Georgia Tech Aerial Robotics System Competition Entry

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ABSTRACT

The Georgia Tech Aerial Robotics System (GTARS) team is doing state of the art research on autonomous control of an unmanned aerial vehicles. GTARS's Association for Unmanned Vehicle Systems (AUVS) competition entry is a modified conventional model helicopter featuring an on-board Stability and Control Augmentation System (SCAS), a custom Attitude and Heading Reference System, a fail-safe override switch, and a retrieval sub-robot. Ground support systems for mission completion include a vision tracking system, a two-way digital telemetry data link, and an integrated ground control station with mission planning capabilities. After demonstrating a completely autonomous flight at the 1993 AUVS contest, the '94 team is enhancing the entry by (1) optimizing air vehicle configuration and components for performance, (2) redesigning SCAS for weight reduction and faster response, (3) optimizing mission planning software for efficiency, (4) developing an accurate and robust vision tracking system for outdoor performance, and (5) constructing an intelligent robotic disk retriever.

1.0 INTRODUCTION

1.1 Team Organization and Development

The goals of the GTARS team are to (1) advance Unmanned Aerial Vehicle (UAV) technology, (2) construct an entry for the annual International Aerial Robotics Competition (IARC), and (3) study potential commercial issues of UAVs. The GTARS Team was formed in November 1990 and has participated in all four Annual IARC Competitions. The team follows a Concurrent Engineering (CE) approach, which stresses the horizontal integration of disciplines (AE, CE, EE, ME, CS) and vertical integration of product and process characteristics such as design, manufacture, test, and operation.

To develop and test a vehicle capable of completing the mission, the GTARS team is building a testbed with support capabilities for UAVs. Additionally, the testbed is used for applying UAV advancements to the commercial sector. A specific commercial use of the GTARS UAV is radiation detection over toxic waste dumps of the Savannah River Waste Facility. Other UAV applications such as reconnaissance, aerial surveillance, communication, and sensor placement are also being addressed for commercial uses.

2.0 CONTEST ENTRY STRATEGY

2.1 Disk Acquisition and Transfer Strategy

Proposed GTARS Team strategy for the 1994 competition is illustrated in Figure 1; eight distinct mission segments are described. The basic team strategy includes (1) takeoff from a specified starting box, (2) controlled flight to a predetermined location over a source bin, (3) deployment of the retriever to acquire a disk, (4) climbing of the helicopter to transition altitude, and (5) controlled flight to drop-off bin where (6) disks are deposited. The helicopter then (7) returns to the source bin to gather more disks and when the mission is complete; (8) the helicopter returns to the start. Under the given strategy, acquiring and transferring all 6 disks is performed in under 12 minutes.

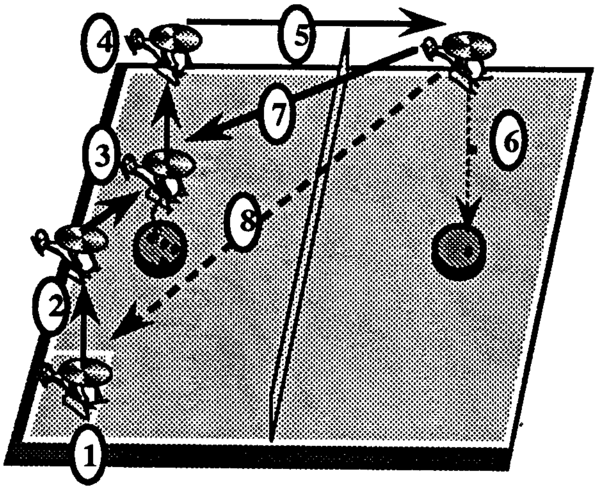


Figure 1. GTARS Mission Strategy.

2.2 Vehicle Design Strategy Overview

To accomplish the mission strategy, the GTARS entry includes (1) an air vehicle for autonomous flight and hover, (2) a Stability and Augmentation system (SCAS) for inner-loop control of the air vehicle, (3) a ground-based machine vision navigation system (NavSys) and a ground-based mission planning system (MPS) for outer-loop feedback control of the vehicle in the contest arena, and (4) a deployable retriever to accomplish disk acquisition. The GTARS system is shown in Figure 2 with the air vehicle in the center and the inner-loop onboard controller shown in red and the outer-loop feedback control components of the NavSys (blue) and MPS (Green) below the air vehicle.

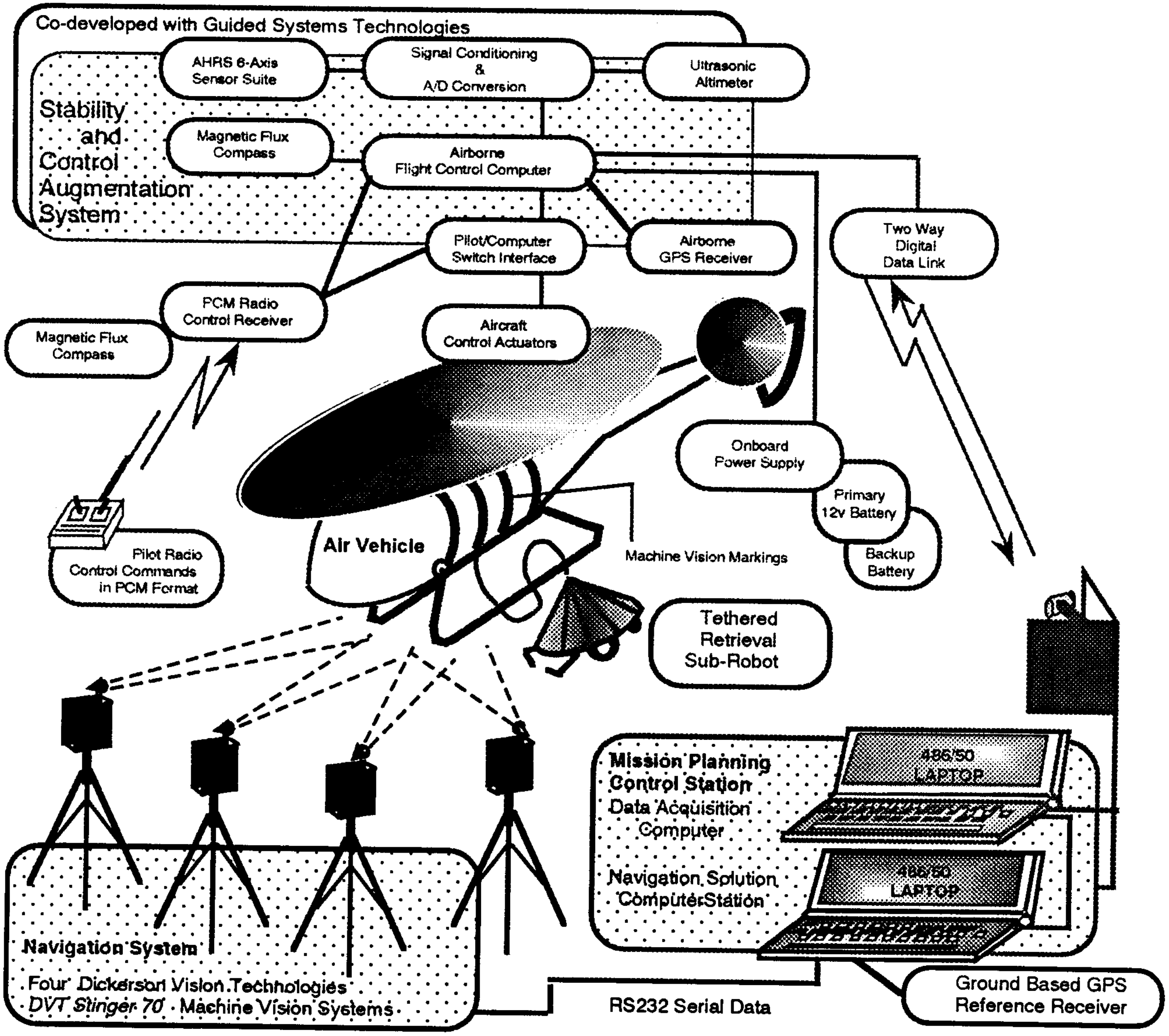


Figure 2. GTARS System Entry Block Diagram.

Another attribute of the GTARS strategy is to design for cost, vehicle maintenance, and sustained operation. The aerial robot, which includes the air vehicle and SCAS of the inner-loop, is designed for performance and explained in detail in the technical section.

The modifiable MPS is used to dictate the commands to the vehicle by way of the SCAS for trajectory planning, mission operations, and diagnostic display of air vehicle information. These operations are high-level decision tasks for vehicle transitions between points outlined by the GTARS strategy. Feedback to the MPS is provided by a NavSys consisting of four machine vision systems placed around the playing field. From vision images, the NavSys detects 2-D helicopter linear movements of depth and lateral motion. The altitude, 3rd coordinate dimension, of the vehicle is determined onboard via ultrasonic sensors on the tail boom and sides of aircraft.

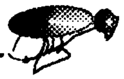
The aerial robot's three dimensional position is referenced to a 'world model' of the competition arena residing in the MPS Computer. The model posses the locations and features of the arena in reference to the corner starting zone - from which the flight starts. The aerial robot navigates by the a priori knowledge of bin, wall, and boundary locations in the 'world model'.

To perform the disk recovery task, the team integrates a microprocessor controlled disk retriever. Once deployed from the helicopter, the retriever has a controlled lowering to the bin and begins a search pattern until a disk is acquired.

In addition to hardware design, the GTARS design strategy also includes (1) simulations to determine the dynamic characteristics of the system, (2) flight tests to validate a working system model and hardware, (3) logistics support to provide continuous testing throughout the year (4) adherence to the competition rules, and (5) strategies for participant safety such as a safety switch for human pilot control.

3.0 TECHNICAL DESCRIPTIONS

3.1 Air Vehicle



3.1.1 Aircraft Selection

GTARS strategy requires the ability of vertical take-off and landing (VTOL), hover and control with respect to a ground point, and payload capacity to carry the required flight control equipment. Additionally, the most efficient lift configuration for vertical flight consists of low disk loading and low rotor speed with minimum wake downwash velocity. The conventional helicopter posses these desirable attributes. Using the efficient lift design also offers the advantage of precise control of the thrust vector for vehicle movement, allowing for the ability to precisely hold position with respect to a ground point even in unsteady wind.

The GTARS team uses a Miniature Aircraft X-cell 60 model helicopter. The aerobatic radio-control model helicopter exists as an off-the-shelf flight vehicle solution, commonly available in weight ranges from 3 lb. up to 15 lbs. Being designed for aerobatic maneuvers, these models provide a high degree of structural safety, when not in aerobatic maneuvers, but restricted to hovering flight. Additionally, local hobby clubs have experienced builders and pilots, providing assistance in the construction and operation of model helicopters. Spare parts are widely available from local hobby shops and mail order suppliers. These advantages, combined with the extensive theoretical and computational knowledge in rotorcraft research found at Georgia Tech, made the conventional model helicopter configuration the most suitable platform for the GTARS team.

3.1.2 Airframe Design

The GTARS team is using an X-cell Model helicopter modified for system development and mission completion. Figure 3 illustrates the GTARS modifications to the model airframes with a payload baseplate to accommodate electronics for the '93 developmental configuration, and a full fuselage for the '94 integrated configuration.

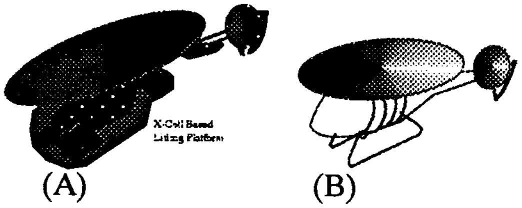


Figure 3. Air Vehicles - (A) '93 Developmental, and (B) '94 Integrated.

To address payload additions to the aircraft, the developmental configuration uses a carbon fiber/ balsa sandwich payload carrying plate designed to support the avionic components and absorb hard landings of developmental flight testing. For routine maintenance and repair, the payload plate is joined by quick release pins through the stock landing gear struts. Avionics can be arranged around the plate to ensure proper weight and balance of the aircraft. This configuration proves to be an excellent developmental platform with its inherent flexibility and modularity; but, the plate introduces undesirable aerodynamic effects by reducing the effective lift area of the blade. Both payload capacity and maneuverability is hindered; however, the integration of payload area into an aerodynamic fuselage reduces these effects.

The new, fully integrated, design of the airframe shape includes a combination of a fiberglass shell and crashworthy carbon-fiber/balsa sandwich internal frame (similar to the payload baseplate). The design for the fuselage shape consists of three parts, detachable (a) starboard and (b) port upper halves - for quick access to the engine, the rotor hub, and swashplate for maintenance; as well as a detachable (c) bottom section to house the retriever system. The detachable bottom section can be reconfigured for any UAV mission and allows autonomous testing with or without the retriever section.

3.1.3 Air Vehicle Optimization

Air vehicle optimization for different UAV missions is necessary as vehicle weight increases beyond the normal lifting capability of the model airframe. GTARS optimizes the configuration of the X-Cell helicopter based on the constraints imposed by the competition rules and existing hardware. The optimization process is as follows:

1. Develop a mission profile from contest rules and constraints;
2. Create a sizing model for weight growth based on vehicle configuration;
3. Determine parameters available for optimize such as chord (width) and radius of blade design - as shown in the plot of Figure 4;
4. Develop objective function to optimize payload weight and volume for the prescribed mission;
5. Optimize configuration with respect to the function variables;
6. Make necessary modifications to the vehicle to implement the new configuration, and
7. Test modified configuration against the original performance.

'Off-the-shelf' models, although very capable for their size, are limited in payload capacity of weight and volume, but prove reliable and easy to support. After investigating several aerobatic models, it was clear that the lifting capacity could be improved with minor modifications.

An analysis model of the air vehicle system is developed utilizing simple momentum theory for rotor performance predictions. For a given engine option, with a respective engine-gear ratio, operating at maximum torque, an inverse solution for maximum thrust with a given set of rotor parameters of blade radii and chord (blade width) is calculated. Thrust minus projected weight is the generated effective payload, and an optimal blade geometry and gear ratio for greatest effective payload is sought. The vehicle weight is calculated using weight growth rules based on stock vehicle component sizing, for the rotor, main gear, and tail boom; since, these parameters change with the rotor sizing. Figure 4 illustrates the optimum chord and radii, constraints of a max. coefficient of lift (C_l) of 1.2, and a max. Mach Number of 0.55 are imposed to select the optimal configuration in the range of linear aerodynamics - the condition where the method is valid. The selected optimum configuration with an O.S. 0.61 engine (a 0.61 c.i.d. glow fuel, 2-stroke engine) occurs with the chord line of 2.0 inches at a radius of 28 inches, and a gear ratio of 9:1; where the effective payload is approximately 26 lbs., nearly three times the stock payload.

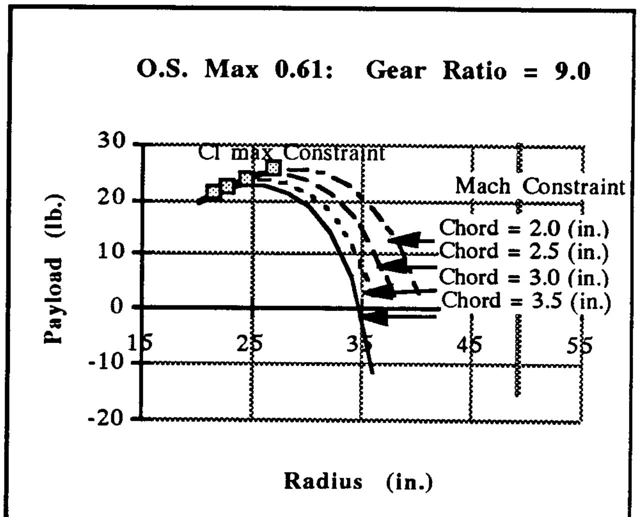


Figure 4. Helicopter Blade Design Optimization.

3.1.4 Helicopter Control Actuation

Control of a helicopter is performed by pitch changes to the rotor blades. Collectively changing the pitch at all azimuths, through one rotation, changes the magnitude of the trust; cyclically varying the blade pitch results in vectoring of the thrust, which allows for control of pitch, roll, and translation velocity. Yaw control is attained through balance of rotor reaction torque and moment exerted by the tail rotor for hold or change heading. The X-Cell actuator system consists of 5 servo actuators - 3 for main rotor pitch controls, 1 for tail rotor control, and 1 for throttle control. Command of actuator position is open loop, directed by a 1.5 ms duty cycle pulse width provided either by the radio receiver or by the flight computer. The X-Cell airframe rotor control inputs are separated into dedicated servos for longitudinal cyclic, lateral cyclic, and collective pitch. The separation of control functions of the X-Cell simplifies the SCAS interface to the aircraft actuator system, eliminating complex control command mixing.

3.2 Flight Avionics - Stability Control and Augmentation System (SCAS)

The SCAS, co-developed with Guided Systems Technology (GST) incorporates (1) an inner-loop controller for helicopter stability including the avionics and ultrasonic sensors; supervised by (2) an outer-loop controller which uses information from the NavSys and the MPS to determine the trajectory of the vehicle. Without human interaction, the top-level functions of planning and guidance are accomplished by state machines and modeled tracking of the outer loop. Lower level functions such as reactions to environmental alterations (which act to destabilize the vehicle) are accomplished by proportional, integral, and derivative (PID) feedback loops in the inner-loop flight control system. Outer-loop mission planning commands such as "change heading" or "go to the bin", complement the inner-loop stability system with objectives of "keep level flight" and "raise collective to keep the altitude at 45 centimeters" maintaining the operation of a desired stable system. The procedure for tuning and modeling of the flight control system involves using available flight test information of a similar vehicle, and comparing to and testing the gains of the new fully instrumented aircraft.

3.2.1 Inner-Loop Stabilization Control

The on-board SCAS is employed to stabilize flight and to track attitude and position. The primary elements of this system are sensors, a three-axis sensor suite, interface electronics to facilitate communication between the processor and sensors, a power supply, flight control computer and associated software, air vehicle actuators for control, and a data link suitable for communication the ground computer.

Critical design requirements are weight, volume, cost, and power consumption, especially with regard to choice of sensors. For instance, pitch and roll attitude angles are typically sensed with a two-axis vertical gyro; however, identified units were very expensive ($5K or more), weighed several pounds, and consume large amounts of power. The primary on-board technology alternative is an Attitude and Heading Reference System (AHRS) based on traditional inertial systems. Here, outputs of angular rate sensors are integrated to determine attitude angles. The integration process is stabilized using detection of the gravity vector with linear accelerometers. Quartz rate sensors are integrated into control software using fluid angle sensor outputs to stabilize the integrals. The AHRS sensor suite consists of a three-axis set of quartz rate sensors on loan from Systron Donner and two 360 degree fluidic inclinometers for direct attitude determination. For steady-state heading feedback, a flux gate compass is integrated which utilizes the Earth's magnetic field lines as a heading reference to magnetic north. The result is a solid state AHRS package of minimum weight and power consumption providing the necessary pitch, roll, and yaw attitudes and rates required to stabilize the vehicle [4].

An ultrasonic altimeter system is used for altitude and sink rate determination. The altimeter is implemented digitally with a dedicated microprocessor and is accurate to a fraction of a centimeter with a range of approximately 10 meters. The altimeter system employs up to eight ultrasonic sensors to determine the vehicle height with respect to ground level by an echo-sound travel time. Time differentiation of the height provides an estimate of vertical (sink) rate.

Inner-loop sensor systems provide the feedback error signals to stabilize the air vehicle in low speed flight and hover. The feedback closure of inner loop control is implemented digitally with the onboard flight control computer. The flight control computer is based on the Motorola 68332 processor, augmented with 16 channels of 12 bit resolution analog-to-digital conversion for the handling of sensor signals. Digital sensor data is read directly by the 68332 through one of several built in timer ports and the 68332 generates a pulse-width signal to command servo actuators for vehicle control. Functions of computation, sensing, and signal conditioning are implemented into interchangeable functional blocks in the flight control computer. The integrated system weighs less than 6 lbs. and consumes less than 15 watts during operation.

Airborne power supply for the GTRAS system is a set of NiCd batteries, dedicated to particular functions. A 12V NiCd pack and a custom power conditioning board supplies the flight control computer. Control actuators and the safety override are isolated with a separate 5V supply. With a fully charged battery set, the system's endurance is over an hour.

3.2.2 Outer-Loop Planning Control

Outer-loop high-level directing and control is performed by the MPS, NavSys, data link, and the safety/override switch. The MPS, which assimilates data from the NavSys, is used to issue mission commands and to monitor mission performance. A two-way digital data link between the MPS and flight control computer allows for flexible and effective flight tests. During testing, the MPS allows real time in-flight tuning of 250 control system parameters in the SCAS software. Through the data link, data telemetry is issued from the MPS to the air vehicle and unlinked communication is implemented in an RS232 serial format between the flight control computer and the MPS PC. While the helicopter is in flight, the MPS gathers detailed data on system performance for off-line analysis. Data such as actuator inputs, aircraft rates, etc., are transmitted down to the MPS PC and displayed in numerical format or stored in a file in one of up to 15 data windows capturing data in real-time.

Safety is a concern, especially in the case of uncontrollable flight. For this reason, the flight control computer "talks" to the actuators through a SCAS on/off switch providing the safety pilot a means to bypass the flight control computer in the event of hardware or software malfunction. As a contingency in the outer loop, a skilled safety pilot has the ability to take direct control of the vehicle, bypassing all computer commands, to regain vehicle stability or terminate the mission.

3.2.3 Control Software Design Analysis

The software for flight control is designed to address a multitude of tasks, including communication with the ground station, interpretation of pilot commands, filtering and analysis of sensor data, closure of the feedback loops, coordinate transformations, and actuator commands. A linear, continuous-time model of the helicopter is constructed for control system design with initial gain selection and simulation of controller performance carried out in the continuous-time domain. The resources of the on-board processor manage to maintain on-board sensor sampling and feedback-loop update rates of several hundred hertz. The transport delay in the on-board loops is not a problem; however, finite word-length representations of sensor data following analog-to-digital conversions, both on-board and in the off-board vision system (i.e. finite pixel size and camera servo step size) limit the performance of the inner-loop onboard control system. To maintain processing speed, calculations are carried out in integer form, leading to significant truncation errors, but critical data calculations are implemented using floating point operations.

Perhaps the most difficult software effects to overcome are associated with off-board outer-loop determination of the vehicle position and velocity. The NavSys, described in detail later, consists of individual vision units with image processing capabilities that communicate serially with the MPS 486 PC. Position data, along with an estimate of velocity, is transmitted to the inner-loop controller on the vehicle by the MPS. The finite processing time of the system and the serial communication link between NavSys and MPS PC lead to a significant time delay between capture of a set of images and delivery of position data to the on-board flight control system. The effects of the delay are exacerbated by noise and the additional time delay introduced by a mechanical system that introduces damping in the rotor system. A filtering technique that trades output smoothness for frequency response is used to provide acceptable velocity data.

3.3 Ground Based Mission Planning System

The functions of the mission planning subsystem (MPS), are to (1) provide vehicle commands to achieve mission objectives, (2) display and modify vehicle parameters, and (3) perform real-time data acquisition for flight tests. The MPS is a state-based program on the ground computer with a digital data link to the helicopter. The MPS matches status information downlinked from the air vehicle and the NavSys with the preprogrammed objectives.

The MPS computer provides user-friendly interfaces to modify the over 250 vehicle parameters, sends flight commands from the keyboard, and displays the vehicle status and an air vehicle diagnostic set of parameters. A mission profile is provided in an ASCII file and processed with the position, velocity, and trajectory data from the NavSys by the ground computer to produce the appropriate vehicle commands. Figure 5 shows the MPS function.

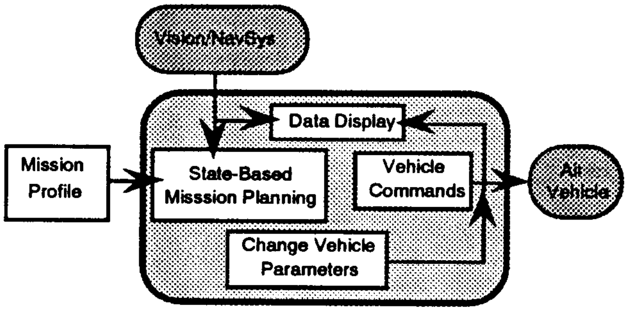


Figure 5. Mission Planning Control Flow.

Tolerance limits on the state transitions are tuned to avoid abrupt state changes which could affect stability. For instance, the helicopter must be hovering within 1 meter of the bin center for at least 20 seconds at the required attitude before the retriever is deployed. Since the mission profile is rather simple (8 previous outlined steps), there are few decisions for mission completion.

However, the stability of the aircraft is subject to environmental conditions of temperature and wind. In the case of an emergency, contingency plans exist for such component complications as data loss, vehicle limitations, or vehicle not-in-vision-line-of-sight. For each flight, gains are tuned for optimum performance given environmental and component conditions and displayed in one of the 15 data windows. The sophistication of the planning software increases as the mission profile becomes more uncertain or the mission becomes more complex.

3.4 Navigation System

The navigation system (NavSys) consists of a barcode retro-reflective target mounted onboard the vehicle, four strategically placed Integrated Vision Units (IVU) with charge coupled device (CCD) servo-panning platforms, and the navigational computer. The IVU controls a 1.8° stepper motor, which rotates the CCD assembly to track the target. Given measurements from three of the four cameras and the known IVU locations, angle calibrations are used to triangulate the position. Velocity is computed as the average of position change over time.

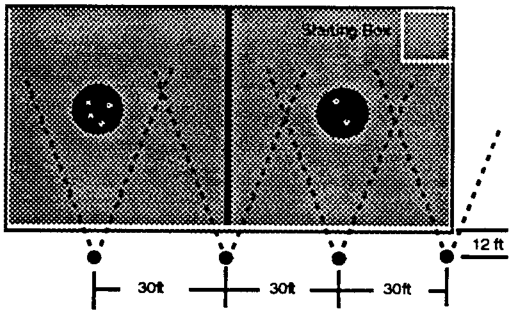


Figure 6. Machine Vision Navigation System.

The IVU, a Dickerson Vision Technology (DVT) Stinger 70, integrates a low-resolution CCD array with a programmable 6800 microprocessor, photodetector, optics, digitizing electronics, and serial communications into a single device. To address the problem of fiducial, target pattern, recognition outdoors for the AUVS contest, a novel design incorporates a Xenon strobe tube to enhance the retroreflective/black contrast. For other missions which necessitate longer ranges, GPS units are being considered.

3.4.1 AUV Navigational Constraints

For the helicopter to have autonomous control, a [X,Y] position is necessary to close the position feedback loop of the outer-loop system. The position NavSys, which estimates target position, is subject to these constraints:

1. A 10 Hz update rate for system response,
2. 5 to 120 meter visible range ,
3. +/- 3m accuracy to position vehicle over bin,
4. Robust transfer of data, and

5. < 4 kgs of equipment onboard aircraft.[2]

Given these constraints on the system, machine vision is selected because it offers significant flexibility in both hardware and software. Incorporating a C++ based program and passive retro-reflective targets, the flexibility of the NavSys rests in the ability to alter targets at will. The only constraint of the IVS/fiducial-tracking approach is the restricted line-of-sight. To overcome this potential problem, CCD heads are mounted on a panning platform. As the fiducial nears the edge of the image, the servo advances the CCD head, positioning the target at the image center.

3.4.2 NavSys Configuration

The vision-based tracking system uses four gray scale vision systems, each with a one-degree of freedom panning system that expands the 12° field-of-view (FOV) of a CCD head into an effective FOV of better than 150°. A 300 watt incandescent bulb is mounted above each CCD head to enhance image contrast. At night, this arrangement effectively makes the bar code the brightest object in the image and superior tracking results are observed.

In daylight, the effects of ambient unstructured sunlight makes it difficult for the IVS to successfully distinguish the intensity pattern of the bar code from other objects in the image. To compensate for the ambient sunlight alterations to the CCD image, a strobe is placed onboard the aircraft and the NavSys looks for a brightly lit blob; however, with only one blob, the accuracy of the system is reduced to the accuracy of a single point.

3.4.3 AUV NavSys Software

The NavSys software initializes the cameras and then automatically sets the cameras in a continuous loop scanning for the helicopter barcode fiducial. The symmetric stripes of the bar-code target produce a distance-normalized pattern. The NavSys routine scans row by row looking for a particular light(reflective) to dark(absorbing) transition that characterizes the bar-code fiducial. The method the NavSys uses to resolve these features is a gradient threshold edge detection scheme which searches for 6 transitions of light-to-dark and dark-to-light between the 3 equally spaced retro-reflective bars on a black background. If all rows in an image have been scanned and the intensity pattern of the fiducial is not recognized, the servo advances the CCD head to a new field of view. Once the target is located, subpixelization, determining the exact location of the edge between pixels, is performed to improve the accuracy of the target.

The NavSys computer is a standard 486 machine which communicates with the Vision Systems over 38400 Baud serial RS-232 line. In the standard running mode, the IVUs continuously report to the NavSys computer the azimuth angle of the helicopter at the rate of about 36 Hz. The NavSys reports continuously, at about 10 Hz, the best position estimate of the helicopter to the MPS computer at an accuracy of +/- 1. 5 cm.

3.4.4 AUV IVS Results

Onboard the air vehicle, the bar code fiducial is recognizable with a maximum tilt angle from horizontal of 15 degrees.

TABLE 1. Machine Vision Characteristics[3]

	AUV '93	AUV '94
Illumination	300 watt bulb	Xenon strobe
Sample Rate	37 Hz	< 10 Hz
Resolution	0.201 °	0.0156 °
Accuracy	0.618 °	0.0171 °
Field Depth	4 - 40 m	1 to 60 m
Fiducial	4 white bars	3 white bars
Exposure Time	20 ms	1 ms
Gimbal	DC servo	Stepper motor

By using a fiducial on-board the helicopter, the weight of the navigational equipment does not hinder the lifting capabilities of the helicopter. With a larger helicopter, an IVS can be mounted on-board the helicopter in place of or in addition to off-board cameras to improve the operating range of the air vehicle. With a feedback rate of 40 Hz and a position accuracy of +/- 5 cm, the velocity/position measurements from the NavSys assist in helicopter control.

3.5 Digital Data Link

Transferring information from the vehicle to the ground MPS is required for top-level outer-loop guidance. To select the appropriate information transfer system, criteria of low weight, size, power consumption, dynamical effects, and cost are analyzed. The resulting choice is a two-way radio data link.

The data-link system incorporates a pair of digital spread spectrum transceivers based on the Proxim Proxlink. The same spread spectrum radio technology and internal packetizing is used in conventional telemetry systems, but the system is smaller, more robust, and has a greater range due to utilization of external antennas. The link is set up to provide a 12dB gain directional antenna for additional range and the link is capable of 19,200 baud of ranges of greater than 150 meters. The datalink operates on a frequency from 902 to 928 MHz, automatically hopping between specific frequencies for an optimum receiver signal level.

3.6 Disk Retrieval System

The disk retrieval subsystem is designed to acquire a competition disk from a ground bin while the air vehicle maintains hovering flight overhead. Once in the disk source bin, the retriever performs its task as an autonomous sub-robot. The microprocessor-based retriever design has two main components, (1) a sub-robot and (2) a winch. The sub-robot is a wheel driven vehicle that searches the bin for a disk and secures the disk with a mechanical gripper. The winch is attached to the helicopter and is responsible for lowering and raising the sub-robot over the pick-up bin.

Sub-robot features:
1. Light, compact design utilizing fiberglass,
2. A search pattern controlled by a 68HC11,
3. A servo actuated disk gripper, and a
4. Wireless transmitter for winch communication.

Winch features:
1. Controlled clutch, motor, and brake,
2. Optical encoder to sense the speed and position of the sub-robot relative to the winch,
3. Wireless receiver for sub-robot communication,
4. Bi-directional serial communication between the MC68HC11 and SCAS computer, and a
5. Safety device to release the sub-robot in case of helicopter instability.

3.6.1 Sub-Robot Deployment Strategy

On command from mission planning, the SCAS signals the winch to release and the retriever drops from the air vehicle. The winch clutch applies a partial braking action to slow the falling of the sub-robot into the bin. In the pick-up bin, the winch engages a neutral position so that the sub-robot can unwind its tether when moving forward and turning in reverse. When the retriever hits the bin wall, the retriever turns a prescribed ±60°. The search strategy is a random sweep of the bin for a disk and when the switch sensor is activated, the gripper is "told" to grab the disk. The sub-robot transmits a successful disk acquisition to the winch microcontroller, engaging the winch clutch and activating the winch motor to pull up the sub-robot. When the retriever is stored beneath the helicopter, the MPS signals the SCAS computer to fly the helicopter over the drop-off bin. Finally, the SCAS computer signals the winch microcontroller to signal the sub-robot to release the disk.

3.6.1 Retriever Effects

During tests, when the retriever is deployed, substantial dynamical effects are observed which cause instability in the air vehicle. The impulse force from the retriever weight is successfully damped by the altitude loops, but the tether tension and swinging motions affect the position hold. Dynamically, the retriever acts as a pendulum, transmitting moments to the helicopter. To combat the retriever effects, a winch system is used to actively lower and raise the sub-robot. Increasing the raising speed reduces these effects by limiting exposure of the air vehicle to unstable frequencies.

4.0 SYSTEM DEVELOPMENT

4.1 Simulation

The team simulates the modified X-Cell 60 helicopter to optimize the vehicle's performance. A NASA program, ARMCOP (ARMy COPter), is used to model the dynamics of the helicopter in its two operation modes, (1) hovering and (2) low speed forward flight. An accurate model of the GTARS vehicle is built in ARMCOP to provide estimations of vehicle response to disturbances and control inputs. From the nongraphical performance data, important stability characteristics and performance information are obtained.

Additionally, the X-CELL 60 is being modeled using FlightLab, an object oriented simulation program. In this environment, various characteristics specific to the GTARS system are modeled by physical characteristics (i.e. the underslung load of the retriever). It is hoped that design decisions and ideas tested in FlightLab and ARMCOP save valuable development time.

4.2 Safety Pilot

A key safety feature of the GTARS flight test plan is the inclusion of a dedicated safety pilot. In order to ease transfer of control from the pilot to the air vehicle as well as provide required safety mechanisms, a computer command switching interface is utilized. In the event of an emergency, a dedicated radio channel under control of the safety pilot provides a means to remove the flight computer from control - leaving a direct link from the radio transmitter of the safety pilot to the servo actuators.

In a typical flight, the pilot possesses complete control until such time as the pilot switches the flight computer active, which results in an introduction of damping on a single axis up to full autonomy for mission performance. If the pilot detects an unstable behavior or a mechanical problem, he can assume control immediately. The flight control computer features additive control inputs where, when active, the pilot controls add or subtract inputs to the vehicle's controls providing a gradual transition from manual authority to computer control, ultimately resulting in safe flight operations throughout development.

5.0 CONCLUSIONS

The GTARS entry meets the competition constraints of:

1) autonomy, by SCAS, MPS, and NavSys;
2) size, with max. blade dimensions of 5.2 ft; and
3) safety, based on the on/off SCAS override switch intended for safe termination of an unstable flight.

and has the ability to:

1) fly, hover, and take off and land vertically;
2) retrieve disks in flight; and
3) sense and navigate in the arena;

which are aspects needed to accomplish the mission of the International Aerial Robotics Competition.

At the 1993 competition, the Georgia Tech Aerial Robotics Systems Team demonstrated a controlled autonomous flight, and in 1994 the team is advancing UAV technology through development of a SCAS system, vehicle optimizations, and an outdoor vision tracking system, as well as featuring a robust, compact, and maintainable rotorcraft system. The GTARS team continues to work towards an autonomous helicopter entry capable of performing the complete competition mission.

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TABLE 2. Team Sponsors.

Guided Systems Tech.	SCAS Architecture
Dickerson Vision Tech.	Stinger 70 IVUs
Systron Donner Inert.Div.	Rate Sensors
Fredericks Co.	Angle Sensors
Fiber Rite Composites	Carbon Fiber Cloth
Proxim / GE Erickson	Data Link
Motorola	Electronics and HC11s
Douglas / Intermetrics	Compilers
3M Corp.	Retro-Reflective Material

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