N88-17252

ROBOTIC AIR VEHICLE

Blending Artificial Intelligence with Conventional Software

Christa McNulty Joyce Graham Paul Roewer

Texas Instruments Incorporated
P.O. Box 660246, MS 238
Dallas, Texas 75266

1 ABSTRACT

This paper describes the Robotic Air Vehicle system sponsored by both the Defense Advanced Research Projects Agency (DARPA) and Air Force Wright Aeronautical Laboratories (AFWAL). The program's objective is to design, implement, and demonstrate cooperating expert systems for piloting robotic air vehicles. The development of this system merges conventional programming used in passive navigation with Artificial Intelligence techniques such as voice recognition, spatial reasoning, and expert systems. The individual components of the RAV system are discussed as well as their interactions with each other and how they operate as a system.

2 INTRODUCTION

Challenging modern air defenses poses significant dangers such as loss of crew and aircraft. Intelligent unmanned flight systems can provide a viable solution to eliminate the loss of high-value aircraft and complement our manned force. The technology to allow the intelligence and adaptability of a pilot to be added to an unmanned flight system is being developed on the Robotic Air Vehicle (RAV) program. The RAV contract was awarded in September of 1985 by the Defense Advanced Research Projects Agency (DARPA) and Air Force Wright Aeronautical Laboratories (AFWAL). The program's goals are to design, implement, and demonstrate cooperating expert systems for piloting robotic air vehicles. The approach being used by Texas Instruments is to combine conventional programming with Artificial Intelligence (AI) techniques. This approach leverages established technologies, such as control theory and navigational terrain algorithms, with more recent techniques such as expert systems that give the RAV system the ability to plan, execute, and alter its mission. The mission scenario addressed in this paper is the reconnaissance of heavily defended areas.

The AI techniques applied in the RAV system are natural language understanding, voice recognition, expert systems, and spatial databases. The conventional software systems in the RAV system are the aircraft simulation, passive navigation, and the terrain following/ terrain avoidance route planner.

The following section, Robotic Air Vehicle System Software Architecture, explains the individual systems, both AI and conventional, that compose the RAV system. The RAV Hardware section describes the types of computer systems and their configuration required to run the entire RAV system. The Reconnaissance Mission Example section illustrates the interaction of various RAV system components executing during a reconnaissance mission.

3 ROBOTIC AIR VEHICLE SYSTEM SOFTWARE ARCHITECTURE

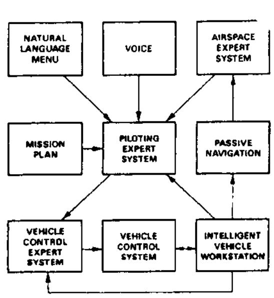

Figure 1. RAV SYSTEM SOFTWARE ARCHITECTURE

3.1 Command Inputs

The Robotic Air Vehicle system has two methods for command input: a natural language interface and a voice recognition system. During system execution, either input method can be used provided the user completes a command with one method before changing to the other method to enter the next command.

A natural language interface is provided to the expert systems through Texas Instruments NLMenu (TM). NLMenu is a menu-based approach to natural language understanding. The user is presented with a series of menus from which valid commands can be built. The menus are semantically constrained by a defined grammar so that only valid phrases within a context can be generated. The TI-DARPA fighter pilot grammar used in this interface is a set of in-flight commands used by pilots in general that has been tailored to the characteristics of high performance aircraft. This interface establishes an easy means to view the valid commands, to enter only complete commands, and to quickly enter commands for running the RAV system during knowledge engineering sessions with piloting experts.

Voice recognition technology is applied to the RAV system to enable communication with air traffic control or other manned aircraft and to receive intel and weather updates. The same TI-DARPA fighter pilot grammar used for the NLMenu system is also used in the grammar for the Voice system. The voice recognition in the RAV system uses the connected word recognition technology developed under the DARPA Robust Speech contract. This technology is currently implemented on the Texas Instruments Odyssey signal processing board.

3.2 Mission Plan

A route planner generates the mission plan using a conventional algorithmic approach. Given both a starting and ending point, the route planner finds an optimal path between these points. The mission plan consists of a series of intermediate waypoints, headings to those waypoints, and various altitudes to maneuver along the terrain following, flying close to the ground and terrain avoidance, flying around mountains instead of over them, path. This plan is used as input to the Piloting Expert System for navigation during the ingress, at-target, and egress phases of a mission.

3.3 Passive Navigation

For covert missions, the RAV system uses passive ranging of distant ground objects to navigate. Passive ranging relies only on passive sensors such as video and Foward Looking Infra-Red radar (FLIR) for its inputs. The Passive Navigation System uses these inputs in conjunction with data from a digital map to calculate algorithmically the current aircraft position with respect to the terrain. This position is sent to the Airspace Expert System where it is then distributed to the other RAV systems as needed.

3.4 Airspace Expert System

The Airspace Expert System (AES) provides situational awareness to the Piloting Expert System about any airspace object whose sphere of influence encompasses the aircraft. In a three-dimensional airspace, these objects can include airports, tactical aids to navigation, jet routes, circumference of missile sites, and other aircraft.

The AES is a multi-layered system with increasing layers of functionality. At the core is a spatial database built using the TI Relational Table Management System. The spatial database contains information essential for navigation such as aeronautical charts, instrument approach plates, and airport directory information. Residing on top of the spatial database layer is an intelligent query translator which provides access to information from different database sources without the user having to know the database structure. A computational layer is used to perform basic navigational computations such as bearing, range, or time to a specified point. The highest layer contains expert reasoning capabilities used to give early warning notifications of airspace boundaries or threats and to respond to such queries as locate a suitable divert base.

3.5 Piloting Expert System

The Piloting Expert System (PES) has the capability to perform both piloting and navigational tasks. The PES contains the knowledge to execute mission plans which include takeoff, standard instrument departure, navigation to an IP and target, egress, final approach and landing. The PES is initially activated by receiving commands from NLMenu or Voice. The PES accomplishes a command or series of commands by executing the appropriate plans in the knowledge base and doing any combinations of the following: executing the plan from the route planner, retrieving spatial knowledge from the Airspace Expert System, or issuing commands to the Vehicle Control Expert System or Vehicle Control System.

The PES contains multiple knowledge bases such as takeoffs, departures, navigation, holding patterns, approaches, and landings. These knowledge bases are written in the TI Dallas Inference Engine and Inference Corporation's Automated Reasoning Tool (TIDIE/ART) knowledge representation. Briefly, the TIDIE/ART representation consists of three main components, OBJECTS which represent aircraft state variables (e.g. airspeed, altitude, etc.); NEEDS which designate what task is needed (e.g. departure-climb); and PLANS which are how that need or designated task is to be performed (e.g. intercept-inbound-plan). Within the plans are steps which can be either event or time driven conditions to be met before continuing to the next step or actions in the form of directives to the Vehicle Control Expert System or the Vehicle Control System.

3.6 Vehicle Control Expert System

The Vehicle Control Expert System (VCES) has the capability to perform basic aircraft and aerobatic maneuvers for fighter aircraft. The VCES contains the knowledge to perform expert autopilot maneuvers such as turns at varying bank angles, loops, aileron rolls, Immelmanns, and others. Commands can be received from NLMenu and Voice to execute a maneuver or from PES to execute a sequence of maneuvers.

Also written in the TIDIE/ART knowledge representation, the VCES has the same structures for decision making as the PES but the knowledge is at the task level for specific maneuvers as opposed to the mission level knowledge in the PES. Within a given plan are both waits on specified conditions and settings of objects such as bank to a designated or "target" value. Through the setting of various combinations of target variables of over 20 different objects, the VCES is capable of performing any aerobatic maneuver.

3.7 Vehicle Control System

The Vehicle Control System (VCS) is designed to provide vehicle control of the aircraft using the same abstraction barrier as a pilot, that of the basic aircraft inputs of rudder, stick, and throttle. The VCS is responsible for achieving and maintaining the target values of aircraft state variables set by the expert systems. The VCS makes changes to the appropriate physical control mechanism and monitors the progress of the current value toward the target value. It continues to make corrections as needed until the current value equals the target value, or is within some tolerance of the target value. Then the VCS makes corrections that are required to maintain this target value.

The VCS is written in Lisp and runs in conjunction with the aircraft simulation. The aircraft state variables are classified into two groups: those whose value is the current value set by the simulation equations of motion and those whose value is the target value set by either the VCES or the PES. The variables are named by both a particular area such as airspeed, altitude, heading, etc. and by the physical control mechanism to be used such as stick, throttle, speedbrake, etc.

3.8 Intelligent Vehicle Workstation

The Robotic Air Vehicle program is one of the first users of the TI Intelligent Vehicle Workstation (IVW), a tool for the development of expert systems in the area of intelligent vehicles. The IVW allows the user to 1) define a vehicle platform with equations of motion and the environment in which the vehicle will operate, 2) display a variety of viewpoints (e.g. cockpit panel, out-of-the-canopy, contour map), and 3) observe the vehicle's behavior under the control of the expert system. For the RAV system, the IVW houses the F-16 equations of motion, displays the aircraft dials and gauges, and simulates the navigation and communication world.

3.9 Inter-System Communication

To communicate between the individual systems within the RAV system, both a message scheme and command interpreter are used. The command interpreter translates the commands from either NLMenu or Voice into the appropriate need for the expert systems or into the state variable setting for the simulation. The message scheme, known as the Postoffice, routes commands and other information to the proper RAV system. It performs the system configuration by installing the individual systems on particular machines. Thus the Postoffice can easily determine the location of the system receiving the message and can quickly route the message to the correct address.

4 ROBOTIC AIR VEHICLE SYSTEM HARDWARE ARCHITECTURE

The Robotic Air Vehicle system software currently resides in a hardware configuration of five TI Explorer Lisp Machines and one Digital Equipment Corporation MicroVax II. This configuration is used during system development and test when it is advantageous to have the individual system's displays visible, however, other configurations with fewer Explorers can be used. All the machines are linked together via Local Area Network (LAN). The Explorers, symbolic processors, house all the AI software and the vehicle control and simulation software. The MicroVax II, a floating point numeric processor, performs the mathematical computations required for the conventional software systems.

4.1 Explorer (TM) Lisp Machine

The Explorer is a symbolic computer, developed by Texas Instruments as a tool for developing Artificial Intelligence software systems. It is a seven slot enclosure, single user workstation designed to process high level, stack oriented, LISP like languages. The Explorer utilizes the NuBus (TM) architecture that handles 32 bit addressing and data. The basic Explorer system consists of: a black and white monitor with a mouse and keyboard, a system chassis, and mass storage units. This basic system can easily be expanded to include a microphone or headset utilized by the Voice system, via the connections in the monitor. The system chassis contains one slot for the addition of optional hardware as well as one for additional memory, providing up to a total of 24 megabytes of Random Access Memory (RAM). The top surface of the system chassis allows the stacking of up to four mass storage units. The system hardware has built-in self tests and is user maintainable, meaning that the user has the ability to alter both the system hardware and software configurations.

4.2 Odyssey Processor

The Odyssey board can be installed in an Explorer chassis and connected to the NuBus. The processor can communicate directly with the RAV software environment via its Lisp-callable device-service routines. Although the Odyssey board is used exclusively in the RAV system for voice recognition, it also can perform signal and image processing for other applications.

4.3 MicroVax II (TM)

The MicroVax II parallels the computing power of the larger Digital Equipment Corporation's Vax systems such as the 11/780, but is smaller in physical capacity. The system has 5 megabytes of RAM and 70 megabytes of disk storage. Since floating point arithmetic is best executed on the MicroVax, the mathematical computations of the RAV route planner and passive navigation are performed there and the results transmitted across the network to the Explorer systems.

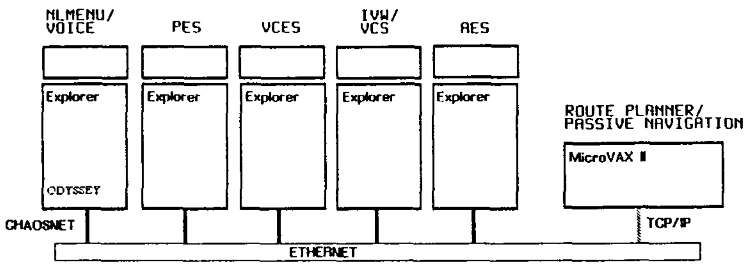

Figure 2. RAV SYSTEM HARDWARE ARCHITECTURE

4.4 Ethernet (TM) And Software Protocols

When more than one Explorer is required for software development, a means of communication is provided to permit asynchronous data transmissions. The Explorer is equipped with Ethernet hardware and controlling software to permit integration into any LAN. The Explorers and the MicroVax II used for the RAV system are physically connected via an Ethernet cable. Ethernet is an industry standard for computer communications and easily supports a multi-system development environment as in the RAV system. The network communications between the Explorer and the MicroVax II is through the Department of Defense's protocol software, TCP/IP. The Explorer to Explorer communications utilize the selected standard protocol for the Explorer, M.I.T.'s Chaosnet.

5 RECONNAISSANCE MISSION EXAMPLE

This section is provided to illustrate how the RAV system components interact during a typical reconnaissance mission. A reconnaissance mission consists of the following mission phases: takeoff from home base, fly a standard instrument departure to an initial waypoint, navigate the various ingress waypoints to the IP, at the target take the recon photos, navigate the various egress waypoints, and finally perform an approach and landing to the home base.

To start the RAV system, the beginning, IP, target, and ending waypoints are specified to the route planner that produces a terrain following/terrain avoidance route. A command is issued from either NLMenu or Voice to execute the mission from a specified airport. The PES processes the command performing a takeoff and standard instrument departure from the specified airport. Once airborne, the PES is continually receiving its current position from the passive navigation system via the AES. Next, the plan from the route planner is processed by the PES for use in navigating the aircraft to the initial waypoint and to each successive waypoint. Navigation to these waypoints includes the PES' issuing of airspeed, altitude, heading, radial, and other targets to the VCS. To monitor the progress of the RAV along the misson, the aircraft's current position is dynamically updated on an aeronautical section map displayed by the AES. A display of the pertainent cockpit dials and guages by the IVW system continually updates the current status of the aircraft. As the RAV nears its home base, the PES issues a query to the AES to determine the bearing and range to the approach fix, the point at which final approach begins. The AES also updates its display to show the approach plates and runway diagram of the airport. Using the airports Instrument Landing System, the PES executes plans for final approach and landing.

6 SUMMARY

This paper discribed the Robotic Air Vehicle system currently under development at Texas Instruments for the DARPA/AFWAL contract F33615-82-C-1841. The RAV system has combined multiple forms of both numeric and symbolic processing to achieve the objectives of piloting a robotic air vehicle and navigating with passive sensors.

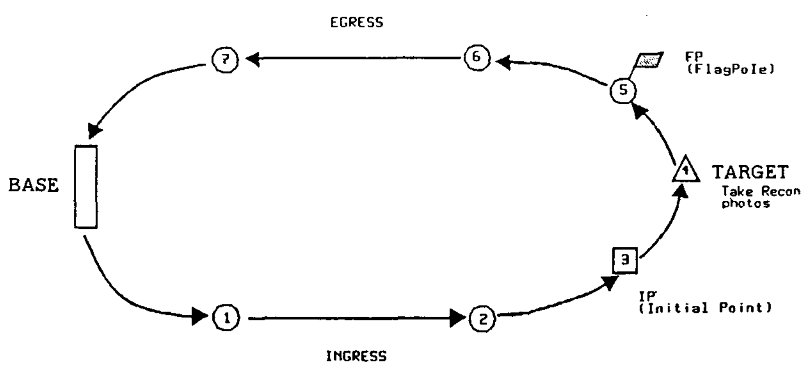

Figure 3. RECONNAISSANCE MISSION EXAMPLE

7 ACKNOWLEDGEMENTS

Explorer, NuBus, and NLMenu are trademarks of Texas Instruments Incorporated. Ethernet is a trademark of Xerox Corporation. MicroVax II is a trademark of Digital Equipment Corporation.

8 REFERENCES

ART Reference Manual, Los Angeles CA: Inference Corporation (1986).

Blair J., Schricker K. "Robotic Air Vehicle: A Pilot's Perspective" NAECON '86 Proceedings, Dayton OH (1986).

Lystad G. "The TI Dallas Inference Engine (TIDIE) Knowledge Representation System" NAECON '87 Proceedings, Dayton OH (1987).

McNulty C. "Knowledge Engineering for a Piloting Expert System" NAECON '87 Proceedings, Dayton OH (1987).

Scott S. "A Generalized Airspace Expert System" NAECON '87 Proceedings, Dayton OH (1987).

Texas Instruments Explorer Technical Summary, Austin TX: Texas Instruments Incorporated (1984).

U. S. Air Force, Tactical Air Command Regulations 60-2, Vol III (8 July 1985).

U. S. Air Force, Flight Manual USAF/EPAF Series Aircraft F-16A/B, USAF, Change 1 (16 April 1982).