Distributed multi-modal sensor system for searching a foliage-covered region

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On September 23, 2010, Lincoln Lab held a Challenge Event. The Challenge was for researchers to obtain situational awareness of a forested region, with area $1km^2$, in a time period of 3 hours. The researchers were not permitted to enter the region themselves. Critical elements of the Challenge were kept deliberately vague, and that the specific region was not disclosed. Our team designed and developed the SNOOP (Sensing Networks and Objective Observing Platforms) system to respond to the Challenge. This abstract describes the SNOOP system; the SNOOP system performance on the day of the Challenge will be described in the conference paper. Our conference paper will also discuss the search strategies in more detail.

The SNOOP system was designed to be multi-modal, distributed, and low-cost. The system includes sensor platforms of RC (radio-controlled) planes, RC trucks, and SensorMotes (throwable sensors). To achieve multi-modal sensing capability, the planes, trucks, and SensorMotes were designed to survey different aspects of the region, as shown schematically in Fig. 1. The planes take aerial pictures of areas that are not obscured by foliage. The trucks survey regions that are obscured from aerial view. The SensorMotes are lightweight networked sensors, dropped from an aircraft. These SensorMotes give coverage in areas that were obscured from aerial view, and where the trucks could not traverse. An integrated map shows the real-time positions of each vehicle.

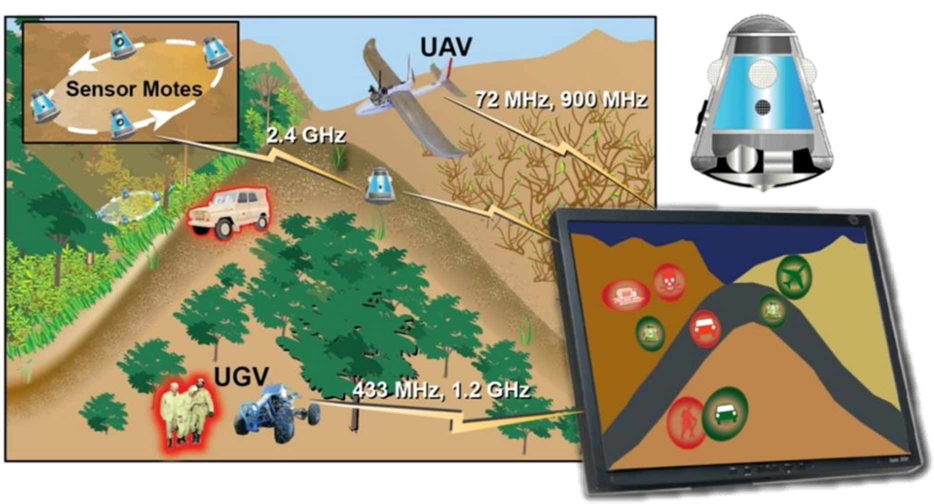

Figure 1. SNOOP system designed with SensorMotes, airplanes, vehicles, and integrated map.

The SNOOP system of 4 trucks, 2 planes, and SensorMotes is designed as a distributed system. Subteams of 1-4 people are designated to a certain vehicle. These subteams allow for a distributed command architecture, where each subteam is responsible for moving around the region, and making independent decisions. There was no single point of failure; if one subteam's vehicle became disabled, another subteam could cover their region. This distributed architecture allowed system operation even if communications between subteams was lost.

The components of the system, shown in Fig. 2, are low-cost, with much of the equipment based on COTS (commercial off-the-shelf) technology. Low component cost enables vehicles to be expendable, so that it was acceptable to take risks and try to maneuver a vehicle through rugged terrain. If a vehicle found a region of interest, it could be left in that region for persistent surveillance. In this system concept, several backup vehicles are assigned to every subteam.

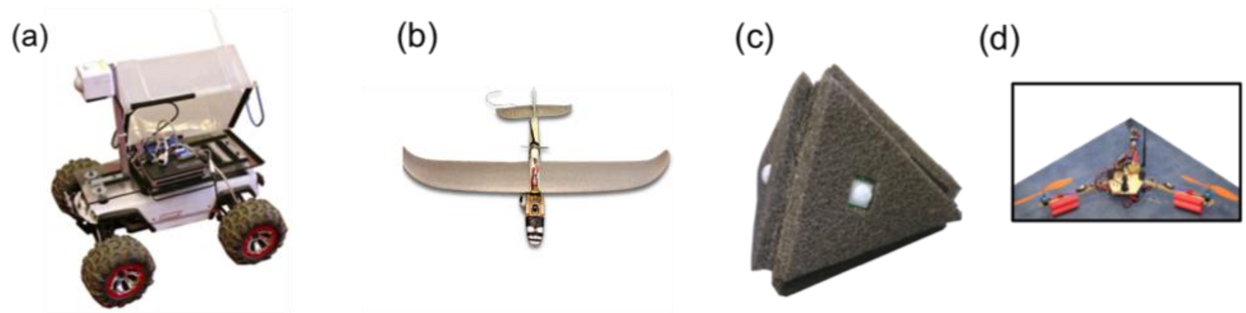

Figure 2. Components used in the SNOOP system were based on COTS technology and modified for the challenge. (a) Wi-fi off-road RC truck (b) RC plane equipped with digital camera (c) SensorMote (d) Tri-copter.

The RC trucks are designed to be rugged vehicles with extensive sensor capability. We used the frame of a COTS off-road RC truck, and modified the vehicle so that vehicle control and sensor communication was done entirely through Wi-Fi. Testing the truck in the field, we found communications to be a significant difficulty. Lower frequencies (<1GHz) could transmit reasonably well over 1km distances through forested regions. But at higher frequencies (2GHz), the attenuation could exceed 1dB/m. This limited our video link range to 150-200m. By distributing our trucks around the perimeter, we could traverse approximately 64% of a $1km^2$ region with the trucks. We also developed an approach to longer range communications, whereby 2 trucks were linked together by a Wi-Fi network. These long-range trucks increased our penetration through the forested region to ~350m, enabling us to survey ~90% of the region. Since we expected the Challenge region to be only partially forested, these long-range trucks appeared to be a sufficient solution to give us full coverage of the region.

Another limitation on the trucks that our experimentation uncovered is that the trucks are primarily suitable for roads and trails. Even though the trucks are rugged, the fall foliage in Massachusetts is extremely thick and difficult to penetrate. Our initial notion that the trucks could cover large wooded areas was optimistic. Therefore, we decided to use satellite imagery from the web to identify roads and trails in the region of interest. Our trucks would focus on covering these paths, which we did not consider a significant limitation, because we estimated that humans and associated targets would be more likely to be located on and around trails.

The SNOOP aircraft include RC planes and tri-copters. The planes are quite durable and had a long flight time, and were used for wide-area surveillance. Digital cameras on board the planes took high resolution imagery that was stored on the cameras, and downloaded when the cameras returned to base. The tri-copters had a shorter flight time, but could be used for waypoint navigation to acquire a high-resolution image of a desired area.

The SensorMotes are designed to be dropped from the tri-copters. They are lightweight foam tetrahedral packages, which would not injure anyone should they happen to strike them during flight. The SensorMote has pyroelectric motion detectors, as well as audio recording capability. Other sensors can be added as desired, although the weight and power are limited to a few ounces, and less than 5 Watt. The tetrahedral shape of the SensorMote allows us to place an optical sensor on each of 4 faces, so that at least 3 sensors would not be facing down, regardless of how the SensorMote fell to the ground. The SensorMote communicates over an IEEE ZIGBEE-like network using Digi's digimesh firmware network, so that a chain of SensorMotes forms a mesh network.

The SNOOP system was successfully deployed on the day of the Challenge, and we detected a range of static and dynamic targets. In future work, we will further develop the component technologies, as well as investigate methods of integrating the large volumes of data that the sensors acquire.