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APPENDIX A

UAV Simulation Testbed

This chapter presents a non linear automatic UAV simulation testbed and an autonomous control implementation with way point navigation. The UAV simulator is an integrated product that combines a vehicle operator station with a simulated environment to support UAV research, training and operations while providing the operators (Internal Pilot-IP) with a consistent interface. In the synthetic mission space the simulated air vehicle operates against simulated terrain, weather, and computer generated forces. External pilot and internal pilot are also allowed interacting into this synthetic simulation testbed with consistent interfaces. Previously implemented control system is tested by using this simulation testbed.

The simulation environment that will use for low-level controller development is an aircraft dynamics testbed simulator previously developed with the help of unmanned dynamics called AeroSim toolbox that provides a complete set of tools for rapid development of detailed 6 degrees-of-freedom nonlinear generic manned/unmanned aerial vehicle models (which may be customized through parameter files), including, among others, the Aerosonde UAV and the Navion general-aviation airplane. Due to this flexibility any kind of UAV can be tested under this analysis with minor changes.

A.1 Implementation

The Objective of developing a UAV testbed is to test it up to the level of a full non-linear simulation with the help of both external pilot (EP) and internal pilot (IP) to ensure that the flight avionics function as expected. The Autonomous control system is based on the Aerosonde UAV and major considerations of controller performance and minimum instability within manual and autonomous switching have been evaluated with full software simulation. Major requirements for the good control system are minimum overshoot, minimum setting time without undesirable oscillation and low cross coupling between high level commands are verified using simulation testbed tool. A MATLAB simulink standard configuration environment and the aerosim aeronautical simulation block set are utilized for simulation studies, presented through a flightgear interface and custom graphical user interface (GUI).

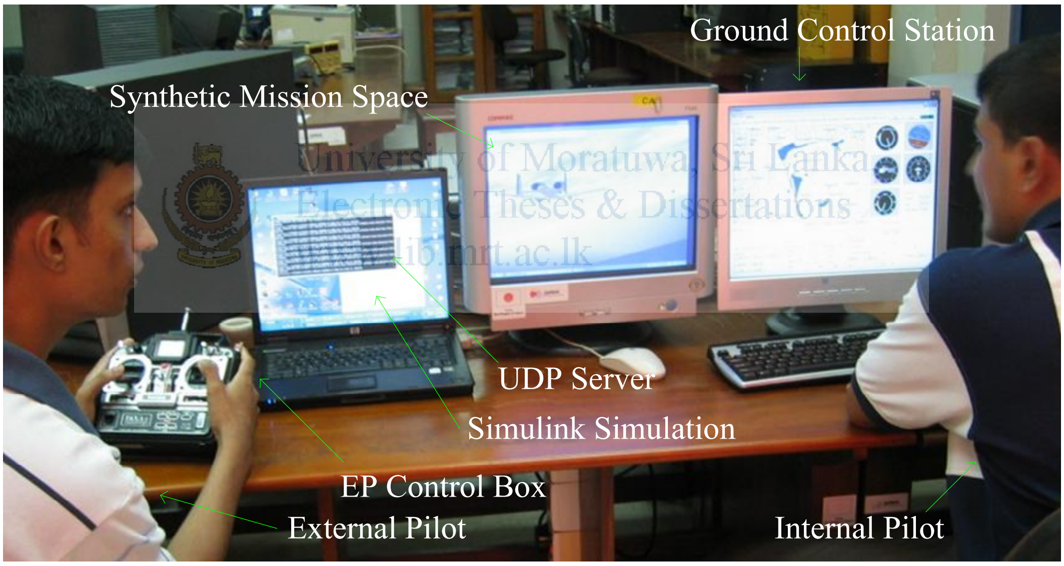

Figure A.1: Performing UAV mission testbed with new testbed

This UAV simulator is an integrated product that combines a vehicle operator station with a synthetic environment to support UAV research, training and operations. The ground control station (GCS) can be switched to control either a real air vehicle in the real mission space or a simulated air vehicle in a synthetic mission space, while providing the operators (Internal Pilot) with a consistent interface. In the synthetic mission space (Figure A.1), the simulated air vehicle operates against simulated terrain, weather, and computer generated forces (CGF). External pilot also can interact into synthetic simulation as shown in above Figure A.1 and below Figure A.2.

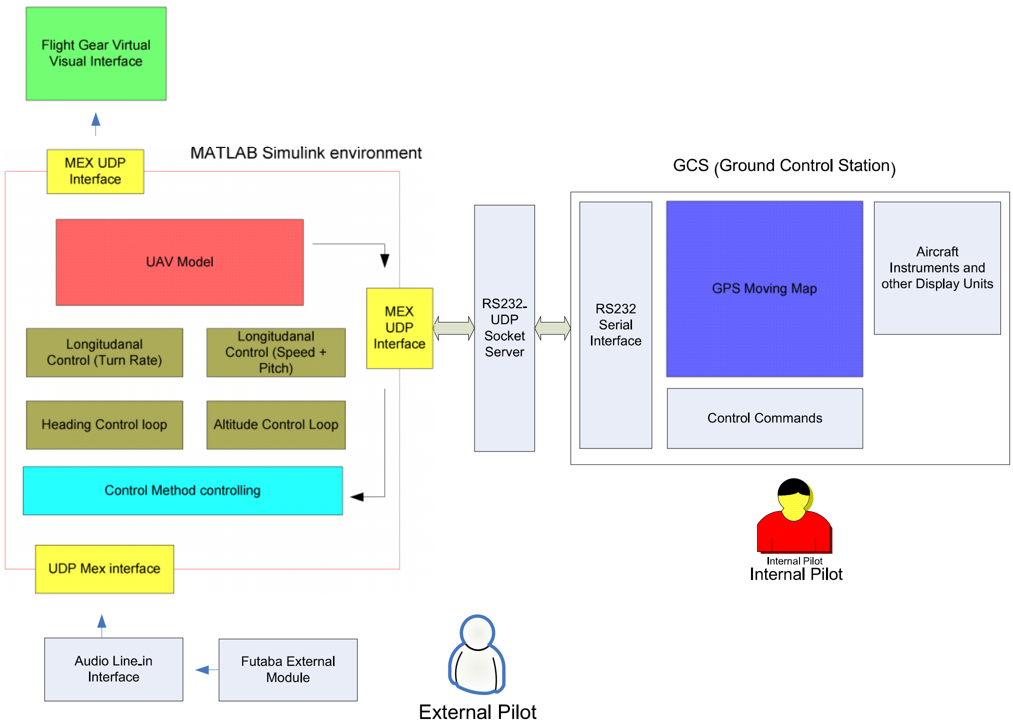

Figure A.2: Testbed Configuration

UAV simulation testbed consists of GCS, external pilot box, synthetic vision environment, aircraft model and autopilot with navigation sub modules. Most of sub units communicate via UDP socket connections. Entire UAV model, communication blocks and controller were implemented in Matlab simulink environments (Figure A.3) and major sub system can be identified as

- Non linear UAV Model (1)
- Low Level Stability Controller
  - Longitudinal Controller (Pitch and Air speed(2)
  - Lateral controller (Turn Rate) (3)
- Major Outer Control loops
  - Heading(4), Altitude (5)
- Data handling (UDP socket communication) (6)
- Actuator Modeling (7)
- Futaba Controller (EP Box) interface via mic input (8)

– Throttle, Pitch and Turn rate middle commands

Custom c based mex files are used for real time accessing of hardware levels such as sockets and mic input within different interfaces. All the communications were handled by UDP socket communication. It also helps to distribute work load of simulation process into several computers while minimizing crashing probability and by improving high reliability. GCS, however, connects to this software simulation via RS232 communication due to a serial communication problem identified within GCS and UAV.

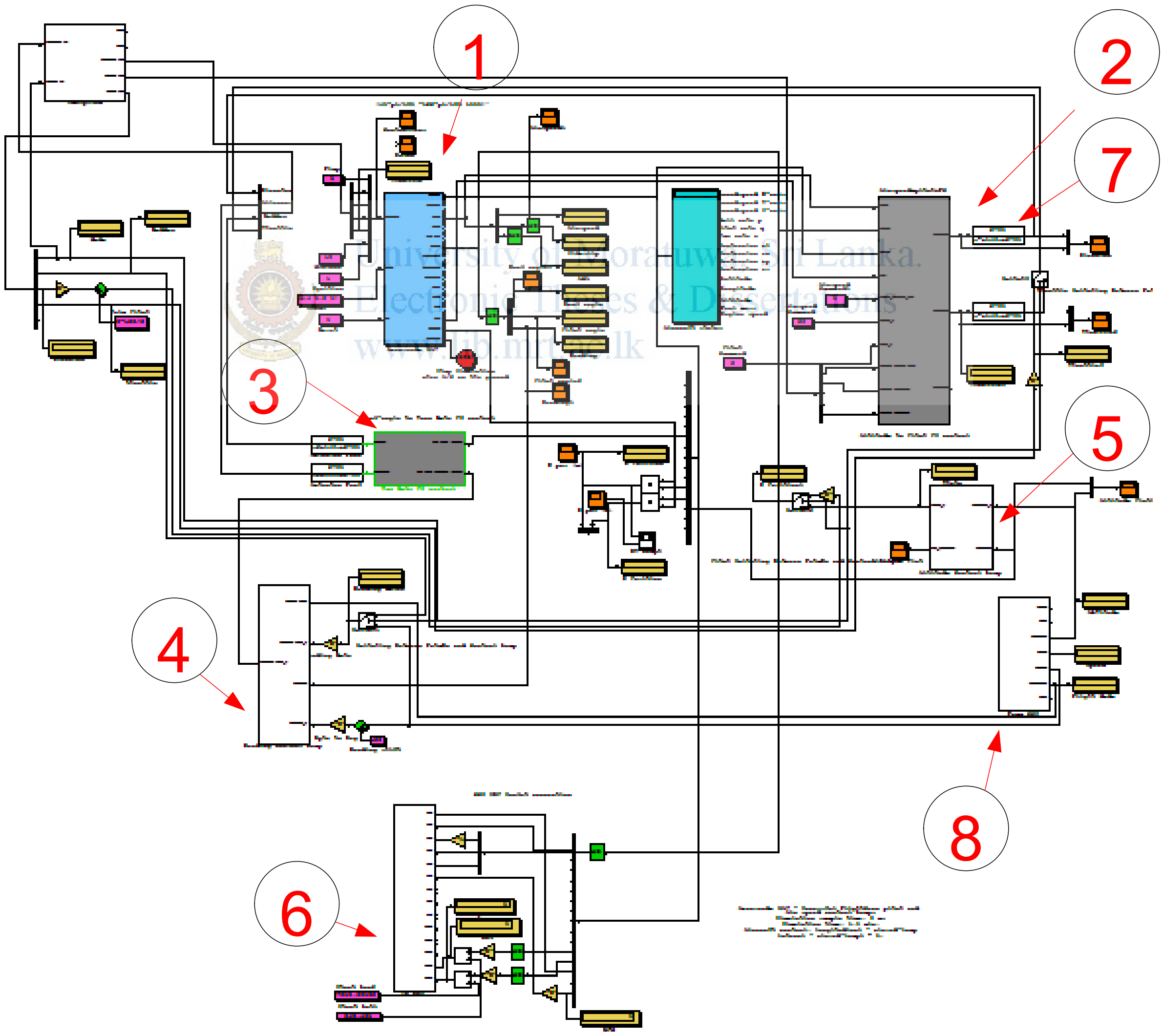

Figure A.3: Matlab Simulink environment component for UAV testbed

The original C codes of these models are first converted to Matlab MEX files, and calls to these functions are carried out in a Simulink S-function. The S-function for the vehicle nonlinear flight dynamics was written to compute the time derivatives of all state variables, which are then integrated using either one of Simulink's built-in integration schemes. The architecture of the GCS is illustrated in the following Figure A.4. Each of the five subsystem has the same degree of importance and responsibility in maintaining the GCS in the functional mode, which are

- Communication subsystem
- Display subsystem
- Configuration subsystem
- Control subsystem

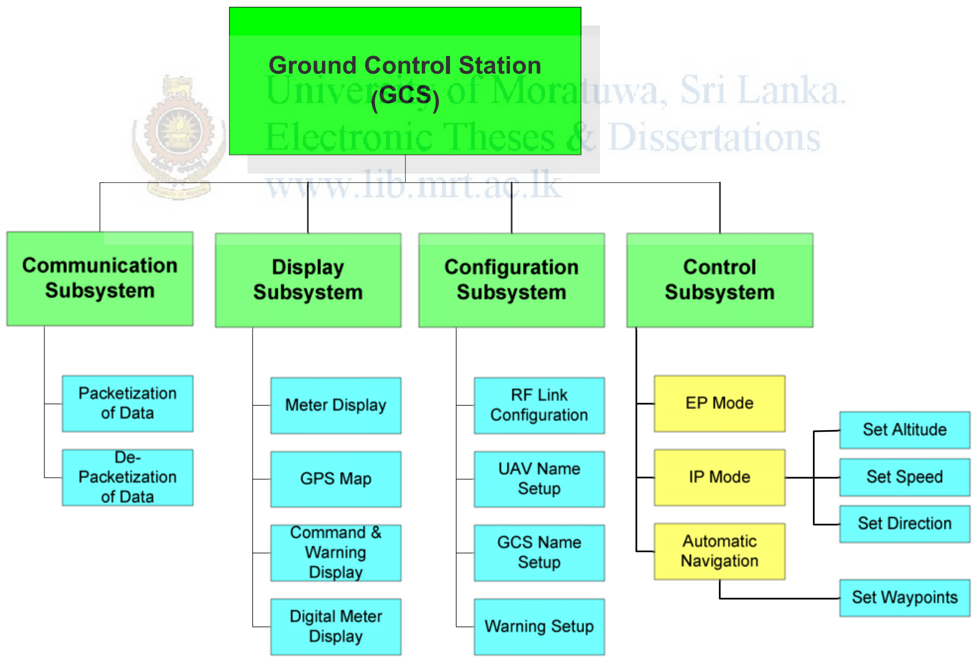

Figure A.4: GCS Architecture

All of above sub systems can be identified in below Figure A.5. Necessary flight instruments were added to display sub system, which are artificial horizon, altitude, engin RPM and temperature, indicated air speed, heading, power bus voltage.

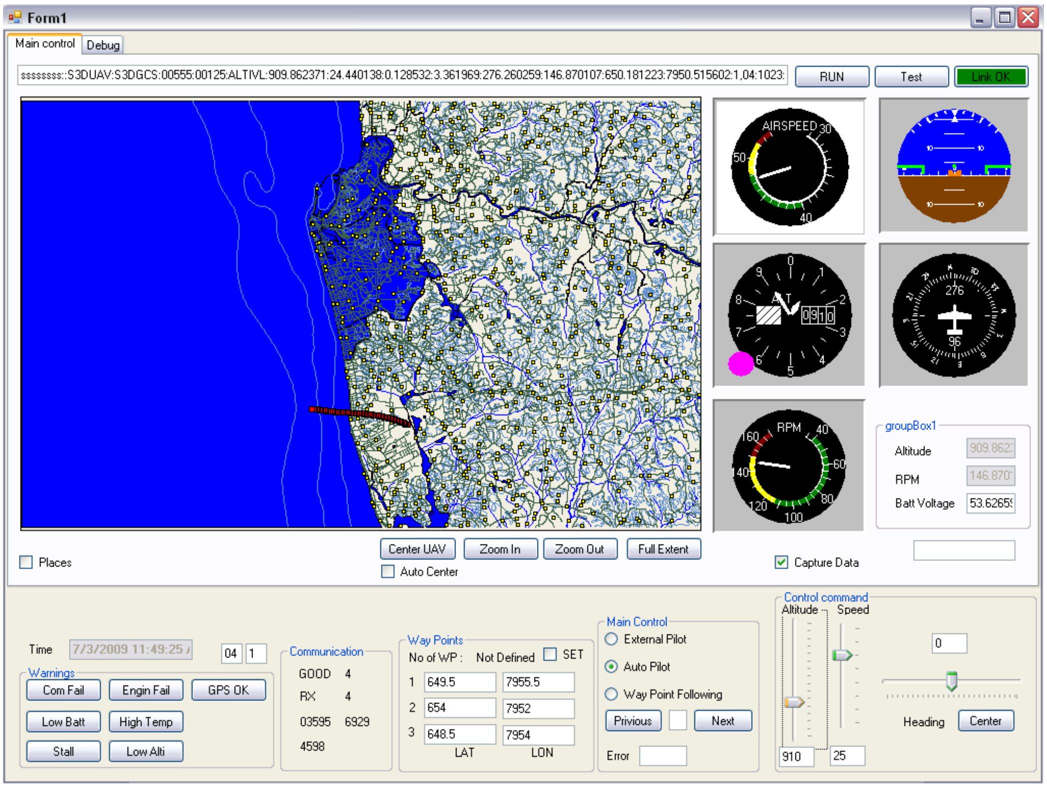

Figure A.5: UAV Ground Control Station (GCS) panel

Major control modes are highly depend on the mission requirement and for normal general UAV application following basic control modes can identify,

- Direct Controlling - EP takes direct controlling without augmentation system
- Augmented Controlling - EP takes controlling with well stabilized augmentation system
- Autopilot
  - Direct IP control with mid level commands (Pitch, speed and heading rate command)
  - Direct IP control with high level commands (Altitude, speed and waypoint)
  - Fly by camera (Loiter around a point to get good camera view)
  - Fully autonomous way-point navigation

Augmented manual control gives interesting flight mode. The stabilization provided by the yaw and pitch control led to the idea of augmented manual control: the aircraft is controlled by the combined efforts of the pilot and the SAS. The automatic control maintains level flight and stabilizes against wind gusts, while the pilot provides navigation. The total rudder and elevator deflections are equal to the computed SAS values plus the deflections commanded through the radio.

Complete view of GCS with way point configuration, control mode selection and internal pilot major three commands (Altitude, Speed and Heading rate) can be identify in Figure A.6.

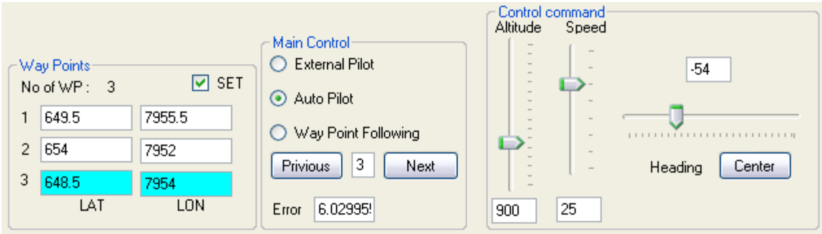

Figure A.6: UAV Ground Control Station (GCS) control panel

Major navigation modes can identify as,

- "Return-home" navigation. If the radio signal is lost, the GPS-NAV aims for the launch point of the aircraft..

- "Circle" navigation. On a command from the radio, the GPS-NAV aims for the current location, resulting in circling around the present location. This is useful to lock into favorable lift conditions.
- Augmented manual mode. No attempt is made by the GPS-NAV to navigate, only the yaw and pitch controls are engaged. This results in an interesting flying mode, described in below.

A.2 Simulation Types and Results

Proposed new modern autopilot is implemented and tested it with non linear software simulation using proposed UAV testbed using following methods.

- Plot analysis
- Flight simulator visual environment
- GPS moving map with necessary instruments, warnings and alarms

A.2.1 Plot Analyzing

Plot analyzing can be used to analysis the stability performance of mid level and high level commands of control and autopilot levels. On line tuning can be performed using different kind of plots. Any kind of aircraft state can be analyzed using these kinds of plots. Figure A.7 shows performance of speed and pitch control loops.

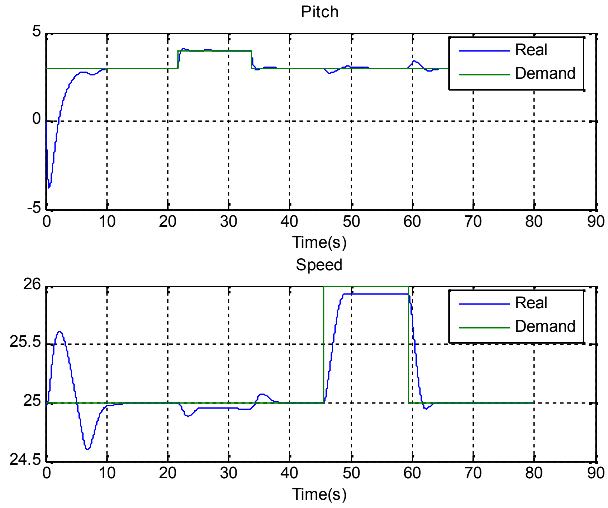

Figure A.7: All three modern control loops

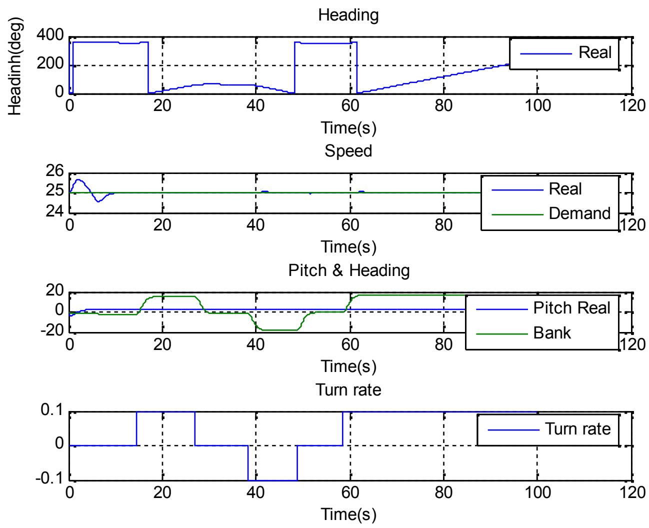

Figure A.8: Speed and pitch control loops

Also, mutual coupling between these two loops can be investigated and this is very important for high maneuverable flight. Likewise Figure A.8 shows performance of speed and turn rate control loops under constant pitch angle.

A.2.2 Flight Simulator Visual Synthetic Environment

External pilot (EP) can do the testing and training using flightgear synthetic mission space Figure A.9. Aircraft orientation and positioning can be observed through this mission space.

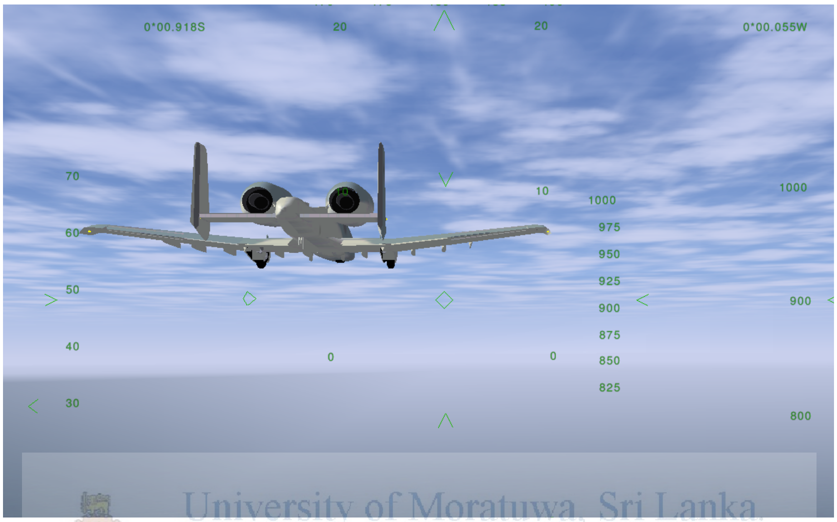

Figure A.9: Flightgear synthetic virtual environment

A.2.3 GPS Moving map with navigation

Figure A.10 shows simulation mission profile under all operating modes - manual External pilot mode, Normal Internal pilot mode and Waypoint navigation. Here, the aircraft takes off at airport1 using the manual external pilot mode and travels along a 300^o heading. Then the control is handed over to the waypoint navigation mode and aircraft automatically changes its heading toward the first waypoint. After the first waypoint is reached with an acceptable position error, the aircraft then moves to the second waypoint and finally to the third waypoint. Once reaching the last waypoint, the UAV circles around the waypoint and after finishing its activities, it moves to the final waypoint and get readies for landing. During the landing stage internal pilot does the initial controlling and when the aircraft is within the visual range control is transferred to External pilot.

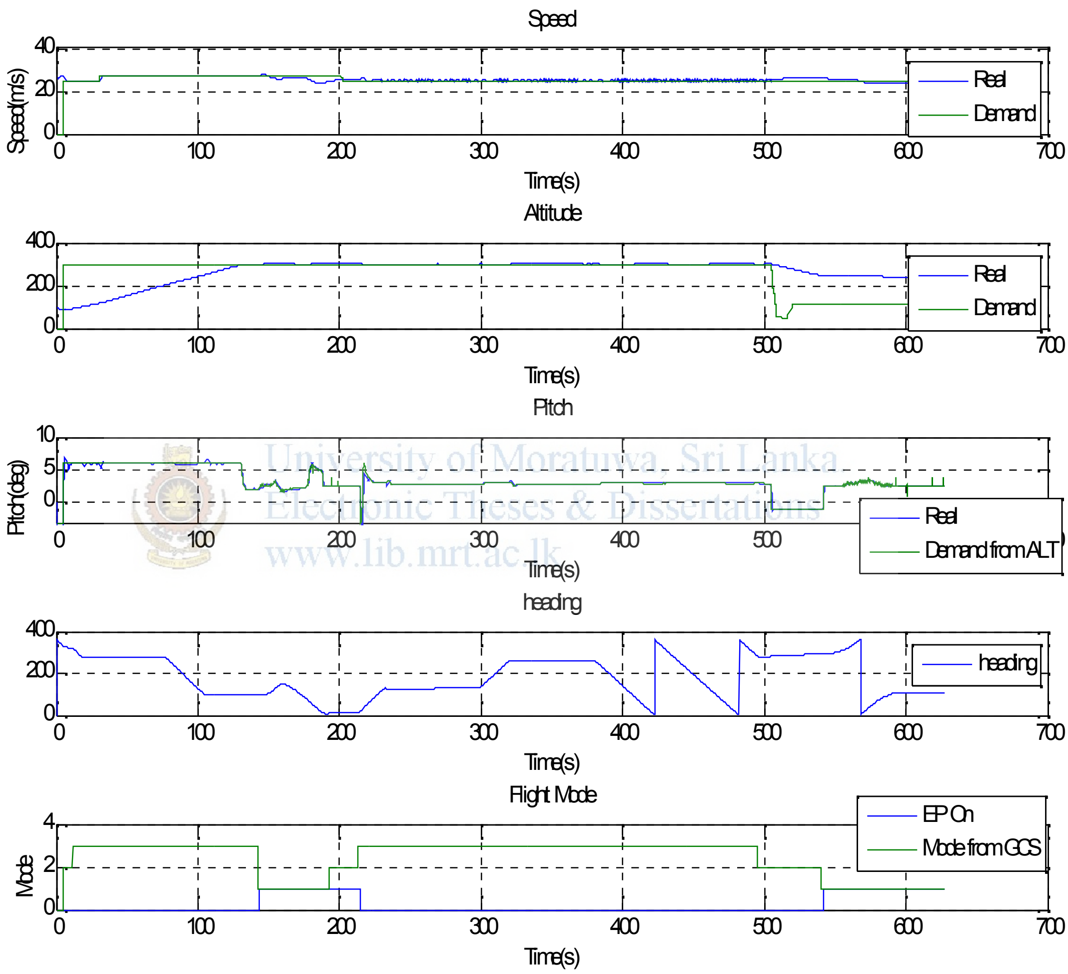

Figure A.10: UAV mission profile with all operating modes

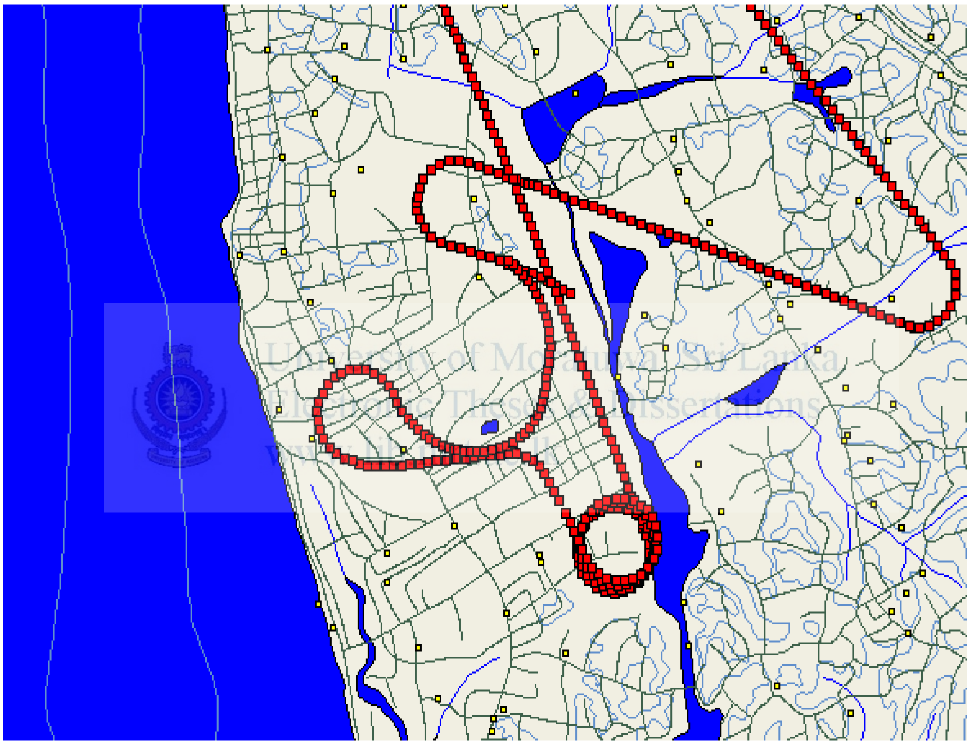

Figure A.11: GPS Moving map with navigation