Evaluation of a Commercial off-the-shelf (COTS) Autopilot and Avionics System for UAVs

Edmond Leong, Shahriar Keshmiri, Rylan Jager
Aerospace Engineering Department
The University of Kansas
Research Background

• CReSIS is established by NSF since 2005 in support of science research in sea level change.

• Science Mission
  – Impact of seal level changes due to ice sheet dynamics.

• Center Mission
  – Develop the advanced sensing and platform technology to support the science mission.
The Meridian UAS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weights</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Takeoff Weight</td>
<td>lbs</td>
<td>1,100</td>
</tr>
<tr>
<td>Empty Weight</td>
<td>lbs</td>
<td>791</td>
</tr>
<tr>
<td>Payload Weight</td>
<td>lbs</td>
<td>165</td>
</tr>
<tr>
<td>Fuel Weight</td>
<td>lbs</td>
<td>120</td>
</tr>
<tr>
<td><strong>Performance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cruise Speed</td>
<td>kts</td>
<td>130</td>
</tr>
<tr>
<td>Range</td>
<td>nm</td>
<td>950</td>
</tr>
<tr>
<td>Endurance</td>
<td>hrs</td>
<td>12</td>
</tr>
<tr>
<td>( L/D_{cr} )</td>
<td>~</td>
<td>13.9</td>
</tr>
<tr>
<td><strong>Powerplant</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine</td>
<td>~</td>
<td>TAE Centurion 2.0</td>
</tr>
<tr>
<td>Power</td>
<td>hp</td>
<td>135</td>
</tr>
</tbody>
</table>
Flight Testing for the Autopilot
March 13\textsuperscript{th} Flight Test Incident

- Three separated flights were performed.
- Temporary loss of control had been reported three times by the pilot.
- During final approach in the last flight, the communication link dropped once again.
- Pilot lost the control of the aircraft causing it to impact the runway.
- Poor communication was suspected to be the cause of the incident.
Communications Systems

Uplink transmits up to 10Hz update rate

900 MHz
Or
2.4 GHz

Telemetry data at downlink 1Hz or 20Hz update rate selected by users RSSI signal to monitor

Pilot commands transmit through ground station
Action Plans for the Loss of Communication

• Pilot Time Out
  – Event: losing the manual pilot command signal
  – Action: switch to autopilot mode
  – Threshold: user defined (set at 0.2 seconds)

• Communication Time Out
  – Event: losing the entire communication link
  – Action: switch to autopilot mode
  – Threshold: user defined (set at 5.0 seconds)
Taxi Test Data

- Taxi test data was conducted before take off to fulfill the pre-flight checklist requirement for communications check.

RSSI Signal  - Flight Test Date : Thu Mar 13 2008;  Time : 08-09-13

-71 dBm : Best Signal Strength
-115 dBm : No Signal

Green: Autopilot Mode Date
Blue: Manual Mode Date
Signal Drop Outs at 1st Flight

RSSI Signal - Flight Test Date: Thu Mar 13 2008; Time: 08-43-28

RSSI Signal - Flight Test Date: Thu Mar 13 2008; Time: 08-43-28
Signals Drop Outs at 2^{nd} Flight

RSSI Signal - Flight Test Date: Thu Mar 13 2008; Time: 09-21-31

Time (sec)

RSSI (dBm)

Time (sec)

CReSIS
Signal Drop Outs at 3\textsuperscript{rd} Flight

RSSI Signal - Flight Test Date: Thu Mar 13 2008; Time: 10-02-05

RSSI Signal - Flight Test Date: Thu Mar 13 2008; Time: 10-02-05
Engine Data during Final Approach

Engine Data - Flight Test Date: Thu Mar 13 2008; Time: 10-02-05

Link resumed after the crash
Time Step Analysis Method

- Example: Assume 3 seconds of data are received at a 20Hz update rate

- Expected data points: \( 3 \times 20 + 1 = 61 \)
- Available data points: 42
- Lost data points: \( 61 - 42 = 19 \)

Normal time step = 0.05 seconds for 20Hz data

1 second signal drop out
Time Step Analysis for Taxi Test

RSSI Signal - Flight Test Date: Thu Mar 13 2008; Time: 08-09-13

RSSI (dBm) vs. Time (sec)

δt (sec) vs. Time (sec)
### RSSI Distribution on March 13th Flight

#### RSSI Signals Distribution (%) - (2.4GHz at 20Hz Update Rate)

<table>
<thead>
<tr>
<th>RSSI Signals (dBm)</th>
<th>Taxi Test</th>
<th>1st Flight</th>
<th>2nd Flight</th>
<th>3rd Flight</th>
<th>Signal Lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>-71</td>
<td>96.5844</td>
<td>54.3841</td>
<td>54.1862</td>
<td>56.8031</td>
<td>0.0035</td>
</tr>
<tr>
<td>-79</td>
<td>0.6489</td>
<td>38.3038</td>
<td>36.7397</td>
<td>32.3086</td>
<td>0.4645</td>
</tr>
<tr>
<td>-86</td>
<td>0</td>
<td>2.1347</td>
<td>2.5871</td>
<td>3.5631</td>
<td>0.1507</td>
</tr>
<tr>
<td>-93</td>
<td>0</td>
<td>0.3758</td>
<td>2.0748</td>
<td>2.0675</td>
<td>0.58</td>
</tr>
<tr>
<td>-101</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.0083</td>
</tr>
<tr>
<td>-108</td>
<td>0</td>
<td>0.4645</td>
<td>0.1507</td>
<td>0.58</td>
<td>4.6694</td>
</tr>
<tr>
<td>-115</td>
<td>0.0035</td>
<td>0.0731</td>
<td>0.0043</td>
<td>4.2572</td>
<td>4.2641</td>
</tr>
<tr>
<td>Signal Lost</td>
<td>2.7631</td>
<td>4.2572</td>
<td>4.2641</td>
<td>4.6694</td>
<td></td>
</tr>
</tbody>
</table>
Drop Outs Distribution on March 13th Flight

Signal Drop Out Statistics - (2.4GHz at 20Hz Update Rate)

<table>
<thead>
<tr>
<th>Duration of Drop Out Time (sec)</th>
<th>Taxi Test</th>
<th>1st Flight</th>
<th>2nd Flight</th>
<th>3rd Flight</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 0.5</td>
<td>432</td>
<td>476</td>
<td>732</td>
<td>592</td>
</tr>
<tr>
<td>0.5~1.0</td>
<td>21</td>
<td>14</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>1.0~1.5</td>
<td>16</td>
<td>5</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>1.5~2.0</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2.0~2.5</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2.5~3.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&gt; 3.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Numbers of Drop Out Events
Average Signals Lost from All Flights

Average Drop Out (sec/min) in Different Flight Tests Date
(2.4GHz at 20Hz Update rate)

<table>
<thead>
<tr>
<th>Test Item</th>
<th>Taxi Test</th>
<th>Flight Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar-13-08</td>
<td>1.68</td>
<td>2.66</td>
</tr>
<tr>
<td>Feb-29-08</td>
<td>2.88</td>
<td>2.82</td>
</tr>
<tr>
<td>Dec-20-07</td>
<td>1.72</td>
<td>3.19</td>
</tr>
<tr>
<td>Aug-31-07</td>
<td>1.10</td>
<td>1.10</td>
</tr>
<tr>
<td>Jun-19-07</td>
<td></td>
<td>4.34</td>
</tr>
</tbody>
</table>
Summary of Flight Test Results

• Signal drop out existed in every single flight.
• About $3\text{~}5\%$ of data was lost in each test.
• About $5\%$ of signal drop outs lasted longer than $0.5$ seconds.
• Average loss of data $\approx 2.0 \text{ sec/minute}$ in each taxi test.
• Average loss of data $\approx 2.8 \text{ sec/minute}$ in each flight test.
Laboratory Tests

• Purpose
  – Investigate the drop outs in a stable environment.

• Tests Conditions
  – Update rate : 20Hz vs 1Hz.
  – Autopilot Unit : (S/N)1024 vs 1027.
  – Radio Module : Switch between 1024 & 1027.
  – Frequency : 2.4GHz vs 900MHz.
  – Others : No networking, no servo power, battery vs bench power, wall power to GS.
Summary of the Laboratory Tests

Average Signal Drop Out (sec/min) Comparison in Different Lab Tests Setup

Test Items

<table>
<thead>
<tr>
<th>Test Items</th>
<th>Manual Mode</th>
<th>Manual Mode Radio Switch</th>
<th>Autopilot Mode</th>
<th>No Networking</th>
<th>No Servo Power</th>
<th>Bench Power to Autopilot</th>
<th>Wall Power to Ground Station</th>
<th>900 MHz Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>1027 20Hz</td>
<td>2.38</td>
<td>1.93</td>
<td>0.02</td>
<td>2.35</td>
<td>2.66</td>
<td>1.85</td>
<td>2.64</td>
<td>2.36</td>
</tr>
<tr>
<td>1024 20Hz</td>
<td>2.31</td>
<td>2.57</td>
<td>0.02</td>
<td>2.21</td>
<td>2.19</td>
<td>2.14</td>
<td></td>
<td>0.06</td>
</tr>
<tr>
<td>1027 1HZ</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1024 1HZ</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Autopilot ON due to Pilot Time Out

Lab Test Results - S/N: 1027; 1 Hz Update Rate; Manual Mode

RSSI (dBm)

Time (sec)

Δt (sec)

Time (sec)
Pilot Time Out Events

Autopilot ON due to Pilot Comm Out

<table>
<thead>
<tr>
<th>Dates</th>
<th>Numbers of Autopilot ON due to Pilot Time Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jun/Aug-07</td>
<td></td>
</tr>
<tr>
<td>Dec-20-07</td>
<td>20</td>
</tr>
<tr>
<td>Feb-29-08</td>
<td>6</td>
</tr>
<tr>
<td>Mar-13-08</td>
<td>15</td>
</tr>
<tr>
<td>Lab Tests</td>
<td></td>
</tr>
</tbody>
</table>

**CReSIS**
Lab Test Results

• Using 1 Hz update rate will reduce the drop out probability in downlink.
• In auto mode, chances of drop out in downlink will also be reduced.
• Signal drop outs behavior are unpredictable.
• Drop out problems DO NOT relate to:
  – Range
  – Power setup
  – Networking setup
  – Autopilot unit
  – Radio module
  – Transmission frequency
Pilot Time Out Issue

• The uplink issue is not necessarily improved even using the 1 Hz update rate.
• Uplink performance cannot be detected by either RSSI value or time step analysis method.
• No appropriate approach can be applied to predict and prevent the unintended autopilot activation.
• Pilot time out events can only be indicated in data post processing from the unintended autopilot activations.
Summary of Investigation

• The cause of incident is due to the pilot time out issue that triggered the unintended autopilot activity right before touch down.

• The pilot time out event is caused by the pilot command signal drops out in the uplink.

• The pilot time out was not due to:
  – Range
  – Power setup
  – Ground station setup
  – System configuration
  – Pilot or ground crew error
Conclusion

• It is concluded that the COTS autopilot inherits an inevitable communication problem.
• The COTS autopilot system cannot satisfy the Meridian safety requirement.
• It is decided that the COTS autopilot is no longer acceptable for the Meridian UAS program.
Thank You!

Questions?