A Network-Based Implementation of an Aerial Robotic System

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Abstract

This paper describes a unique and generic approach to solving complex aerial robotics missions. This approach is based on an intelligence system that is distributed over a remote vehicle network. In this paper a specific implementation of this generic approach is designed to fulfill the International Aerial Robotics Competition requirements. This design consists of a four level remote vehicle network comprised of a base station, a transport vehicle, a delivery vehicle and a payload vehicle. The specific design decisions for each of these vehicles are discussed throughout this paper.

1 Introduction

1.1 Problem Statement

Traditionally aerial robotic systems were limited in their capabilities by their low level of intelligence, their single vehicle approach and their reliance on off-board processing. These systems were often programmed to operate within a predetermined environment, and would fail if the environment was unstructured. The approach in this paper is to design an adaptive aerial robotic system that consists of a team of autonomous and human controlled vehicles that are capable of operating cooperatively in a dynamically changing environment. It has long been recognized that the use of multiple coordinated autonomous aerial robots can result in more effective operations [1]. This type of distributed control could allow operations to be distributed amongst a team of simple and cost-effective aerial robots.

1.2 Conceptual Approach

The University of Waterloo Aerial Robotics Group (WARG) has devised a unique general solution that is applicable to a wide variety of aerial robotic missions. The main concept of this solution is to use decentralized intelligence distributed over a network.

Each vehicle is considered a node on the network. The nodes are arranged in a tree-structured hierarchy where each node is responsible for coordinating the activities of the nodes below it and executing the commands from the nodes above it. Nodes that have the same hierarchical level are considered equal in terms of their physical and intelligence capabilities. Nodes communicate with one another through message passing. If two nodes are required to communicate but are not directly connected then the data must be relayed across the tree structure.
Every node on the network is based on a modular design where components provide defined functionality through standardized software and hardware interfaces. This design creates a tree of modules that minimizes the number of direct communications links that each vehicle contains. As a result, vehicles at the same level of the network can be located further apart. Each group of sub-nodes below each vehicle offers an increasingly refined view of the environment. This type of system can implement a divide and conquer approach if the vehicles at each level successively divide the physical mission space, which is useful for an aerial robotic mission. This design was uniquely created to solve various types of problems in aerial robotic missions.

WARG has constructed an implementation of this approach to meet the mission requirements set out by the current International Aerial Robotics Competition (IARC). [2] The mission requires a system that can travel to the interior of a remote building and return reconnaissance information within a set time frame.

A four-level vehicle network, as shown in Figure 1 was chosen by WARG to fulfill the IARC mission requirements as shown in Figure 1. A stationary base station located at the point of origin of the mission is the root node of the network. The second level nodes are one or more transport vehicles that carry their sub-nodes to the remote location. These transport vehicles are designed to carry sub-node vehicles and to move quickly to remote locations. The third level of the system consists of multiple delivery vehicles whose primary role is to deliver the payload vehicles (the fourth level of the system) from the transport vehicles to their intended locations. The role of the payload vehicles is to perform specific tasks that can only be performed at the remote location.

![Figure 1: Remote Vehicle Network for IARC Mission](image)

The remainder of this paper discusses the specific choices made for the implementation of the four-level vehicle network designed to accomplish the IARC mission requirements.

### 1.3 Yearly Milestones

By the 2004 IARC competition, WARG plans to implement a first revision of the system in which the payload vehicle is transported to its desired location by the transport vehicle and deployed via the delivery vehicles. For each individual vehicle node, WARG will initiate the design of the modular architecture and begin interfacing the various sensors with the vehicle network.

Looking ahead to 2005 and beyond, WARG will implement, test, and refine the mission sensor algorithms and control systems. The mechanical and electrical systems will undergo further revisions to optimize the systems capabilities. Also, the choices for the vehicles that implement the four-level network will be continuously evaluated. It is prudent to recognize the possibility that the implementation of a complex aerial robotic system may not work as planned. For this reason, WARG will continuously develop alternate
approaches to the mission, so that if significant problems are encountered, development does not have start from scratch.

2 Transport Vehicle

The purpose of the transport vehicle is to carry the delivery vehicles to the remote location. The transport vehicle would then deploy the delivery and payload vehicle and coordinate their operation upon arrival. Also, a set of mission sensors that must determine the location that the payload vehicle must be delivered to are to be carried by the transport vehicle.

2.1 Propulsion and Lift System

A number of design constraints have been established for a transport vehicle that can fulfill the mission requirements of the IARC competition. The transport vehicle must be able to travel large distances at high speeds. It must be able to carry and deploy a number of delivery vehicles. Finally it should be naturally stable in order to simplify controller design and increase safety at flight tests.

The various types of vehicles considered to fulfill these requirements were a helicopter, a VTOL ducted fan and a fixed wing aircraft. A helicopter is able to carry the weight of and successfully deploy the delivery vehicles. However helicopters are too slow and too unstable to meet the requirements. A VTOL ducted fan of sufficient size could carry the payloads and could achieve a high speed, but it is only stable when it is combined with an active control system and is therefore unable to meet the design constraints. A fixed wing aircraft of sufficient size can carry and deploy multiple delivery vehicles, travel at high speeds efficiently and is naturally stable. However it is the only vehicle that cannot hover at one location.

A fixed wing aircraft was chosen for its ability to meet all of the design constraints. Its inability to hover adds additional constraints that any mission sensors, delivery vehicles and payload vehicles that the aircraft will carry must be able to operate within a transport vehicle that is always moving at a high velocity.

WARG has chosen to design and build an aircraft to meet its requirements. The airplane needs to be of sufficient size to carry and deploy the delivery vehicles. WARG’s design has a wingspan of 4m and a length of 3m. The propulsion system consists of two electric motors mounted on the wings. The location of the motors allows additional space for payload at the front of the fuselage. The use of electric motors reduces the vibrations typical of combustion engines.

Further constraints will be defined by the choices made for the delivery vehicle and will be integrated into the design of the aircraft.

2.2 Guidance, Navigation and Control

Figure 2 illustrates the overall control system architecture for the transport vehicle. The control system receives its requested behavior from the base station node.

Figure 2: Overall Control System Architecture
2.2.1 Stability Augmentation System

The fixed wing aircraft chosen is naturally stable, therefore the control inputs required to maintain straight and level flight are minimal in ideal flying conditions. In order to provide maneuverability the control problem has been decoupled into four independent control systems and have based the controllers on proportional, integral and derivative (PID) control theory.

Figure 3 illustrates the layout of the controllers for the stability augmentation system.

![Figure 3: Stability Augmentation System](image)

2.2.2 Navigation System

The purpose of the navigation system is to provide a toolkit of basic flight modes, such as a straight line, a way-point and a circle. These flight modes can then be combined to form simple or complex flight paths. The navigation system outputs the desired pitch, roll, airspeed and lateral accelerations. Each flight mode has its own way of generating a desired heading.

For a waypoint flyby, a desired heading is calculated that points directly at the waypoint from the current location of the aircraft.

If the aircraft is tracking a straight line, the closest point to the aircraft on the straight line is calculated. A second point is offset from the first by a fixed distance in the desired direction of travel. The desired heading is calculated as the vector pointing from the location of the vehicle to the second point.

When the aircraft is circling a point the navigation system utilizes the location of the vehicle, the center of the circle and a vector normal to the plane of the circle to calculate its desired heading. A first point is a normal projection of the location of the aircraft onto the plane that contains the circle. A line is then drawn between the center of the circle and this first point. Where this line intersects the circle a second point is created. The third and final point is located along the tangent to the circle a fixed distance away from the second point (the point of intersection). The desired heading is calculated as the direction from the location of the aircraft to the location of the final point.

Using a fixed offset distance rather than a variable one in the tracking and orbiting modes causes the vehicle to approach at an asymptotic slope without the need for complex computations. Reversing the direction of offset can reverse the direction along the line or around the circle that the plane follows.

In order to transform from the three-dimensional vectors for measured and desired headings to the aircraft’s stability control system, the direction vectors are transformed into azimuth and elevation angles with respect to an earth fixed reference frame. Since rotations do not commute, it should be noted that the azimuth rotation is applied first followed by the elevation rotation. These angles have a range of +/-180 degrees and +/-90 degrees respectively.
Once the desired and actual roll and pitch have been calculated, PID control is applied to the angles and its results are output to the stability augmentation system. The airspeed controller is set to maintain a constant value. The desired lateral acceleration is set to zero to maintain coordinated turns.

2.2.3 Flight Termination System

The IARC mission requirements specify that the flight termination system "shall immediately stop the engine, shall be activated by an independent communication link, and shall have an independent power supply" [3] and that "electric powered vehicle shall have an independent method of removing main electrical power from the vehicles propulsion motor." [3]

As per these requirements, an independent R/C receiver and transmitter (powered by an independent power supply) will control two normally open relays that are each in series with the main electrical power of the two electric motors. Using this system, a human operator can immediately stop both motors in the event of an emergency.

3 Delivery Vehicle

The purpose of the delivery vehicles is to deploy a payload vehicle from the transport vehicle to the desired location. It also acts as a communications node between the delivered payload and the transport vehicle.

A number of design criteria and constraints have been created for determining the ideal vehicle for the task. The IARC mission requirements [2] specify that a vehicle must enter the building through a 1m x 1m window. Therefore the delivery system must be accurate enough to successfully hit a target of this size. An important design criterion for the delivery vehicle is that it must provide constant feedback control to correct for errors as it travels through the open window.

A number of secondary design criteria are related to the reusability and flexibility of the design. In order to the ensure cost effectiveness of the project any solution capable of entering the building must also be recoverable for repeated use. Also, the delivery vehicle must be designed so that the transport vehicle can carry as many payload vehicles to the remote location as possible. Multiple types of delivery vehicles were considered. These are ballistic projectiles, gliders and ram air parachutes.

Ballistic designs were considered for their mechanical simplicity. Separating a bomb-like projectile from the transport vehicle at the appropriate position and velocity does not meet the primary objective of having a highly accurate solution. It also does not satisfy the second criteria of being consistently reusable as there is a high probability of damage upon impact. Other designs involving projectiles being fired from the ground were eliminated because they too would be inaccurate and easily damaged during regular use.

A glider was considered for the delivery vehicle because it is a highly maneuverable vehicle. It could be mounted to the airframe of the transport vehicle and deployed once the window was located. This method would allow for a much more accurate and reliable method of entering the building than a ballistic design. However, due to its speeds it would be just as easily damaged on entry. Another drawback is that this method does not allow for multiple delivery vehicles per transport vehicle as is possible with other solutions discussed.

A ram air parachute is a very controllable vehicle [4], which significantly increases the likeliness of hitting the target. Because of a parachute’s relatively slow speed it will not be easily damaged, which allows for repeated testing and use. The compact nature of an inflatable air foil means the vehicle will take up very little space prior to deployment allowing multiple payload vehicles to be carried on one transport vehicle. However, there are two main drawbacks with a parachute. It can never increase its altitude and it will not work as well in windy conditions. Despite this, a ram air parachute satisfies all of the design constraints and criteria and was therefore selected as the delivery vehicle.
3.1 Mechanical Design

A series of canopy prototypes have been created and tested[5]. After testing different canopies, a commercially available high performance kite was selected as the canopy[6]. Through testing, it has been found that there is sufficient maneuverability and lift for the application. The canopy control lines act as left and right brakes. This allows there an unbalanced force between the left and right sides of the canopy to create an angular acceleration. It also allows the control unit to adjust the total forward acceleration resulting in control of the glide slope.

3.2 Navigation System

The objective of the navigation system is to guide the parachute along a desired path. During the majority of the flight, the parachute will follow a path laid out by the mission sensors on the transport vehicle. Once the parachute gets close to the window, the parachute’s navigation system begins to determine its own path. An overview of the parachute’s control system is shown in Figure 4.

![Figure 4: Parachute Control Architecture](image)

To provide the parachute with a desired flight path a series of consecutive way points will be uploaded to the parachute’s navigation system from the transport vehicle. The positioning of the way points will guide the parachute around any obstacles and lead it to the desired final destination. Based on the position of the parachute relative to the way points, the parachute’s navigation system will interpolate a straight line between the points and uses a position controller to track it. Once the parachute is sufficiently close to the window, it will start to use its own single camera vision system to adjust the control lines.

The position control is a complicated problem because the autopilot is required to control the (x, y, z) position of the vehicle as well as the direction of travel with only the two actuator outputs. This challenge has been addressed by systematically simplifying the problem resulting in two PID controllers with outputs to series of simple dynamics equations where the results of these equations are the deflections of the control lines.

The initial challenge is to determine the desired heading of the vehicle. Simply aiming for the programmed way points may result in the parachute attempting to aim for a way point behind it when it
would be better to aim for a way point below it. To avoid this fault the parachute uses an algorithm similar to the straight line tracking algorithm of the aircraft. Since we are not able to rely on the parachute increasing its altitude, the first step of the algorithm is to determine which of the two loaded path points the parachute is between vertically. The control algorithm will then attempt to have the vehicle merge with a line connecting these two points.

The control is broken down into heading control and glide slope control. This decoupling of the control will allow for the tuning of the vehicles to be simplified.

Heading control only deals with the x and y positions of the parachute and the x and y positions of the loaded path points. A top down view diagrams the algorithm in Figure 5(a). The algorithm calculates the point that is closest to the parachute on the line between the two way points and then has the parachute aim a distance delta in front of this point of intersection. When delta is held constant it results in the parachute merging with the desired path in an asymptotic fashion.

Glide slope control is shown from a side profile in Figure 5(b). Calculations are made based on the vertical plane that the two closest way points are located on. The slope of the line between the two way points of interest is the loaded glide slope. Using the projection of the location of the parachute on this plane, the distance from the parachute to the line is calculated. A desired glide slope is calculated as this distance multiplied by a control constant and added to the loaded glide slope.

The final equations of the parachute’s dynamics require a desired total braking force and a desired rotational torque. To provide the total breaking force required a PID is used in conjunction with the glide slope error as the input. To acquire the desired torque a PID is operated using the heading error as the input. The force and torque are then translated into the necessary actuator deflections.

3.3 Camera Control

Once the parachute is within proximity of the window it will begin to use its on board camera to determine the desired heading and glide slope by visually homing in on the location of the window. The use of the onboard camera will prevent the parachute from missing the target and hitting the wall in the event that there is an error in the calculated coordinates of the window.
4 Payload

4.1 Sensor Suite

4.1.1 GNC Sensors

In order for the navigation, stability augmentation and mission sensor systems of the transport vehicle to be effective, accurate measurements of the location and orientation of the transport vehicle are required. Guidance, navigation and control (GNC) sensors are used to provide the required accuracy.

Position, attitude and airspeed sensors are used for guidance, navigation and control. They are a NovAtel SuperStarII GPS receiver [7], a MicroStrain 3DM-G orientation sensor[8] and a custom airspeed sensor. A non-integrated GNC sensor system will be used for the initial revision. Future developments will improve the functionality of the GNC sensor system by combining the measurements of different types of sensors to compensate for their individual inaccuracies by integrating the components using various sensor fusion algorithms into one GNC system.

4.1.2 Mission Sensors

The purpose of the mission sensors is to determine the location that the payload vehicle should be delivered to. Multiple vehicles in the vehicle network will to work together with the mission sensors to gather visual data that will accomplish this goal.

The transport vehicle’s mission sensors will consist of vision system comprised of two digital still-cameras that will be used for identification and location, of relevent features in the urban area, such as the IARC symbol and open windows. This vision system will also be used for threat avoidance. The cameras are set apart from each other by a fixed distance and provide the vision system with stereoscopic vision data by repeatedly taking pictures at a fixed frequency between 35Hz and 70Hz.

Edge-detection will be applied to images gathered from both cameras to highlight the salient features. Edge-matching is applied to remove stray edges and find edges that may meet. The points in one image are matched with the points in the other image that are most likely to correspond to the same object, based on relative proximities. Then the points are triangulated according to the absolute locations of the two cameras and their focal lengths to determine the distance between the transport vehicle and the object. This data is used to assemble a voxel map of the urban area that is being searched. This three-dimensional voxel map of the urban area will be used to generate search paths for the transport vehicle to follow.

Threat Avoidance  The main problems of threat avoidance for the transport vehicle can be solved by restricting its flight to an altitude that is well above that of the highest buildings and trees in the area. This places a reliance on the human operator to accurately set these limits.

The payload vehicles, which must descend between the buildings, must be provided with a safe path to follow. A safe path will be calculated from the voxel map to that begins at a feasible release point of the delivery vehicle and ends at the location of the target window. The delivery vehicle uses this information in its guidance navigation and control algorithms.

Target Identification

IARC Symbol Recognition  As a transport vehicle flies above the urban area and constructs the depth map that is used in threat avoidance, it also conducts image analysis to find the IARC symbol. The vision system will use neural networks to detect the symbol in the image.

Once an image is found to contain the target symbol, the location and orientation of the transport vehicle provided by the GNC sensors is recorded. The location and dimensions of the target symbol is determined by triangulation using a pair of stereo images. The dimensions are used by the vision system to perform a final verification of the accuracy of the results from the image recognition algorithms.
**Target Window Location** The IARC mission requires the system to identify the absolute location of the target window within 25cm. The algorithms that are used for the IARC symbol recognition will be used to locate the target window, however they will not be able to provide the 25cm accuracy.

A multi-vehicle strategy has been designed to locate the window to within 25cm. This strategy utilizes the advantages of the node-based vehicle network by collaborating the sensor data of multiple vehicles. After the approximate location of an open window is determined, the transport vehicle will flyby the location multiple times along flight paths offset by small angles. This will increase the accuracy of the location of the window by allowing the stereo vision system to analyze images of the window from different orientations. The main source of error in these measurements is a result of the inaccuracy of the attitude sensor, which is amplified due to the significant distance the transport vehicle is away from the window. At this point, the measured centroid of the window may not be located within the opening of the window. Because of this the delivery vehicle may not be able to enter the window, but may be within range to capture images of the open window. Since these images are from a closer range, any errors introduced by the GNC sensors’ inaccuracy would be greatly reduced. The refined location and orientation of the target window will be transmitted back to the transport vehicle.

If a delivery vehicle should fail to enter the target window, it can still be used by its transport vehicle to refine the location and orientation of the target window. The transport vehicle can now capture the target window and the delivery vehicle in the same image. Since the delivery vehicle will be brightly coloured, it will be easily recognizable to the vision system. The delivery vehicle’s GNC sensors will provide its location to the transport vehicle. The transport vehicle can use this known location along with the position of the target window relative to the payload vehicle in captured image to further refine the position of the open window.

The three step process of deploying a payload vehicle, gathering close up visual data of the window and locating the window with respect to the known payload vehicle location (used only if the vehicle fails to enter the window) will be repeated until a payload vehicle is successful at entering the building. The earth-fixed location of the window reported to the IARC judges will be that of the final location that the successful delivery vehicle travels through.

**4.2 Communications**

The communications system serves as a means of transmitting instructions and information relevant to the mission between each vehicle node to its sub-nodes as described in the introduction of this paper.

The communications system is structured as a network of wirelessly connected vehicles that are arranged as a tree rooted at the base station. The base station is connected to multiple transport vehicles. Each transport vehicle is connected to multiple delivery vehicles. Each delivery vehicle is connected to multiple payload vehicles. Therefore, three communication interfaces can be formulated: the delivery-payload interface, the transport-delivery interface and the base station-transport interface.

This arrangement has led to the choice of the following communications technologies. The communications link between the payload vehicle and delivery vehicle will be short range wireless RS232 for instruction data and frequency modulation (FM) radio transmission for image data. The transport vehicle and delivery vehicle will communicate over 802.11 wireless Ethernet. 802.11 will also be used as the link between the transport vehicle and the base station for the initial revision. Future upgrades will add broadband satellite internet that has recently become available in some areas [9].

**4.3 Power Management Systems**

A power management system has been implemented for transport vehicles to provide sufficient power for the motors and electronics during a sustained flight.

All vehicles will use identical types of Lithium Polymer battery packs. Lithium Polymer battery packs were chosen because they have a power density of approximately 170Wh/kg. Three independent sets of
batteries will be used for the transport vehicle, one for each motor and a third for the electronics.

### 4.4 Payload Vehicle

The payload vehicle is used to return reconnaissance information from inside the target building. Design constraints include having a deployment mechanism to free it from the delivery vehicle and allow for more payload vehicles to be carried on each delivery vehicle. The vehicle must also be sufficiently robust to survive delivery. The payload vehicle is to navigate inside the building and must use a suitable sensor to return the desired information. It is important that payload vehicle maximize the coverage of the buildings’ interior to ensure the target is located. The actions of multiple payload vehicles will be coordinated by the delivery vehicle.

A ground vehicle was chosen for the payload vehicle due to simplicity and cost-effectiveness. Since the payload vehicle is to return visual information, a camera will be mounted as the primary sensor on a lifting mechanism. The camera will return images to the delivery vehicle where they will be accessible to the rest of the vehicle network.

### 5 Operations

#### 5.1 Man-Machine Interface

The purpose of the man/machine interface between the operator and the vehicle network is to provide human interaction to allow the operator to monitor and control various components of the system. Through past experience, it has been found that restricting the operator’s access to only a few specific software components may limit the system’s versatility in the field due to the variety of situations that may arise. For instance, if during a flight a parameter or algorithm needed to be changed that was not accessible remotely, the vehicle may need to land to be reprogrammed on the ground. However, if it were possible to change these parameters or code while the vehicle were still flying, it would allow the vehicle to be much more versatile. For this reason, the goal is to design a modular software system that provides the operator with access to all software components of the vehicle network. The basis of the software architecture is provided by QNX’s Neutrino Operating System (OS)[10]. This OS provides two technologies that are essential to our design: Resource Managers and QNET. QNX Neutrino also provides full POSIX compatibility. This allows the operator to interact with every aspect of the vehicle network through familiar UNIX shells.

Graphical user interfaces will be used as a user-friendly alternative to the command line interface for monitoring and interacting with the remote vehicle system.

#### 5.2 Flight Preparations

In any remote vehicle system, preparations are essential to both safety and success. If the appropriate procedures are not followed, the results can be catastrophic. For this reason, it has been decided that all preparation procedures should be interlocked with the startup systems. Therefore if the critical procedures are not followed, the entire system will not be able to start.

##### 5.2.1 Checklist

Items on a software checklist can be automated using scripts and startup programs. However, for non-software components, the checklist is implemented by asking the operator if the appropriate preparations have been made. If the operator does not respond correctly, the system will not initialize. At this stage, the reliance is on the operator to respond to the checklist queries with the appropriate engineering judgment to ensure safety.
The above outlines the method in which a checklist will be implemented; however, at the time of writing this paper, the vehicles are not yet developed to the stage where it is beneficial to specify the individual items on the checklist.

6 Risk Reduction

6.1 Vehicle Status

It is important for the operator to have full access and control of the status of all vehicles. This is achieved through the node-based architecture described in the Introduction. Additionally, the status of the vehicle is not limited to just full manual or full autonomous control. The human pilot and the autopilot can share the various decoupled controls allowing for a number of partial autonomous control modes.

6.2 Shock, Vibration and EMI Isolation

All of the vehicles must deal with shock, vibration and electro-magnetic interference (EMI) to varying degrees. The methods used by each vehicle to deal with these issues depend on the amount of weight that a vehicle can carry.

The transport vehicle has a high payload capacity and can therefore afford to contain its onboard electronics within protective casings. These casings are mechanically isolated from the airframe to provide resistance to shock and vibration, they are constructed largely of aluminum to protect against EMI. The design of these cases would be modular in the sense that they can be entirely removed from the transport vehicle and used independently.

The delivery and payload vehicles are not able to carry a large protective case because they are required to be small and light weight. Isolation is more tightly coupled to the vehicles systems. Foam padding and aluminum foil were used and worked well for light weight vehicles.

6.3 Safety

One of the design criteria for the vehicles was safety and the choices of an aircraft, a parachute and a ground vehicle reflect were made partly because they were safer than most of their alternatives.

The most dangerous vehicle is the fixed wing aircraft. To increase safety, there are hardwired takeover relays that allow the pilot to take control of the vehicle in the event of an electronics failure. This is in addition to the Flight Termination System previously discussed. Restricting the transport vehicle to an altitude above the level of the highest structure helps to increase the safety. This means that the only vehicles operating autonomously in close proximity to any buildings or the ground will be the parachute and ground vehicles.

6.4 Modelling and Simulation

The control software can be tested and simulated using models of the vehicles dynamics and control systems that are developed in Matlab and Simulink. These types of models are readily available for aircraft and are being developed for the parachute and ground vehicle.

These software packages can provide hardware-in-the-loop testing using TCP/IP communications with QNX-based hardware. There are plans to use this technology to validate the software and hardware systems.
6.5 Testing

The first step to ensure success is to develop and test a reliable mechanical system that can be controlled safely by a manual pilot. This is essential because if a failure is encountered, a disaster can be averted by simply reverting control back to the pilot.

The next step is to test the appropriate control sensors and onboard computers. Once the sensors can provide sufficient measurements of the vehicles’ current state and the onboard computers are running reliably the modeling and simulation process can begin.

After a dynamic model of the vehicle has been generated, it must be verified against the actual mechanical system. A testing process will output the same signals to the vehicle’s actuators and to the simulated model’s inputs. By comparing the results, the simulated model can be verified and improved. Once sufficient accuracy is obtained, the simulated model can begin to be used to test control systems with the hardware in the loop.

7 Conclusions

In conclusion, a remote vehicle network was discussed as a unique and generic approach that can be applied to any aerial robotics missions. An implementation of this approach was designed to accomplish the IARC mission objectives. This implementation requires a base station, a transport vehicle, a delivery vehicle and a payload vehicle to be different types of nodes on a tree structured network. This paper discussed the specific implementations chosen for each of these vehicles.

To summarize these choices in terms of the IARC mission requirements: A fixed wing aircraft will travel a three kilometer distance to an urban location. Once there, it will search for the marked building and an open window to that building using its onboard stereo cameras. These cameras will use their depth information to create a path from the aircraft into the window that can be followed by a parachute vehicle. Once the parachute has entered the building through the open window, it will deploy a ground vehicle that will search the interior for the required visual information. This information will be relayed back to the base station through the remote vehicle network.

References


