Ground-to-Air Signalling for Agricultural Applications

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Airspace Conflicts

Fig 1 DJI AGRAS MG-1 Precision Spray Drone, © DJI

Increased airspace activity from Remotely Piloted Aircraft (RPA) for sensing, photography, and spray application.

Physical hazard for airborne pilots who are unaware of RPA operations.

Fieldworker Exposure

Pilot uncertainty about the position of ground based operations.

Exposure presents a risk to the health of agricultural fieldworkers, and a liability to operators of agricultural aircraft.

Fig 2 Aerial view of agricultural fields.
Photo by Noah Silliman on Unsplash

Potential Solution - Lighted Beacon

- Emergency vehicle warning lights, fixed hazard beacons (cell towers, power lines)
- Prior efforts by Woldt & Smith (University of Nebraska) - Stationary square array
- Add rotation component match orientation to an aircraft's likely/possible flight path
  - Power savings, using fewer strobes
- Incurs no expense to the aircraft pilot

Objectives

- Develop a model for how a groundworker aerial-awareness beacon system (GAAB) can be seen by airborne pilots
- Construct a physical system capable of operating under the model parameters
- Demonstrate the effectiveness of the model for a number of test cases using the physical implementation

Establishment of Mathematical Model

- Visual GAAB model improves visibility optimization effort
- Primarily focused on the timing and spatial aspect of beacon signal
  - Does not explicitly model human visual perception(color, pattern, etc)
- Flight paths, beacon orientation and rotation speed determine when the GAAB illumination intercepts the field of view (FOV) of an aircraft for a dynamic (time-dependent) series of data
- Implemented using MATLAB

Model Characteristics

At each point in time, the model:

- Calculates Beacon rotation and elevation, using the triangle wave function
- Aircraft position and heading in a local coordinate system (from GPS)

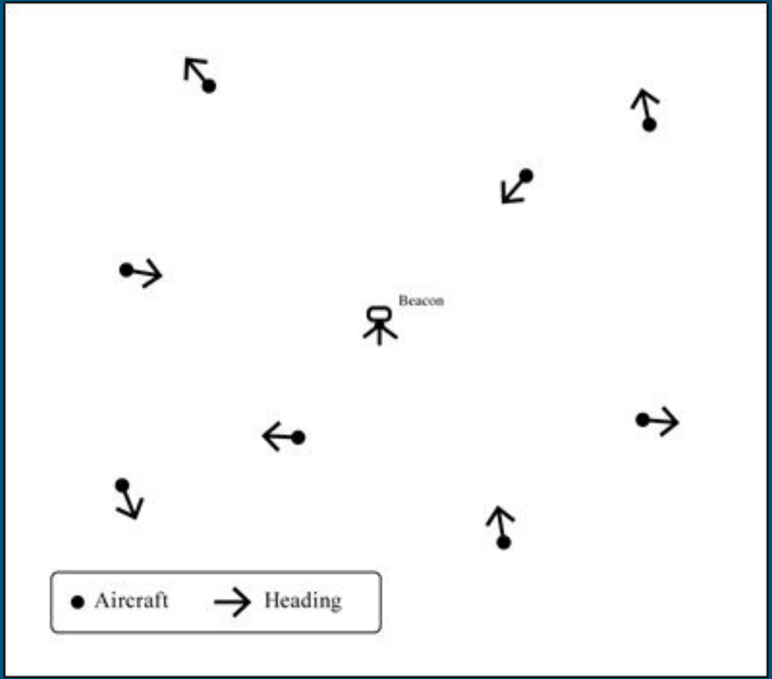

Fig 3 Sample aircraft positions and headings around a beacon.

Model Characteristics - Coordinate Axes

- Simplify calculations, comparisons
- Aircraft located in the rotated beacon system by the use of consecutive rotation matrices:
- Fixed axes rotated about the Z(Up) axis, then the resulting Y axis to give rotated Beacon system
- Use rotation matrices to convert from one system to the other

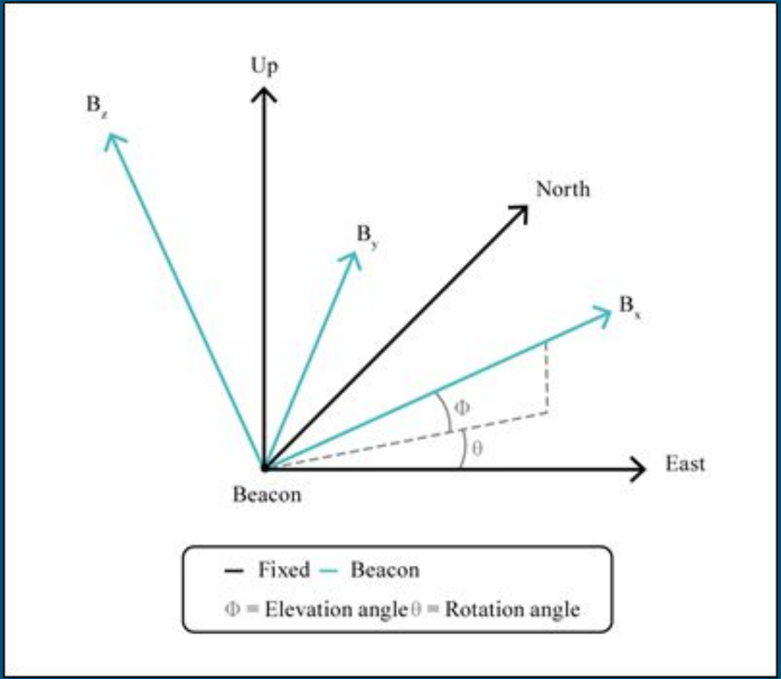

Fig 4 Coordinate axes for beacon model.

Model Characteristics - Illuminated Cone

- Aircraft position relative to cone determined
- Cone formed by 50% intensity of beacon signal (110 degrees apex angle)
  - Off-axis view of LED light source reduces intensity perceived

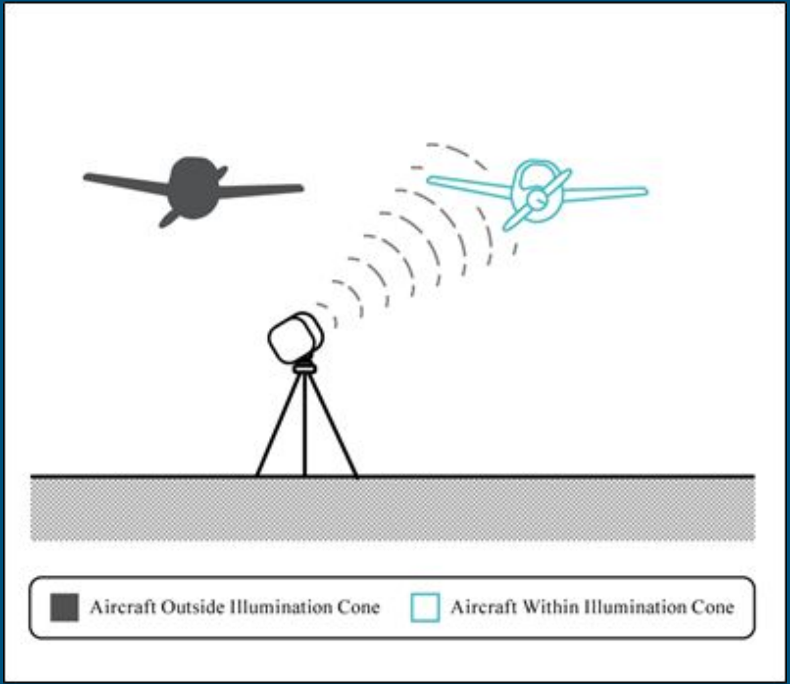

Fig 5 Illustration of aircraft position in illuminated cone.

Model Characteristics - Heading

GPS Heading verified to match orientation with GAAB inside pilot FOV

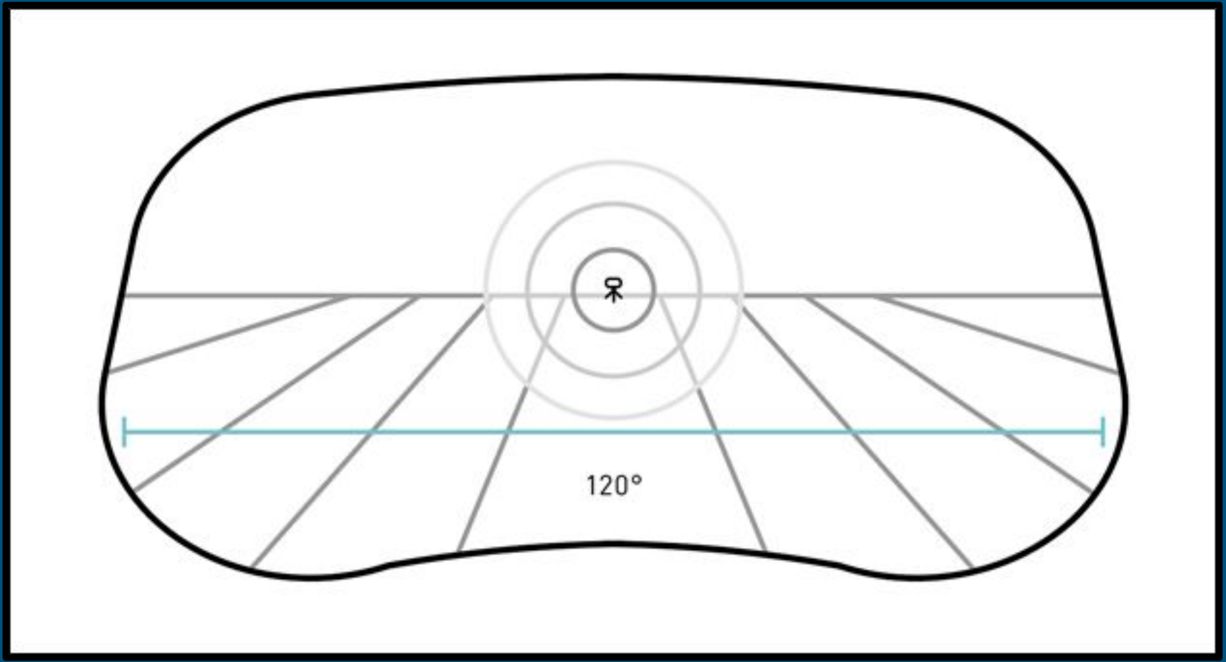

Fig 6 Illustration of beacon within field of view

GAAB System Components

- Whelen M9, Surface mount - Emergency vehicle strobe established by Woldt (Univ. Nebraska) to be visible in ag environs at an average distance of 2.9km
- Arbotix-M microcontroller with 2 Dynamixel MX-64 high capacity servomotors, 12V compatible
- 12V Marine battery, weather-resistant control enclosure, fuse protection & voltage regulation
- Programmed to perform with same spatial limits and speed as model

GAAB Prototype

Fig 7 Beacon lighting element and enclosure in a vineyard.

Model Performance

- Initial Trials: beacon was more visible to a human observer than a video camera
- Scaled-down testing of model characteristics using the DJI Matrice 100,
  - RPA equipped with high resolution digital camera, and detailed flight recording logs
- Spatial and limited dynamic(time dependent) characteristics were tested in 3 separate trials

Model Performance

- During each trial, the RPA had a predetermined flight path, recording its position, heading, and video footage throughout.
- Post Flight:
  - Position and heading input to simulation model, which generated interceptions
  - Video verification of interceptions

Model Performance- Directed Focus

- Fundamental way to verify GAAB visibility: with predetermined position and heading.
- Hover in place at a point of interest (POI) for a full rotation to guarantee video capture of beacon regardless of timing, then proceeding to the next
- POI timing can be affected by unexpected wind, other factors

Notes:

10 Intercepts, confirmed

1 Non-intercept, confirmed (K)

1 Positioning error, due to wind (J)

Fig 8 Summary figure for Directed Focus trial.

Model Performance- Variable Heading

- Shows differentiation between headings that result in interception, and those that do not
- Hover for a full rotation to confirm outcome regardless of timing

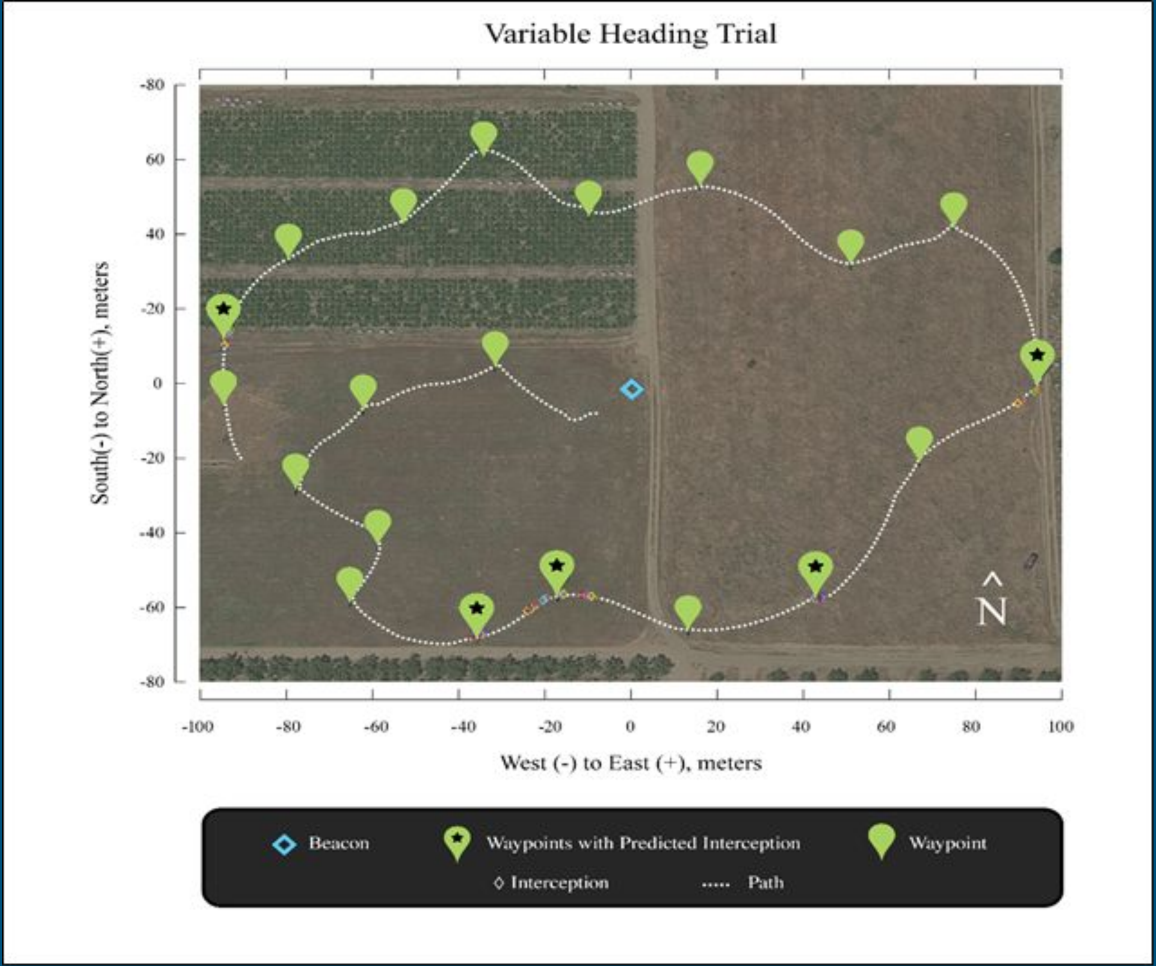

Fig 9 Summary figure for Variable Heading trial.

Notes:

15 Non-intercepts, confirmed

5 Intercepts, confirmed

Model Performance- Linear Course

- Introduces dynamic dependence, but aggregates interceptions over a path
- Flight plan is between two points with a heading toward the beacon
- “How often will a moving pilot intercept the rotating signal?”

Fig 10 Flight plan summary for Linear Course trial.

All 5 repetitions confirmed the total number of interceptions over the flight plan.

Each repetition was predicted to have 8 interceptions.

Considerations - Complex Paths

- Additional trials with complex paths require more time-precision (syncing the clock of the GAAB with the clock of the quadcopter)
- With precise timing of interceptions, beacon parameters can be optimized for human observers on typical flight paths

Further Considerations - Human Perception

- Incorporating human perception research suggestions into the color, frequency and duration of signal can maximize attention
- PIlot trials using optimized system
  - Simulated cockpit study: Virtual Reality
  - Full - sized fixed wing trials

Further Considerations - Beacon Design

Tying the results of human perception & timing optimization together, a mechanical system could be designed for longer term field use

This system would be rugged, effective, and portable