System Architecture

V1.6
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This document describes a proposed overall system architecture for accomplishing Level 4 of the IARC.

VEHICLES

The mission is accomplished by the following three vehicles, which consist of a primary air vehicle and two subvehicles.

Primary air vehicle:

UAV – The UAV searches for symbol and portals and carries two subvehicles. Airplane configuration.

Subvehicles:

DRV -- Drop Vehicle. Glides to the portal and enters the building. Missile configuration.

Rover -- Ground vehicle, searches for target inside building. Wheeled vehicle configuration.

There are stringent size and weight limits on all vehicles. In particular, the airplane has a wingspan limit of 1.3 m and mass limit of 1.5 kg.

UAV CAMERAS

The UAV has two cameras, each with high resolution, wide angle, high bandwidth, slow frame rate. Camera 1 has a fixed position, and camera 2 has a simple pan mechanism with two positions, A and B:

Position	Description
A	Both cameras have adjacent, non-overlapping fields of view. The pair of cameras form, in effect, a single camera with an ultra-wide field of view.
B	The two fields of view overlap. Both cameras record the same image except for a small parallax effect.

Position A is used for the symbol search, when we need the maximum field of view.

Position B is used for the portal search, when we can tolerate a smaller field of view. The two images are also polarized at right angles to each other.

PORTAL SEARCH

The portal search is divided into two phases -- cavity detection and windowpane detection.

PHASE 1 -- Cavity Detection. An internal cavity (i.e. room) is detected by analyzing stereo images of the target building.

Since a cavity tends to be dark, we need to be able to control exposure settings on the UAV cameras. A high exposure setting is needed to see details inside a dark cavity. External walls may have to be overexposed in the same frame. Note that cavities aren't always dark -- for example, a sunlit white interior could easily be brighter than a shaded external wall.

PHASE 2 -- Windowpane Detection. For each cavity detected, we need to determine whether the portal is covered with a transparent windowpane. Light polarization is used for this purpose. The twin cameras have polarizing filters that are oriented at right angles to each other. The orientation angles are chosen for maximum sensitivity to the polarization vector of light reflected from windows when the cameras are at their optimum view angles.

DRV CAMERA

The DRV has a nose-mounted camera for portal targeting. The camera has a clear field of view even when it's mounted on the UAV. When the DRV is attached to the UAV, the DRV camera acts, in effect, like a bombsight. After release, the camera is used to track the portal.

The camera has a low resolution and high frame rate. The frame rate is 30 frame/s.

The DRV camera is actually shared with the Rover and is physically part of the Rover. The camera is initially controlled by the DRV during descent, but after Rover separation, the camera is taken over by the Rover.

MISSION PHASES -- UAV

PHASE 1 – PRELAUNCH CHECKOUT

Internal systems are checked out.

PHASE 2 – LAUNCH

The UAV is launched manually. After climbing to ingress altitude, the vehicle is manually trimmed and switched to autonomous mode.

PHASE 3 -- INGRESS

As soon as the system verifies that the UAV is operating normally, the vehicle is rerouted to the 3 km ingress path. At an average speed of 15.0 m/s (33.6 mph) ingress takes 200 s.

PHASE 4 -- SYMBOL SEARCH

Once the UAV reaches the terminal waypoint, the airplane establishes a search pattern to search the 200 m radius circle for the symbol.

PHASE 5 -- PORTAL SEARCH

Once the symbol is found, the UAV is rerouted to a circular orbit around the building. After establishing the orbit, the airplane begins searching the building for an open portal.

PHASE 6 -- DRV LAUNCH

As soon as the UAV selects a portal, the vehicle is rerouted to an oval-shaped racetrack pattern that sets up an approach to the portal.

As the UAV approaches the portal, the DRV camera locks onto the portal image. The DRV is released when the UAV reaches the optimum release position

PHASE 7 -- TERMINATION

After DRV release, the UAV lands autonomously and shuts down.

MISSION PHASES – DRV

PHASE 1 – PRELAUNCH CHECKOUT

Internal systems are checked out.

PHASE 2 – INGRESS

The DRV is quiescent during ingress. Internal systems are monitored periodically at a low rate.

PHASE 3 -- LAUNCH

As the UAV approaches the portal, the DRV camera locks onto the portal image. The DRV is released when the UAV reaches the optimum release position. The ground station receives realtime video and responds with control commands to the DRV. Here latency is critical, and a fast control loop is used.

PHASE 4 – TERMINATION

After landing inside the building, the DRV camera is taken over by the Rover. The DRV then separates from the Rover and shuts down.

MISSION PHASES -- ROVER

PHASE 1 – PRELAUNCH CHECKOUT

Internal systems are checked out.

PHASE 2 – INGRESS

The Rover is quiescent during ingress and DRV descent. Internal systems are monitored periodically at a low rate.

PHASE 3 -- BUILDING SEARCH

After landing inside the building, the Rover takes over the DRV camera, then separates from the DRV. The Rover begins a room-by-room search for the interior target. Video and control signals to the Rover are routed directly to the ground station.

PHASE 4 -- TERMINATION

When the Rover completes its search, it shuts down.

COMMUNICATION SUMMARY

The ground station incorporates a High Gain Antenna (HGA), which is a directional, high gain, high power antenna. The HGA is dynamically pointed at the vehicle or subvehicle that is currently active.

All communication antennas on air vehicles and ground vehicles are small, lightweight, low power and omnidirectional. Since these antennas also tend to have short range, the ground-based HGA antenna compensates for the range limitations.

The following communications are required as a function of mission phase:

LAUNCH/INGRESS -- During these phases, no vehicle communication is required other than low bandwidth status and housekeeping data, plus rerouting data.

SYMBOL SEARCH -- High bandwidth image data input from the UAV for the symbol search. Latency can be high.

PORTAL SEARCH -- High bandwidth image data input from the UAV for the portal search. Latency can be high.

DRV LAUNCH -- For DRV guidance, high bandwidth video input from DRV camera, low bandwidth control output to DRV, fast DRV control loop. Latency is critical.

BUILDING SEARCH -- For Rover search and guidance, medium bandwidth video input, latency TBD. Control loop speed is TBD.

TERMINATION -- No communication is required other than low bandwidth status and housekeeping data. Note that the location of the UAV landing site is known before takeoff.

RATIONALE

This section summarizes the rationales for various aspects of the system architecture.

[1] Rationale for stringent size and weight limits on air vehicles – regarding the required mass and wingspan limits, the following rationale is relative to larger IARC vehicles (which are most of them), as well as our early-2005 UAV design, which had a wingspan of 2.3 m, mass of 6.8 kg and was disassembled into four major sections for ground transport:

> **Safety** -- light weight increases safety. Testing is also easier and more convenient because a wider variety of test sites can be used, such as parking lots.
>
> **Ease of manual takeoff** -- at McKenna, hand launch takeoffs can take place adjacent to the ground station, which is much more convenient than the more distant takeoff site most other teams use for larger vehicles.

Ease of autonomous landing -- smaller size enhances the ability to land off-runway without flaring. This opens up a larger landing area at McKenna and makes it easier to land autonomously. Note that a large area covered with tall grass is available, which is ideal for a small vehicle with a skid landing gear, like we used at the 2005 competition.

Fewer logistical headaches – a one-piece vehicle is easier to handle and transport. The ground crew has a lower workload because of reduced field assembly.

Construction is less labor-intensive – a smaller size vehicle is easier to build. Fewer airframe field joints also reduces structural complexity and reduces weight.

Resistance to crash damage -- damage resistance increases as size decreases, all else being equal.

DRV simplification -- the DRV is small enough to fly completely through the smallest allowable portal. The timing of the ground rover separation is not as critical as it is for the case where a large DRV gets partway through the window before colliding with the window boundaries.

[2] Rationale for high resolution cameras -- high resolution allows a wide field of view, making a pan/tilt/zoom mechanism less of a requirement. Search efficiency is also higher, since a smaller number of high resolution images are required as compared to low resolution images for a given search area. Image overlap becomes an issue with multiple images – it's desirable to minimize the total number of images to be searched because overlap reduces search efficiency.

[3] Rationale for using twin cameras / fixed polarizers vs. single camera / rotating polarizer -- the design reduces the number of moving parts and reduces synchronization issues. Instead of a mechanically rotating polarizer in front of a camera, we can use two cameras with polarizers at right angles to each other, and electrically switch between the two cameras. By controlling the angles at which we view the building, we know beforehand the optimum polarization angles.

[4] Rationale for twin cameras vs. single camera with two-position polarizer -- we can insure that both pictures are taken simultaneously. Otherwise there will be a delay while we wait for the first image to be transmitted before taking the second picture. A delay between the images complicates analysis.