Optimization of Drone Routing for Humanitarian Applications

Thomas LAMBERT

HEC-ULiège
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Introduction

• UAV technology is almost mature
  ▫ New applications and commercial uses
  ▫ Increasing autonomy, new systems
  ▫ Lower prices

• Humanitarian uses
  ▫ Imagery (mapping, inventory, monitoring, etc.)
    • Widely used
    • Cheap and fast
    • Easy to deploy
  ▫ Delivery (medicines, samples, emergency kits, etc.)
    • More complex
    • Risky
    • Too small to be useful
Introduction - Context

• Political
  ▫ Conflicts
  ▫ Mistrust from authorities
  ▫ UAViators consortium to find solution

• Social
  ▫ Population afraid of drones (air strikes)
  ▫ Concerned about espionage, possible destruction of drones

• Legal
  ▫ No proper regulations or very restrictive ones
  ▫ Hard to fly right away with autonomous system
  ▫ Need for special authorizations if possible
Thesis Goal

• Provide **quantitative measurements** relative to the **time gained** by using a drone on a given **inspection mission**.
  ▫ Through the development of route optimization models

• Give NGOs’ managers tools to
  ▫ assess the usefulness of a drone for a given mission
  ▫ evaluate the possibilities for a mission with a known UAV
  ▫ chose the right UAV to complete a given mission
Case study & Models
Case study

• Haiti
  ▫ Stricken by disasters regularly (+340 000 death since 2000)
  ▫ First place where drones massively employed in humanitarian aid

• Simplified network
  ▫ 1 base (Port-au-Prince)
  ▫ 4 cities to visit
  ▫ Large scale operation (+100 km radius)

• Models could be used for any other network
Models

• Traveling Salesman Problem
  ▫ Drone just needs to visit the cities
  ▫ Most simple model, unrealistic

• Distance-constrained Vehicle Routing Problem (+ inspection)
  ▫ Adds limitation on the drone endurance
  ▫ Forces it to return to the base to refuel
  ▫ Significantly increase mission time
  ▫ (+ add time for inspection of cities)

• Capacitated General Routing Problem
  ▫ UAV must scan the physical roads as well
Results
TSP

• No autonomy limitation
  ▫ Too simple, unrealistic for the UAV
  ▫ Reasonable for the Jeep

<table>
<thead>
<tr>
<th></th>
<th>Jeep</th>
<th>UAV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total time</td>
<td>9.45 h</td>
<td>4.6 h</td>
</tr>
</tbody>
</table>
DVRP - UAV

- Limited flight-time
  - Different routes possible
  - Depends on the endurance

<table>
<thead>
<tr>
<th># Routes</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total time</td>
<td>4.6 h</td>
<td>5.95 h</td>
<td>7.4 h</td>
<td>8.15 h</td>
</tr>
</tbody>
</table>

Jeep: 9.45 h

Worst case (min endurance)
CGRP- 1 Jeep

- One single Jeep
- Inefficient, many roads taken twice
- Total time: **19.84 h**!
CGRP – UAV (1)

- Endurance of 6.89 h
- 1 refuel

<table>
<thead>
<tr>
<th>Routes</th>
<th>Green</th>
<th>Magenta</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>6.79 h</td>
<td>6.61 h</td>
<td>13.50 h</td>
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</tbody>
</table>

1 Jeep: 19.84 h
3 Jeeps 9.18 h max
CGRP – UAV (2)

- Endurance of 5.17h
- 3 refuel
- Worst case scenario (min endurance)
CGRP – UAV (2)

- Endurance of 5.17h
- 3 refuel
- Worst case scenario

<table>
<thead>
<tr>
<th>Routes</th>
<th>Green</th>
<th>Magenta</th>
<th>Orange</th>
<th>Blue</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>5.15h</td>
<td>4.99h</td>
<td>3.91h</td>
<td>2.79h</td>
<td>17.14h</td>
</tr>
</tbody>
</table>

1 Jeep: 19.84 h
3 Jeeps 9.18 h max
Conclusion

Conclusion
Future work
Conclusions

• Great tool for humanitarian applications
  ▪ Provide useful aerial imagery
    • Bird eyes perspective
  ▪ Easier to mobilize than satellites or planes
    • Especially after hurricanes / tropical rains

• BUT:
  ▪ Political/social issues
    • War zones, mistrust,…
  ▪ Legal problems
    • Create permissive regulations
    • Entrust NGOs operators (international licenses)
Conclusions

• Drones are considerably faster than ground vehicles
  ▫ For every mission analyzed
    • Should be verified against other networks (mountains, rural, jungle,...)
  ▫ Time spared = lives saved

• Models should be used to determine
  ▫ Performance of a given drone in various situations
  ▫ Benchmark drones before buying a new one

• NGOs should invest in larger scale drones
Future work

- **Extend current models**
  - Target priority
  - More accurate energy consumption model
  - Optimize sub-route time instead of full mission (minimize required endurance)

- **Add randomness**
  - Inspection time
  - Target location and time of appearance
  - Damaged roads (re-routing)

- **Add joint-optimization**
  - Combine Jeep and UAV
  - Position of fuel depots or fuel trucks
Thank you

Thomas LAMBERT

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Optimization of Drone Routing for Humanitarian Assistance

Networks

Roads

Aerial
Model - TSP

\[
\begin{align*}
\min & \sum_{i=1}^{n} \sum_{j=1, j\neq i}^{n} t_{ij} X_{ij} \\
\text{subject to:} & \\
\sum_{i=1, i\neq j}^{n} X_{ij} = 1 & j = 1, ... n; \quad (1.1b) \\
\sum_{j=1, j\neq i}^{n} X_{ij} = 1 & i = 1, ... n; \quad (1.1c) \\
U_i - U_j + nX_{ij} \leq n - 1 & 2 \leq i \neq j \leq n; \quad (1.1d) \\
0 \leq U_i \leq n - 1 & 2 \leq i \leq n; \quad (1.1e) \\
X_{ij} \in \{0, 1\} & i, j = 1, ... n; \quad (1.1f) \\
U_i \in \mathbb{Z} & i = 1, ... n. \quad (1.1g)
\end{align*}
\]
Model - DVRP

\[
\min \left[ \sum_{i=1}^{n} \sum_{j=1 \atop j \neq i}^{n} t_{ij} X_{ij} + \sum_{j=1}^{n} c X_{ij} - \alpha \right] \tag{1.2a}
\]

subject to:

\[
\sum_{j=1 \atop j \neq i}^{n} X_{ij} = 1 \quad j = 2, \ldots, n; \tag{1.2b}
\]

\[
\sum_{j=1}^{n} X_{ij} = 1 \quad i = 2, \ldots, n; \tag{1.2c}
\]

\[
\sum_{j=2}^{n} X_{1j} \leq k \tag{1.2d}
\]

\[
\sum_{i=2}^{n} X_{1i} \leq k \tag{1.2e}
\]

\[
\sum_{j=1 \atop j \neq i}^{n} V_{ij} - \sum_{j=1}^{n} V_{ji} - \sum_{j=1}^{n} t_{ij} X_{ij} = 0 \quad i = 2, \ldots, n; \tag{1.2f}
\]

\[
V_{ij} \leq (\lambda - t_{ij}) X_{ij} \quad i, j = 1, \ldots, n; \tag{1.2g}
\]

\[
V_{ij} \geq (t_{ii} + t_{ij}) X_{ij} \quad i = 2, \ldots, n, j = 1, \ldots, n; \tag{1.2h}
\]

\[
V_{ii} = t_{ii} X_{ii} \quad i = 2, \ldots, n; \tag{1.2i}
\]

\[
X_{ij} \in \{0, 1\} \quad i, j = 1, \ldots, n; \tag{1.2j}
\]
Model - CGRP

\[
\min \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{p=1}^{k} t_{ij} x_{ij}^p
\]  

subject to:

\[
\sum_{m=1}^{n} x_{mi}^p - \sum_{m=1}^{n} x_{im}^p = 0 \quad i, j, n, p = 1, \ldots, k; \quad (1.3b)
\]

\[
\sum_{p=1}^{k} (l_{ij}^p + l_{ji}^p) = d_{ij} \quad i, j = 1, \ldots, n; \quad (1.3c)
\]

\[
x_{ij}^p \geq l_{ij}^p \quad i, j = 1, \ldots, n, p = 1, \ldots, k; \quad (1.3d)
\]

\[
\sum_{i=1}^{n} \sum_{j=1}^{n} \left( t_{ij} x_{ij}^p + e_{ij} l_{ij}^p \right) \leq \lambda \quad p = 1, \ldots, k; \quad (1.3e)
\]

\[
\sum_{m=1}^{n} f_{mi}^p - \sum_{m=1}^{n} f_{mi}^p = \sum_{j=1}^{n} l_{ij}^p \quad i = 2, \ldots, n, p = 1, \ldots, k; \quad (1.3f)
\]

\[
f_{ij}^p \leq n^2 x_{ij}^p \quad i, j = 1, \ldots, n, p = 1, \ldots, k; \quad (1.3g)
\]

\[
f_{ij}^p \geq 0; \quad (1.3h)
\]

\[
x_{ij}^p, l_{ij}^p \in \{0, 1\} \quad i, j = 1, \ldots, n, p = 1, \ldots, k; \quad (1.3i)
\]