

MISSION: IMPOSSIBLE

IARC Advances State of the Art in Intelligent Autonomous Aerial Robots

By Robert C. Michelson



Your mission, for the sixth iteration of IARC: Find, steal and replace that flash drive.

Dr. Edward Teller, father of nuclear weaponry, stated in a 1981 press conference that “the unmanned vehicle today is a technology akin to the importance of radars and computers in 1935.”

That being the case, then I believe the unmanned vehicles of Teller’s day will be seen as the progenitors of an astonishing new class of mobile “thinking” machines able to assemble disparate data from an array of sensors and intelligently draw conclusions upon which to act with the adeptness and fallibility of a human. Among this class of mobile thinking machines are aerial robots, which require the greatest sophistication due to their degrees of freedom, instability under most conditions, potential speed, and requirement for rapid correct decisions coupled with a high cost for failure. These aerial robots vary in their levels of autonomous behavior which have been quantified by different rating scales over the past two decades. Simply put, aerial robotic behavior falls into five generic categories: telerobotic, pre-programmed, autonomous modes, directed autonomy and sentient.

As early as the 1930s, the British had developed a radio-controlled Tiger Moth aircraft (dubbed the Queen Bee) as a target drone. This aircraft was teleoperated using technology that Nikola Tesla demonstrated in 1898. The Nazis developed pre-programmed aerial drones like the V1 “buzz-bomb,” the first of which was launched against London on 13 June, 1944. Since that time, various unmanned aerial vehicles have been developed which exhibit autonomous behavior modes such as the ability to orbit ground targets or performance of pre-specified procedures such as landing and takeoff.

With the advent of the RQ-4 Global Hawk, we started to see directed autonomy in unmanned aerial vehicles. Global Hawk began as an Advanced Concept Technology Demonstration in 1995, and while it has a massive ground crew, including a ground piloting station, it is capable of autonomous takeoff, landing, and mission performance. Mission parameters can be updated in flight, but the air vehicle is

technically capable of conducting an unmanned mission from roll-out to engine shut-down. Still this does not approach the highest level of autonomy that would be found in a sentient machine.

Sentience is the ability to feel, perceive, or be conscious, or to have subjective experiences. In a sentient robotic vehicle, the definition would also extend to the ability to act upon those perceptions and experiences.

My technical career began solidly in the area of remote sensing, but for the past 25 years I have concentrated on autonomous aerial robotics where these remote sensing systems became merely the organs of perception for the robot and the resulting behavior was the focus. During this time, I have had the pleasure to work with some of the most advanced autonomous robots on the planet.

Advent of the IARC

In 1995, the Georgia Institute of Technology and Sikorsky Aircraft were working on the U.S. Army-funded Autonomous Scout Rotorcraft Testbed program. This was an early attempt to track a human-sized target from an autonomous air vehicle. Georgia Tech adapted an XL-60 model helicopter to the task, while Sikorsky adapted their Cypher UAS.

At the time, autonomous flight control systems were rare, especially for rotary wing vehicles. Sensor weight issues and less capable platforms made autonomous flight the central issue rather than the behavior of the automaton itself, but by the late 1990s, I was part of the evaluation team for the WITAS (Wallenberg Laboratory for Research on Information Technology and Autonomous Systems) project being run out of Linköping University in Sweden. An autonomous helicopter system had been developed around the very capable Yamaha RMax helicopter that was able not only to fly missions, but also to

communicate in natural language sentences with a human on the ground in order to ask questions, take direction, and report its activity.

The WITAS machine could carry on a conversation with a human on the ground who could influence the mission. Of note was the fact that the conversation could, as in those between humans, contain various parallel threads. A WITAS-type dialog would go as follows:

Human: Fly to Main Street.

Human: No, I meant Ridge Road.

WITAS UAV: Okay.

Human: Next, continue to the bridge, then look at the parking lot and the building.

WITAS UAV: Which building do you mean?

Human: The one at the airport.

WITAS UAV: The airport.

Human: Look for a car.

WITAS UAV: I am looking for a car and I am flying to Ridge Road.

WITAS UAV: I see a car. Is that it? (note the use of pronouns)

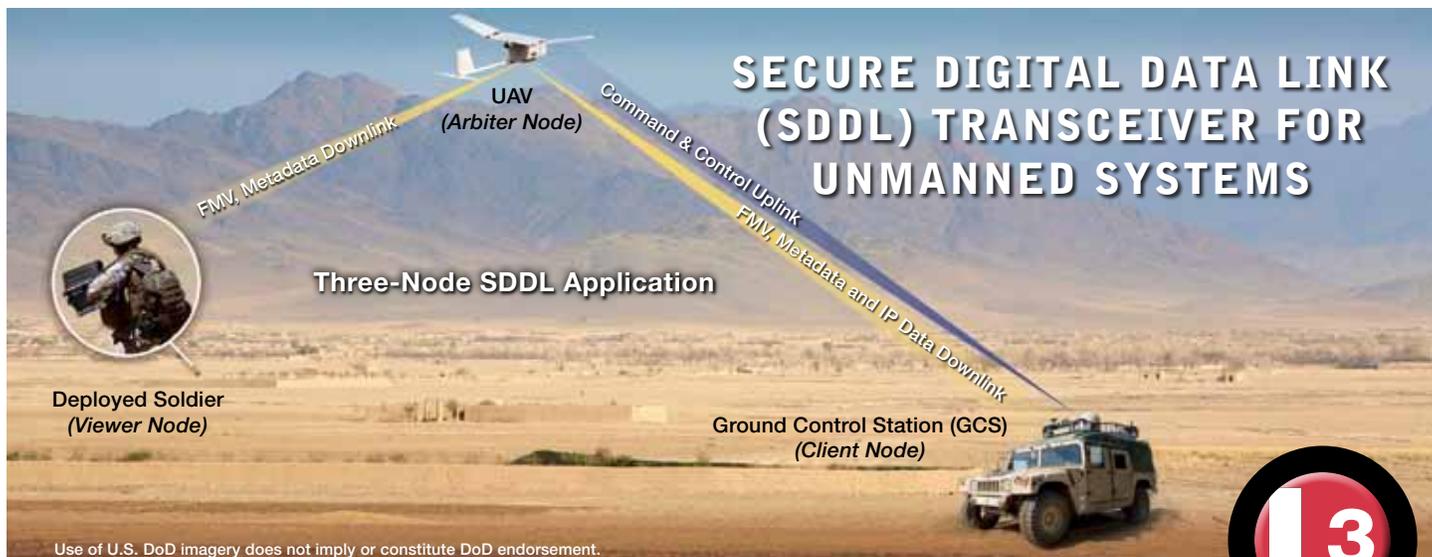
Human: No.

WITAS UAV: Okay, I am looking for a car and I am flying to Ridge Road.

In parallel to these funded efforts, I had the opportunity while serving on the AUVSI board of directors to create a new activity called the International Aerial Robotics Competition. The theme of this competition was “fully autonomous flying robots.” It was limited to university teams from around the world and concentrated on demonstrating previously impossible aerial robotic behaviors to achieve a mission involving environmental perception and situational awareness, autonomous takeoff, flight and landing, as well as interaction with objects on the ground.

The first IARC was held on the campus of the Georgia Institute of Technology in 1991. The mission was to take off autonomously into a tennis court-sized arena, find several objects that were grouped together, select one and pick it up, then move across a visual barrier to deposit the object in a six-foot region located on the other side of the barrier—all without any human intervention. In 1995, a team from Stanford University completed the task using a fully autonomous helicopter that did not use any inertial stabilization, but rather used a triad of phase-carrier GPS units to not only navigate but maintain roll, pitch, and yaw in the vehicle.

The second mission was to locate a toxic waste dump, read the labels on partially buried drums of various explosive, radioactive and biohazardous materials to identify the contents, map the dump from the air and bring back a sample from a specified drum. Equally impossible at the time the mission was proposed, a team from Carnegie Mellon University was eventually able to demonstrate a fully autonomous aerial robot that completed all aspects of the mission except the sample retrieval, which was missed by only centimeters before time ran out. This behavior was demonstrated at the Walt Disney World's Epcot Center in 1998 and did not involve preprogrammed



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tasks, but instead had the aerial robot reacting in real time to the cues and obstacles that it encountered in the area while at the same time compensating for environmental perturbations such as wind.

The IARC was then moved to the Department of Energy's Hazardous Material Management and Emergency Response facility in Washington state. There, the mission was to locate survivors in the aftermath of a massive disaster and distinguish the survivors from the dead bodies strewn around the scene while plotting a safe path so that first responders could enter the area and extract the living. In this scenario, we arranged to have 40-foot gas-fired flames shooting into the air, broken water mains, smoke, and wreckage into which we place dead bodies (realistic mannequins) and moving animatrons (themselves autonomous due to the real dangers of being in the arena) for the aerial robots to find. In 2000, a team from the Universitaet Technische Berlin was able to field an aerial robot that found all of the survivors while surviving itself by avoiding the real-time fire and water hazards that it had to identify and react to during its search.

Increasing the Difficulty

With ever increasing difficulty, the IARC was then moved to Fort Benning, Ga., where my new set of rules required teams to fly three kilometers to find a village—in this case, the McKenna Military Operations on Urban Terrain site at Fort Benning—and identify a particular building in the village. Having identified the correct building, the aerial robot then needed to inspect the building for valid openings (open doors or windows, as opposed to closed doors or

windows) and either fly into the building through the opening or send in a sub-robot to locate a particular target and send back video to the starting point.

Again, this was an impossible challenge at the time it was posed, as there was no UAS in the arsenal of any world government that could be used off-the-shelf to do this high-military-value mission. Nonetheless, after a number of years of development, a several of teams were able to demonstrate all aspects of the mission, albeit not in the 15-minute time limit that we had imposed.

One of the most spectacular demonstrations was from the Georgia Tech team. They used a Yamaha RMax helicopter equipped with sophisticated payloads that enabled it to repeatedly perform the mission. The RMax flew into the area, did aerial pirouettes above the village as it analyzed each building, and then having selected the target, proceeded to map the valid entry points and log them. After selecting one, the aerial robot approached it with a boom that was lowered 90 feet below the helicopter to insert a sub-robot into the opening. All of this was without human intervention and based solely on the aerial robot's perception of its environment.

The fifth mission of the International Aerial Robotics Competition was conducted at the University of Puerto Rico in Mayaguez. The mission was an extension of the prior mission in which a building was constructed in a basketball arena and an aerial sub-robot (assumed to have been launched from the mothership during the prior mission) was to enter the building through an open window and search the interior of the building for a specific target, whereupon pictures of that target would be relayed back to a monitoring station outside the building.



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Georgia Tech's RMax helicopter attempts the fourth mission of the IARC, held at Fort Benning, Ga. All photos courtesy Robert Michelson.

This new mission opened up several areas involving new technologies. For one thing, GPS was no longer an option for navigation as the entire mission was being conducted indoors. Second, the size of the vehicles had to shrink drastically. No longer could powerful RMax helicopters be used. Instead, mini and micro air vehicles of less than one meter in any dimension had to be employed.

In 2009 a team from MIT won the competition by completing the mission with only minutes to spare on their final attempt. Their quadrotor-based aerial robot entered the building and began to map the interior using a SLAM (simultaneous localization and mapping) sensor. It moved autonomously from room to room and down hallways, never retracing its path, until it ultimately entered the room with the designated target which it was able to acquire.

Now in the 21st year of the International Aerial Robotics Competition—AUVSI's oldest competition, and the longest running aerial robotics competition in the world, for that matter—has a task that is again an "impossible" challenge.

The sixth mission is an extension of the prior mission in which much more realism has been added to the scenario. The rather stark environment of the building interior has been enhanced with furniture, oscillating fans and visual cues. The vehicles must now interact with this environment physically as well as visually. Mission six involves

an aerial robot penetrating a building through an upper-story window. It enters a hallway that is protected by a laser barrier. The aerial robot is searching for a flash drive that it has been told is lying in the "in box" on the desk of the chief of security. It must pick up the flash drive and deposit an identical flash drive so that the theft goes undetected.

The aerial robot must then negotiate its way back out of the building before the 10-minute time limit has been exceeded whereupon a security guard will appear in the area. On entry, the aerial robot can disable the laser barrier, thereby disabling the intrusion alarm system. If the aerial robot sets off the alarm, its time to complete the mission is cut in half. A design decision is to determine whether the aerial robotic system can disarm the laser barrier quickly, or if rushing the mission by setting off the alarm is a better strategy. Visual cues in Arabic inside the building indicate which offices are not of interest or contain the target flash drive (chief of security). Teams are developing image recognition algorithms to allow their aerial robots to read these signs.

As with all past missions, every aspect of the sixth mission involves full autonomy, environmental sensing, decision-making, and interaction with the environment both optically and physically, while maintaining tightly controlled flight in confined spaces without benefit of GPS.

These are some of the most advanced robots in the world and they are fully autonomous. It will take a number of years before a collegiate team demonstrates all of the behaviors required by the sixth mission, but as with all prior missions, one of the slate of international teams will succeed. Currently teams from India, Chile, the People's Republic of China, the United Arab Emirates and the U.S.A have taken up the challenge.

Paving the Way

Through these IARC competitions, the state-of-the-art in autonomous aerial robotics has been advanced on several occasions. While the public is invited to attend these competitions, it is not a spectator sport. The reason for the competition is all about technology. Not



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only have advanced systems been demonstrated for a fraction of the cost associated with an industrial contract to achieve the same goal, but Ph.D theses have been based on IARC entries and new start-up companies have been launched as a result of the efforts of various teams and their members.

In a briefing to Newt Gingrich in March of 1999, I explained the concept of the technology competition and showed some of the stellar results achieved to date. Later in an invited keynote speech to the National Academy of Engineering's Workshop on Government-Sponsored Technology Prizes and Contests, Gingrich used the International Aerial Robotics Competition as an "example of an effective technology-advancing contest" that "accurately portrayed the high degree of innovation young future engineers have when given an outlet and challenge."

Since Gingrich's keynote, we have seen a proliferation of events involving autonomous vehicles, most notably the DARPA Grand Challenge, NASA competition announcements and various international micro air vehicle demonstrations sponsored by the U.S. Army RDECOM which I have been honored to help organize based on my unique experience with the IARC.

Fully autonomous aerial robots exist today and have been around for years, but the future of sentient robotic technology is still mostly ahead of us. The day will come when behaviors of robotic vehicles will be indistinguishable from those of manned vehicles. Speech synthesis will allow these robots to communicate with us in a manner that can and will fool us into thinking that we are interacting with another human being.

Not all sentient robots will necessarily interact with humans, however. Interaction may be solely between the automatons. There is no need to interact with all autonomous robots any more than we interact with so many service providers in society today. How often do you interact with the garbage man, or the navigator of a commercial aircraft, or the crew that services high voltage transmission lines that supply electricity to your neighborhood? No, we just know that our garbage disappeared on the appropriate day, our flight landed at the correct airport and our lights continue to burn in our homes. So it will be with most autonomous robots. They will do their jobs, adapt to conditions, and supply us the services we expect without comment or complaint. They will engage in war without fear or fatigue, and they will repair our biological bodies as they fail. Their existence is relegated to the "D4" tasks of society; those involving the dull, dirty, dangerous, and duration (tasks exceeding a human lifetime, such as space travel). In the end, autonomous robots are one of the few areas in which mankind can actually recreate itself in the form of a machine.

Prof. Robert C. Michelson is a past President of the Association for Unmanned Vehicles International, recipient of the AUVSI Pioneer Award, and the originator of the AUVSI International Aerial Robotics Competition. As a member of the research faculty at the Georgia Research Institute, he holds the title of Principal Research Engineer Emeritus.

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