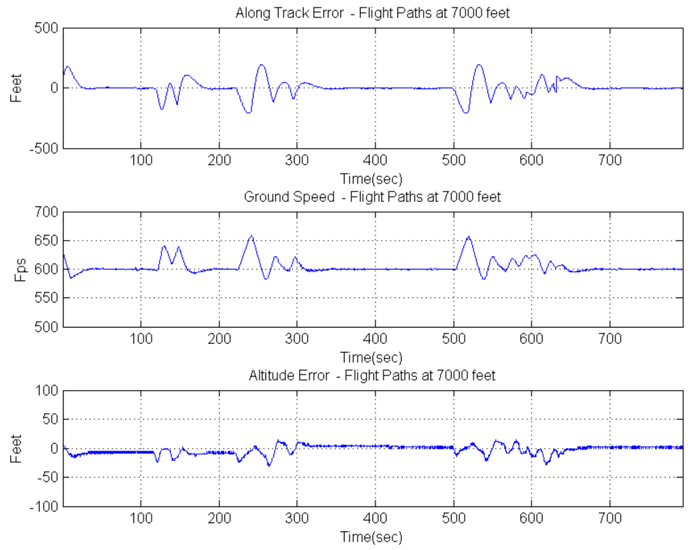
Simulation Results (cont)
Pattern at 7000 feet MSL - Plots 2 and 3



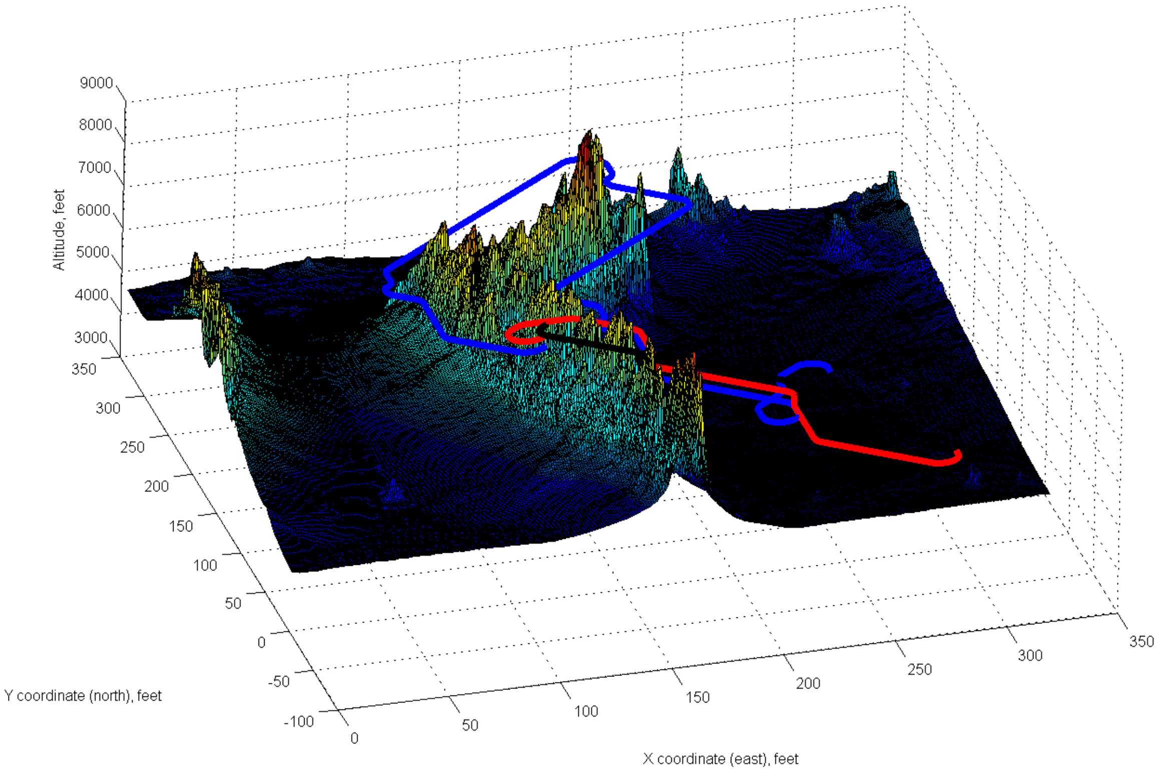


Simulation Results (cont)
Pattern at 7000 feet MSL - Plots 4 and 5





More Simulation Results



RTTP Future Work

- Improve RTTP heuristic function to avoid getting so close to the mountains when not required.
- Incorporate target visibility and obscuration requirements to path generation.
- Control path length and consequently control time of arrival of target to destination point to achieve target synchronization.
- Upgrade user interface – (i.e. touch screens)
- Make RTTP operational

Response to Questions

- QUESTIONS ?
- CONTACTS
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