Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Project

Small UAS Communications and Navigation

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UTM Technical Interchange Meeting
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• UTM Research Transition Team (RTT) Communications and Navigation (C&N) Subgroup

• Communications and Navigation (C&N) Activities during Technical Capability Level (TCL) 2, 3, 4

• Publication of Research Findings

• Areas of Future Work

• Summary
The objective for this subgroup was to explore communications and navigation solutions to ensure that Unmanned Aircraft (UA) are under the operational control of the remote pilot (to the degree appropriate to the scenario) and remain within a defined area (around a planned trajectory or as a defined area).

C&N subgroup kicked-off after TCL 1 concluded:
- 26 meetings including three joint meetings with the Sense and Avoid (SAA) subgroup
- At peak more than 100 UTM community members interacted in the subgroup
- Community responses to the Request for Information (RFI) became the basis of communications and navigation guideline and contingency management requirements

Three C&N technical documentation packages produced, associated with TCL 2, TCL 3, and TCL 4.
C&N Subgroup Activities during TCL 2

TCL 1
- Remote Population
- Low Traffic Density
- Rural Applications
- Multiple VLOS Operations
- Notification-based Operations

TCL 2
- Sparse Population
- Low-Mod Traffic Density
- Rural / Industrial Applications
- Multiple BVLOS Operations
- Tracking and Operational Procedures

TCL 3
- Moderate Population
- Moderate Traffic Density
- Suburban Applications
- Mixed Operations
- Vehicle to Vehicle Communication
- Public Safety Operations

TCL 4
- Dense Population
- High Traffic Density
- Urban Applications
- Dense BVLOS Operations
- Large Scale Contingency Management

Aug 2015
Oct 2016
May 2018
Aug 2019
At the beginning of the C&N subgroup activities, RFI was sent out to gain insights into small UAS communications and navigation.

Responses from 20 organizations were received; discussion of the response led to the following insights:

- C&N system performance must reflect the operational setting:
  - Operation over where and when
  - UAS configuration, mission type, and duration
  - Who else is expected in the area
- Communications between UA and its operator can be disrupted especially when the protected aviation spectrum is not used.
- Given the prevalent use of Global Navigation Satellite System (GNSS) receiver, such as the Global Positioning System (GPS), in the UA navigation system, navigation performance can be degraded due to radio frequency (RF) interference, blocked radio line-of-sight to GNSS satellites, and reflected satellite signal (i.e., multipath).
Notional Relation among small UAS Communications Performance, Level of small UAS Operations Automation, and Operational Setting

Communications Performance

Operation Setting (Where, When, How Long, UAS/Mission Type, who else expected operate, etc.)

Use Case:
- BVLOS Sub-Urban
- Infrastructure Applications
- Agricultural Applications

Level of small UAS Operations Automation

Simple Setting

Moderately Complex Setting

Better

Good

Low

High
Hypothetical Relation between small UAS Navigation Performance and Operational Setting

Required Navigation Performance (RNP) Level

Large Value (e.g., 100m)

Small Value (e.g., 3m)

Risk Awareness Threshold

Operational Risk Derived from Operational Setting

Technological limit of RNP level

\[
\text{RNP level Requirement to Risk} = \frac{\text{Sensitivity of RNP Level}}{\text{Operational Risk} - \text{Risk Awareness Threshold}} + \text{Technological limit of RNP level}
\]

[Jung 2016]
UTM TCL 2 National Campaign (NC 2) highlighted the relation between operational setting and C&N performance [Aweiss 2018] [Jung 2018a]

- C&N data collection flew over sparsely populated area with the unobstructed view of the sky
- UA remained close to the Ground Control System (GCS), maximum distances ranging from 2300 feet to 4200 feet
- 4 out of 47 flights (8.5%) experienced Loss of Command and Control (C2), defined as Received Signal Strength Indicator (RSSI) at UA remaining at or below -90 dBm for more than 10 seconds
- The 900MHz and 2.4GHz radios provided sufficient performance to cover relatively short distance between the GCS and UA
- Unobstructed radio line of sight between UA and the GCS likely contributed to this small number of incidence of loss of C2 link
TCL 2 C&N Evaluations (cont.)

- 2 out of 118 flights (1.7%) encountered loss of navigation, defined as navigation system tracking six or fewer GPS satellites for more than ten seconds.

- The NC 2 aircraft used GPS for navigation and the unobstructed view of the sky likely contributed to this small incidence of loss of navigation.

- NASA TCL 2 test results and analysis [Johnson 2017] showed that communications and navigation performance is not only important for individual UA operation but for overall UTM ecosystem:
  - Weather, operational intent, geo-fence information exchange
  - Beyond Visual Line-of-Sight (BVLOS) operations with altitude stratification
C&N Subgroup Activities during TCL 3

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C&N Off-Nominal Situations Management Requirements RFI

- C&N off-nominal situations management concepts and 18 high-level requirements developed, and RFI for feedback sent out; all requirements were deemed reasonable as written and is needed in UTM [Jung 2020a] [Jung 2020b]

- It was identified that in many cases mitigation of Communications or Navigation off-nominal situations results in the landing of UA
  - Prolonged loss of communications between UA and operator
  - Severely degraded navigation performance

- Therefore, maintaining safe landing capability, where “safe landing” is defined as “landing of UA without causing detrimental impact to people and property” is understood as having paramount importance
Recommendation on Handling C&N Off-Nominal Situations

- When off-nominal situations occur, whether the operation should enter the emergency phase or not should reflect the status of the safe landing capability
  - Uncertainty Phase: The situation is being mitigated with intact safe landing capability
  - Alert Phase: The situation is being mitigated with compromised safe landing capability
  - Distress Phase: The situation poses an imminent danger to people or property

- Safe landing capability can take different shapes and forms: fly to safe-to-land locations (e.g., fenced-off sandbox), avoid people and property when landing, transfer small kinetic energy upon impact (e.g., 11 foot-pounds or less), etc.

- Therefore, the following six areas should be monitored concurrently, constituting safe to land capability monitoring

  **Nav. Health**  **C2 Health**  **Ext. Surveillance**  **Env. Detection Function**  **ADAC Health**  **Resources**

  External Surveillance: Vehicle position information that does not originate from the vehicle’s navigation system
  ADAC: Attitude Determination and Control
  Resources: e.g., range to reach safe-to-land location, thrust to perform vertical landing or reduce kinetic energy, etc.
Nominal operation

Emergency Phase Uncertainty Example 1: Use Ext. Surveillance and C2 to mitigate

Emergency Phase Uncertainty Example 2: With functioning Nav., fly to safe-to-land location to mitigate
Emergency Phase Alert Example 1: Use manual control with line of sight to the vehicle to mitigate

Nav. Health  C2 Health  Env. Detection Health  Ext. Surveillance  ADAC Health  Resources

Nav. Health  C2 Health  Env. Detection Health  Ext. Surveillance  ADAC Health  Resources

Emergency Phase Alert Example 2: Locate the vehicle and clear people under to mitigate, while resources last
Safe Landing Monitoring Examples (cont.)

Emergency Phase Distress Example 1

- Nav. Health
- C2 Health
- Env. Detection
- Ext. Surveillance
- ADAC Health
- Resources

Emergency Phase Distress Example 2

- Nav. Health
- C2 Health
- Env. Detection
- Ext. Surveillance
- ADAC Health
- Resources

Emergency Phase Distress Example 3

- Nav. Health
- C2 Health
- Env. Detection
- Ext. Surveillance
- ADAC Health
- Resources
TCL 3 C&N Evaluations

- Evaluated the Effectiveness of Redundant Communications Systems in Maintaining Operational Control of small UAS, Generating Recommendations for Urban Operations [Jung 2019]

- Analyzed at-altitude Long Term Evolution (LTE) Power Spectra for C2 Communications [Kerczewski 2019]

- Evaluated the impact of Ownship generated Electromagnetic Interference (EMI) on LTE bands [Jung 2018b]
C&N Subgroup Activities during TCL 4

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**Timeline**
- Aug 2015
- Oct 2016
- May 2018
- Aug 2019
Introducing the Notion of “Timeout”

• “Timeout” – fixed amount of time for the operator to resolve off-nominal situations

• Once timed-out, UA must display predictable behavior, such as initiating safe landing procedure

• Three timeouts introduced
  • UA to Operator C2 Link Loss (telemetry loss)
  • Operator to UA C2 Link Loss (command/control loss)
  • Navigation Degradation
Integration of UAS and USS for Off-Nominal Situations Processing

Unmanned Aircraft System Service Supplier (USS)

1200: Nominal operation

202: Com. link nominal?

204: UA Nav. nominal?

114: Start com. Timeout count

210: Contingency operation

212: Any timeout reached?

202: Com. link nominal?

204: UA Nav. nominal?

126: Start nav. Timeout count

214: Confirm UA landing

216: Obtain info. for off-nominal report

218: End of operation
• Practiced C&N off-nominal situations management requirements during the TCL 4 demonstration [Jung 2020b]

• Calculated Measure of Performance for small UAS C&N [Jung 2020d]
  • Rate of loss of C2
  • Rate of C2 loss during a conflict
  • Rate of navigation degradation during a conflict
  • Rate of safe landing

• Collected and analyzed off-nominal situations report [Jung 2020c]
  • USS in a key position to collect both digital and contextual data from off-nominal situations
  • Continued collection and analysis of off-nominal data key to gaining insight and reducing the occurrence
Publication of Research Findings


Publication of Research Findings (cont.)


Areas for Future Research

Necessary C&N Performance Level for BVLOS/Urban operations

- Safety
- Logistics
- Culture

Performance

Time/Engineering Effort/$$$
Summary

• Collaborations with the UTM community was a key to gain insights and develop requirements

• Field testing results showed the following
  • Use of unprotected spectrum could meet the small UAS communications need when UA and GCS are within the radio line of sight, the flight takes place in a remote location away from population and sources of RF interference
  • GPS could meet the small UAS navigation need when UA flies in the area with an unobstructed view of the sky
  • Altitude reporting need to be compatible among operations
  • Off-nominal situations should be mitigated with USS in the loop

• More Research & Development (R&D) to be done for BVLOS/urban operations!