ROBOT TEAMS CH 12

Experiments with Cooperative Aerial-Ground Robots

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Paper Focus
Heterogeneous Teams for Surveillance Reconnaissance

- Definition
  - A robot group is considered to be heterogeneous if at least one member of the group is different from the others in one or more of the following attributes.
    - Mechanics
    - Sensing
    - Computing hardware
    - Nature of onboard computation

Advantages of using a group of robots to perform coordinated activity

- Speed up of task completion time
- Fault tolerance
- Flexibility

Additional advantages/disadvantages that Heterogeneous groups provide.

- Possibility of redundant solutions to problems
- Potentially greater degree of fault tolerance as opposed to homogeneous groups.
- Typically involves higher overhead in terms of system maintenance and design

Problem/Issue being addressed

- Some robot applications require real time system responses, such as a robot helicopter.
- Early reactive architectures, which consist of reactive sensor-effector rules that enable real time system responses have the limitation of not allowing any run-time representations or adaptation.
- This paper introduces a behavior-based approach in implementing these robot applications. Consisting of collections of behaviors using a distributed approach to representation.

Robot control strategy and design used in this work.

- Behavior based
- Decentralized
- Minimal top-down planning
- Robots interact via shared goals
- Individual robots are decoupled from each other

Operational control

- Controlled at a high level by a single human operator using a specially designed control unit.
- Operator is able to task the group with a mission using a minimal amount of training
- Group can re-task itself based on sensor inputs and can also be re-tasked by the operator

Autonomous Vehicle Tracking And Retrieval (AVATAR)

- Radio controlled model helicopter
- Powered by a 4.0 hp twin cylinder gas engine
- Payload capability of approximately 10 kg
- Can be controlled by a human pilot using a hand-held transmitter
- Autonomous operation conducted by computer-generated control inputs

The AVATAR Helicopter

Helicopter sensors

- A variety of sensors are used to provide information about the state of the helicopter as well as the environment.
- Hardware
  - An integrated Global Positioning System/Inertial Navigation System (GPS/INS) device, GPS receiver and an Inertial Measurement Unit (IMU). The GPS/INS provides position (lat, long, & alt), velocity (horizontal & vertical), attitude (roll and pitch), heading (yaw), angular velocity and acceleration information.
  - A downward facing ultrasonic (sonar) transducer provides altitude information.
  - RPM sensor mounted on the main rotor mast measures engine speed. A downward looking color CCD camera provides visual information of the area below AVATAR.
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Sensors (cont)

- Computing needs met using PC/104 boards
  - Timer/counter used to generate actuator commands and read pilot commands.
  - Allow switching between human-generated and robot-generated commands
- GPS receiver, color video frame grabber for the CCD camera
- 2.4 Ghz wireless Ethernet device provides multiway communication between the AVATAR, other robots, and human using an Operator Control Unit (OCU)
- 1.3 Ghz wireless CCD camera provides a video link to operator

AVATAR Software

- Operating System: QNX (Unix like)
- Low-level software drivers for interfacing sensors and actuators
- Flight control software for guidance, navigation, and control.
- Vision processing software
- All software is written in C.

The Ground Robot Testbed

- Hardware
  - Two Pioneer AT robots
  - Four-wheeled base with skid steering.
  - The left wheels are coupled mechanically as are the right wheels. Turning is accomplished by a speed differential between the left and right sides.

- Pioneer AT Robot (from Real World Interface)

Pioneer Sensors

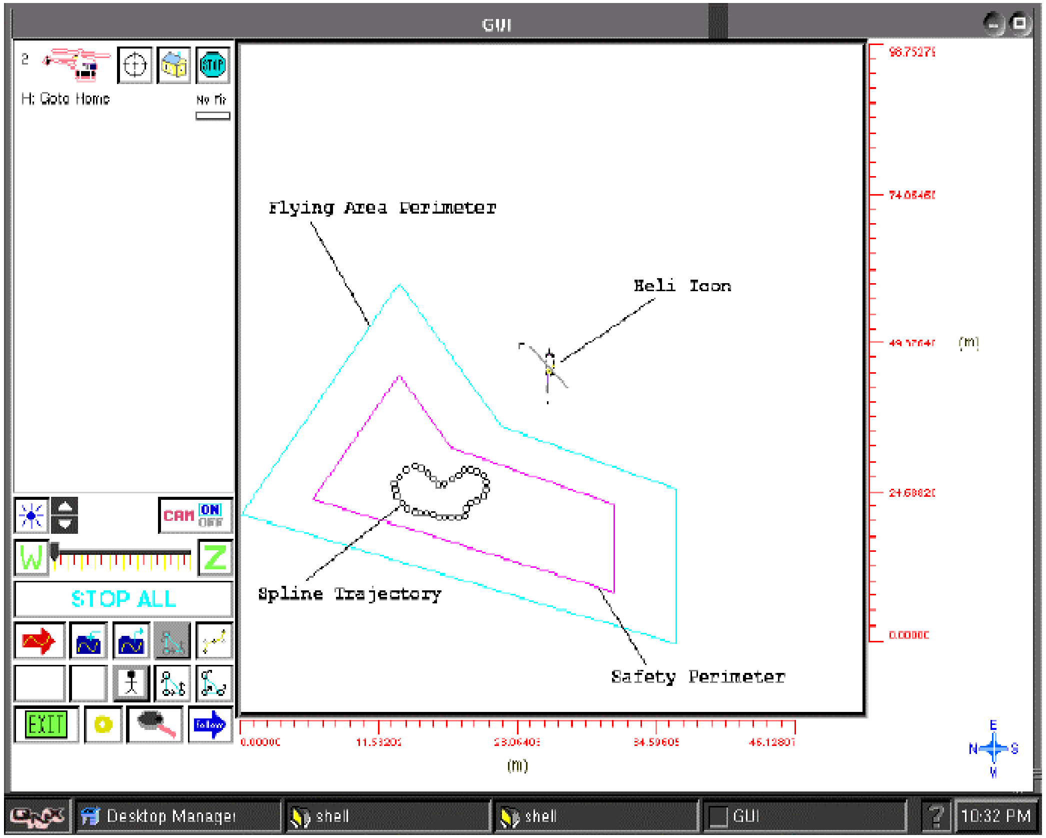
- Ring of seven forward looking sonar's controlled by low-level Motorola 6811 micro-controller.
- 6811 board is connected to a PC/104 stack
- Camera on a pan-tilt head controlled by a Motorola 68332 board
- GPS system connected to the PC/104 processor via a serial port.
- Compass and gyroscope
- 2.4 GHz wireless Ethernet device provides a multiway 2.0 Mbps communication link between each Pioneer and the other robots.
- 2.3 GHz wireless CCD camera provides video to operator

Pioneer Software

- Control system is written in C under QNX on the PC/104 and includes:
  - Low-level software drivers for interfacing with sensors; mainly for the wireless Ethernet and GPS drivers.
  - Control software for obstacle detection and avoidance, navigation, and mapping.

User Interface

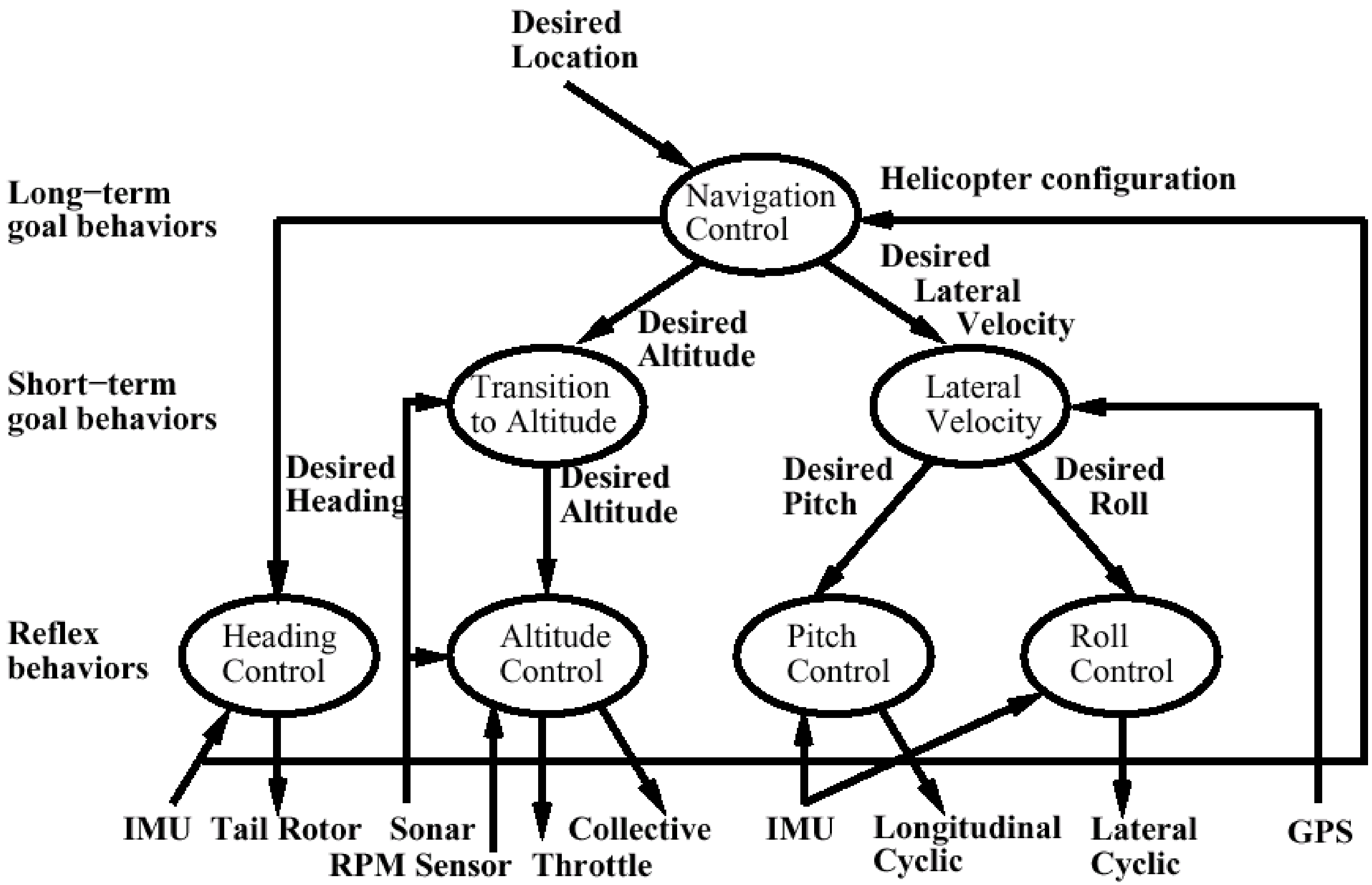
- Exam robot telemetries
- Task individual robots to do specific activities, i.e. Following, Patrolling
- Monitors robot locations in a 2D plan view
- Tasking is done by selecting a robot with the mouse and clicking on a task



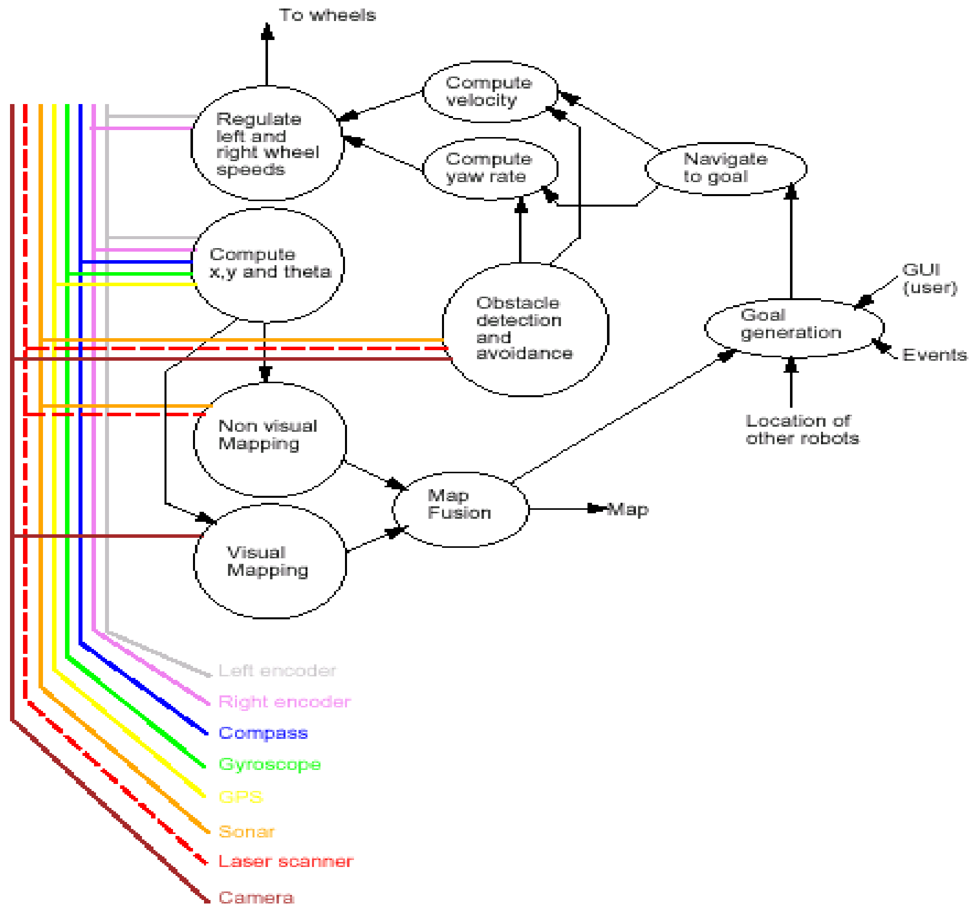
Control and Coordination Algorithms

- The AVATAR Control System is implemented using a hierarchical behavior based control system architecture.
  - Partitions the control problem into a set of behaviors
  - Each behavior is responsible for a specific task and act in parallel
  - Low level behaviors deal with functions requiring quick response time.
  - Upper level behaviors meet less time critical needs.

The AVATAR behavior-based control system architecture



Pioneer behavior based control system architecture



Case Study 1: Marsupial-Inspired Payload Deployment and Recovery

- Purpose: Illustrate the payload deployment and recovery capability of the multirobot system.

Results of the case 1

- While all the robot control was by human tele-operation, this case illustrates the capability of the system as a whole.
- Other than automating the control of the small vehicle which can be carried on-board, all the important sub-parts of this experiment (tracking, localization, communication) have been demonstrated in autonomous mode.
- Good example of the capability of a heterogeneous system which is composed of loosely coupled individual robots.

Case Study 2: Cooperative Localization

- Presents a simple method for estimating the position, heading and altitude of the AVATAR using a single on-board camera.
- Ground platforms can carry larger sensor payloads due to smaller cost in energy, as opposed to aerial platforms.
- Ground robots collaborate and share data with aerial robots IOT provide the extra information needed to localize the air vehicle.
- This reduces the number of sensors required for the aerial robot.

Determining localization for aerial vehicles

- An aerial vehicle can determine its location if given two ground objects with known location using triangulation.
- Alternatively, a single cooperating robot can move over time to establish a baseline on the ground and on the image plane of the aerial vehicle's camera.
- Major assumptions:
  - Aerial robot camera is perpendicular to the plane of the ground, pointing straight down
  - Ground is flat
  - The aerial robot is in the same place and pose when the two vector end samples are taken.

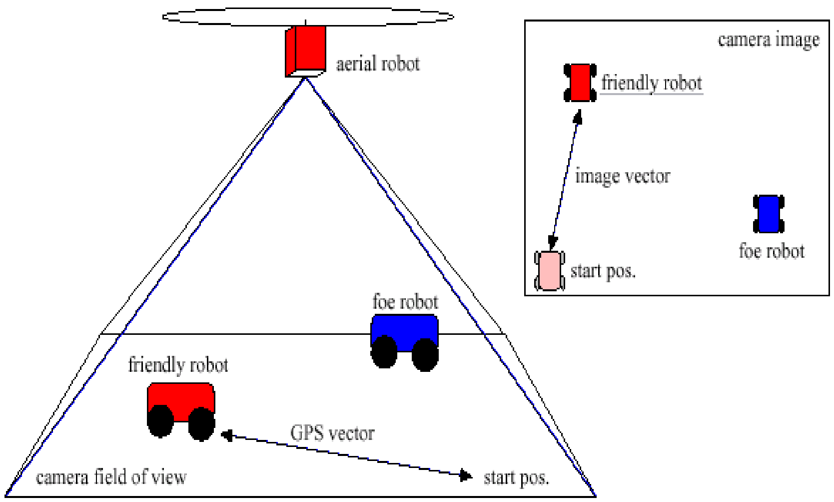


Figure 6: Cooperating aerial and ground robot scenario

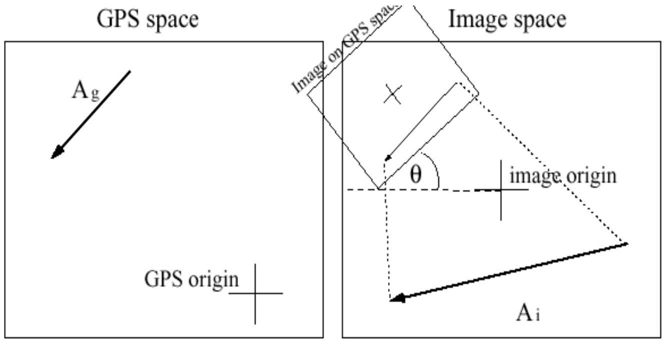
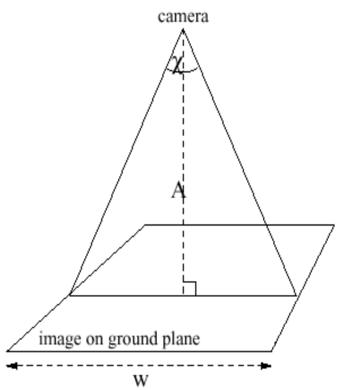


Figure 7: Mapping a vector in image space $\vec{A_i}$ to its correlate in GPS space $\vec{A}$



$$\vec{A_i} = \begin{pmatrix} x_i - x_{i0} \\ y_i - y_{i0} \end{pmatrix} \quad \vec{A_g} = \begin{pmatrix} x_g - x_{g0} \\ y_g - y_{g0} \end{pmatrix} \quad \theta = \angle\vec{A_g} - \angle\vec{A_i}$$

The scaling between image and GPS systems is the ratio of the lengths of the vectors in each coordinate frame $S = \frac{|\vec{A_i}|}{|\vec{A_g}|}$.

Once the scaling is found, given the aperture angle α of the camera and the width W of the image in pixels, the altitude estimate a can be obtained: $a = S\frac{\frac{W}{2}}{\tan\frac{\alpha}{2}}$ (Figure 8).

Now a is the height above the ground in meters. If instead we want to know the absolute altitude above sea level, we can add a to the GPS altitude measured by the UGV.

The aerial robot's (x,y) position is assumed to be at the center of the image i.e. at the origin. To find the GPS location of the aerial robot we find the GPS location of the image origin. To do this we construct the vector $\vec{C}$ from the position of the current image sample to the image origin (Figure 9 left) and transform it into GPS space. First we translate $\vec{C}$ to the position of the current GPS sample (x_g, y_g) (Figure 9 middle left), then rotate it by θ (Figure 9 middle right), then scale by S to complete the coordinate transformation (Figure 9 right). The transformed $\vec{C}$ now points to

To find the GPS location of the aerial robot, we find the GPS location of the image origin by constructing a vector C from the position of the current image sample to the image origin and transform it into GPS space.

Results

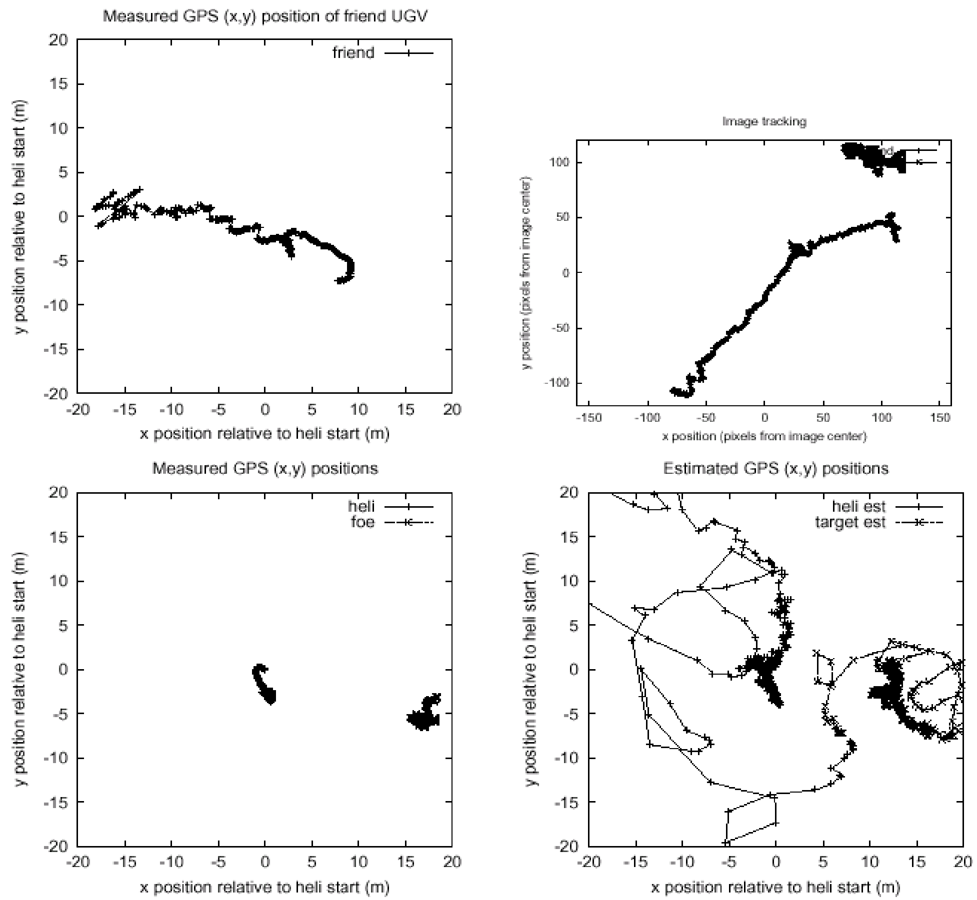


Figure 11: Top: Inputs to the estimator: Friend Pioneer GPS path (left) and tracked image positions of friend and foe (right). Bottom: Helicopter and foe locations recorded by on-board GPS (left) and estimated (right).

Case Study 3: Reconnaissance and Surveillance

- Describe experiments in autonomy by the robot group performing two simple tasks.
  - Independent patrolling activity by the two ground robots. Robots patrol their assigned circular areas completely autonomous.
  - Automatic re-tasking of robots by simulated "alarms" on the area perimeter. Robot nearest to alarm navigates to the alarm scene to provide live video to the human operator while still maintaining basic patrolling functionality.
    - The other robot continues patrolling.
    - All behavior switching is autonomous

Results

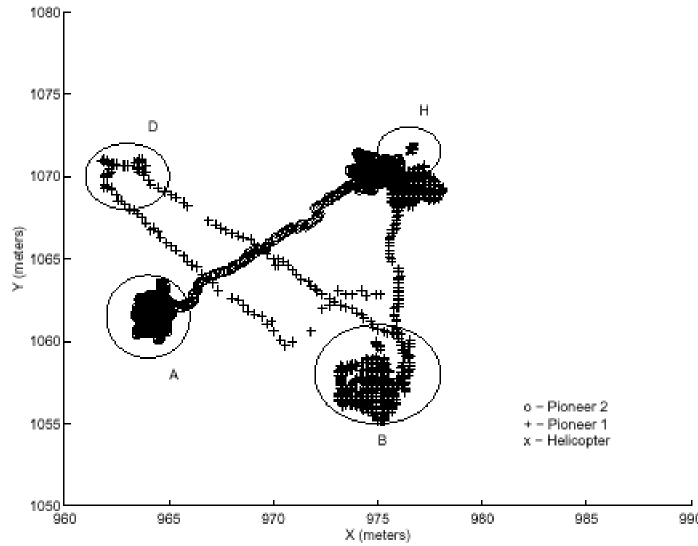


Figure 14: The locations of the three robots over time. The two Pioneers are exploring their designated areas of interest (A and B) while responding to an alarm (D) and following the AVATAR (H).

- **The two Pioneers are initially tasked to follow the helicopter at location H.**
- **Simulated alarm at location B triggers Pioneer 1 to patrol there.**
- **2nd alarm goes off at D, Pioneer 1 navigates to D and sends an image back to the operator and returns to B.**
- **3rd alarm goes simultaneously which causes Pioneer 2 to patrol that area**

Discussion and Related Work

- Helicopter control is a challenging task due to nature of helicopter flight.
- Automated full-size helicopter control, both model-based and model-free was implemented.
- The system described in this paper is designed in the behavior based philosophy.
- Behavior based systems do not have the limitations that reactive systems have with their built-in rules, which allow no run-time representations or adaptation. Instead they use a distributed approach to representation, but still retain real-time properties of reactive systems.

Summary and major contribution

- Case study 1 is an experiment in which an aerial robot was used in a marsupial-style deployment of a small wheeled robot. No control autonomy was involved in this task and all robots were tele-operated.

- Case study 2 experiment in partial autonomy and demonstrated a simple geometric method that approximately localizes an aerial robot by visually locating and communicating with a ground robot.

- Case study 3 showed, with the greatest robot autonomy, is an experiment in cooperative surveillance and reconnaissance by the two ground robots and the helicopter.

- Major contributions were the demonstration of a hierarchical behavior based control system architecture which allowed complex the complex behaviors shown in the three case studies.

Questions?