Hardware-In-The Loop Simulation (HILS) is a real-time simulation setup, in which the UAV platform is tested in the same way as it is in the real experiment.

The motivation is to develop a simulation and testing framework that can be exhaustively used to examine the performance of designed automatic flight control algorithms.
Unmanned Aerial Vehicle

A mini UAV developed by NAL with surveillance as the main application.

Table 1: A mini UAV geometric parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>A (Military Version)</th>
<th>B (Police Version)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>1.2 m</td>
<td>1.2 m</td>
</tr>
<tr>
<td>WingSpan</td>
<td>1.6 m</td>
<td>1.9 m</td>
</tr>
<tr>
<td>Weight</td>
<td>2 kg</td>
<td>2.5 kg</td>
</tr>
<tr>
<td>Payload</td>
<td>&lt;1kg</td>
<td>&lt;1kg</td>
</tr>
</tbody>
</table>

UAV designed by NAL

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Six DOF model for UAV

- In order to develop a 6DOF model of the system, following data is required:
  - Aerodynamic data
  - Propulsion data
  - Mass, Centre of gravity, inertia and moment reference point data
  - Geometry data such as wing-span, mean aerodynamic chord and wing surface area.

- The 1:1 UAV model is subjected to the wind tunnel tests to yield the aerodynamic coefficients.

- The coefficients are in the look table form and it captures all nonlinearities.

- Rigid body Equations of Motion are implemented in MATLAB/Simulink.
Trimming & Linearization

- **Trimming**
  - A nonlinear Least Squares (LS) minimization algorithm is implemented to perform wings level trim.
  - Trim solution is used to start the simulation.

- **Linearization**
  - Linearization is performed using central difference method.
  - The linear models are generated at trim point.
  - The linear models are used for control design.
A HILS framework contains four modules

- Host PC
- Real Time Target Machine and Interfaces
- Autopilot Hardware
- Ground Control Station
The UAV aerodynamic model and engine model along with equations of motions, sensor models, hardware interface blocks and control algorithms are developed in Simulink platform.

Open loop, model in the loop, software in the loop and processor in the loop simulation models are tested on Host PC.

For HILS

- compiles the 6 DOF model and communicates it to the target machine which is a Matlab real time kernel.
- Runs the model in target machine.
- Communicates with target machine through Ethernet.
6DOF Simulation model of UAV
Using embedded real-time target, autocode is generated for the control strategy and is burnt in the micro controller.
Real Time Target Machine and Interfaces

Real time target machine is a real time operating system which meets the timing constraints required for real time applications.

**I7 Single Board Computer**
- Boots MATLAB real time kernel from CD.
- Acts as a root complex andCommunicates with Spartan 6 FPGA through PCIe bus.

**Spartan 6 FPGA**
- SPI, I2C, UART, USB, CAN, GPIO, PWMIO, ADC and DAC IP run in Spartan 6 FPGA
- The IP’s are developed in VHDL programming language
- All hardware signals are isolated from Autopilot using Digital Isolators
Autopilot Hardware

- Focus on low weight with reconfiguration capability.
- Hardware is realized using programmable systems on chip (PSoC).
- On board 3 axis accelerometers, 3 axis gyroscope, 3 axis magnetometer, and a static pressure and temperature sensor.

NAL Autopilot Version 3 (APV3)
Ground Control station

- Open source mission planner software is used.
- Used for direct observation and monitoring purposes.
HILS Architecture

- Classified based on the level of fidelity
  - Low fidelity
  - Medium fidelity
  - High fidelity

- Presentation covers the development of low and medium fidelity HILS architecture
Low fidelity HILS

- Communication between target machine and autopilot hardware is via serial communication.
- Sensor data (IMU and GPS) are generated at regular interval.
- PWM signal are normalized and mapped to the flight control parameters.
Communication protocol

Protocol

Check Sum Range

Header | Data Length | Payload | Check Sum | Terminator

1 byte 1 byte Data Length 1 byte 1 byte

Total Count = Data length(byte) + 4 bytes
Flow of code in the Target Machine

- Receive Data Packet
- Decode the Packet
- Normalization of Data
- Mapping of Data to Flight Model
- Scaling of Data
- Formation of packet
- Send packet through UART/USB
- 6 DOF Simulation Model

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Flow of code in an autopilot board

1. **Mapping of sensor data to the control subroutine**
2. **Decode & scaling of Data**
3. **Receive Data Packet via UART**
4. **Generate Control Deflections (PWM)**
5. **Execute Control Subroutine**
6. **Formation of Packet**
7. **Send packet to Ground Control Station for Visualization**
8. **Send Packet to Target Machine through UART**
9. **Real time Target Machine**

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Snapshot

Target Machine
Host PC
Visualization PC
NAL Autopilot
Medium fidelity

- Sensors data is sent over the interface supported by the autopilot hardware such as I2C, UART.
- Feedback to the flight model in target machine is obtained from the actuator (servos).
Flow of code in the Target Machine

- Receiving Analog Voltages
- Mapping Voltage values to the Flight control parameters
- Aircraft 6DOF Simulation Model
- Scaling of sensor data
- Framing of packet
- Sending data: IMU through I2C interface, GPS through UART interface

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Flow of code in an autopilot board

1. Receive Data Packet via (I2C & UART)
2. Packet Decode & scaling of Data
3. Mapping of sensor data to the control subroutine
4. Generate Control Deflections (PWM)
5. Execute Control Subroutine
6. Drive Servo Motors
7. Encode packet for visualization in Ground Control Station

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Snapshot

Target Machine

Host PC

Visualization PC

Servos

NAL Autopilot
Results

UAV performing way point navigation
Conclusions

- Design and development of a low and medium fidelity HILS for a mini UAV is presented.
- The development is based on Model Based Design.
- These architectures are used to verify the working of control code and sensor fusion algorithms on the autopilot board.
Acknowledgements

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- Dr Jatinder Singh, Head FMCD
- Dr Abhay A Pashilkar, Group head, Flight Simulation
References

5. Software In the Loop Simulation (SILS) for NAL’s Class 1/Similar class MAV.

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Thank You