Wireless Aerial Cooperation Systems

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Outline

• Cooperation modalities
• Middleware
• Ground Wireless Sensor Network
• UAV cooperation
• Load transportation
• Functionalities
• Conclusions and future work
### Cooperation Modalities

**Aerial vehicle cooperation**

<table>
<thead>
<tr>
<th>Physical/hardware</th>
<th>Aerial-Aerial</th>
<th>Aerial-ground vehicles</th>
<th>Aerial-ground static</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
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</tbody>
</table>

**Software**

| ![Image](image4)  | ![Image](image5)  | ![Image](image6)  |

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**Mobility for**

**communication**

- Data Mule
- Air (transient) connectivity repair

**Mobility for sensing**

- Inaccessible sites
- Sensing complementarities
- Cooperative perception (Indoor and outdoor)

**Mobility for Deployment**

- Nodes deployment
- Gateway (load) deployment

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AWARE FP6 project is dealing with all these cooperation modalities
The AWARE project

AWARE (IST-2006-33579)
GENERAL OBJECTIVE

Design, development and experimentation of a platform providing the middleware and all the functionalities required for the cooperation of aerial flying objects, i.e. autonomous helicopters, with a ground sensor-actuator wireless network, including ground mobile nodes carried by persons and vehicles.

Self deployment for the operation in sites with difficult or impossible access and without communication infrastructure.

AWARE: PARTNERS EXPERTISE AND RESOURCES

Coordinator:
- AICIA-UNIV. SEVILLE (SPAIN).

Partners:
- TUB-TECHNISCHE UNIVERSITAET BERLIN (GERMANY)
- FC- FLYING-CAM SA (BELGIUM)
- UT- UNIVERSITEIT TWENTE (THE NEDERLANDS)
- USTUTT- UNIVERSITÄT STUTTGART (GERMANY)
- SELEX – SENSORS AND AIRBORNE SYSTEMS LIMITED (UNITED KINGDOM).
- ITURRI, S.A. (SPAIN).
- UBONN- UNIVERSITÄT BONN (GERMANY)
General experiments Utrera (Seville, Spain): March 07, April 08

AWARE General Experiments

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The AWARE project

AWARE system architecture from a middleware perspective

Architecture and Middleware

System relational view

Research on gateway cooperation:
- Top down Voronoi Tessellation
- Bottom-Up: Convex groups
Network localization

- Good position estimation of mobile robots can be used to localize WSN nodes
- Key idea: To have onboard the robot one node and “project” the position of the node to the WSN through the signal strength.
- Characterization of the model RSSI-distance
  - Gaussian only for a given distance
  - Application of particle filters (non-gaussian distribution)
  - Represent the posterior density at time k: \( p(x_k | z_{1:k}) \) by independent and identically distributed particles \( \{x_k^{(i)}\} \) each with a weight \( \omega_k^{(i)} \)
  - Likelihood function \( p(z_k | x_k) \): probability of obtaining a given value of RSSI on the on-board node at position \( x_k^r \) given the position of the emitter \( x_k \).
- Position refinement by means of the Extended Information Filter (distributed implementation)

Research on Ground Wireless Sensor Networks

- Distributed fuzzy logic reasoning engine for event detection
- Networking protocols
  - Medium access control
    - Mobile-LMAC
    - Added local broadcast functionality for D-FLER
    - Connectivity information is collected
  - Routing
    - Gradient-based routing
    - Implemented multiple data sinks
    - Data is routed to closest sink

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Fire detection and confirmation

- WSN inside the building detects the fire
- Confirmation using image processing

Static video from ground camera nodes
Aerial video from UAVs

IR cameras

Visual cameras

Smoke detectors: color detection + texture detection + motion detection

Global architecture for cooperation of aerial platforms

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Architecture for cooperation

CNP Manager: distributed task allocation

- Mission: set of partially ordered tasks, defined as a set of goals to be achieved.
- Tasks allocated to the UAVs based on their capabilities and on their execution context.
- Multi-robot task allocation problem (MRTA): Which UAV should execute each task
  - Cost: energy, time, etc. for one UAV to execute a certain task.
  - Goal: minimize the sum of all the individual costs (global cost).
- Three different algorithms developed: SIT, SET and S+T.
  - Dynamic scenarios: Task reallocation
  - Distributed algorithms
  - Synchronization needed
  - SET algorithm: subset of tasks
  - S+T algorithm: tasks and services
Plan merging: Conflict resolution

- Research on algorithms for collision avoidance in a multi-UAV context (cooperative and non-cooperative vehicles):
  - Velocity planning problem solved in two steps:
    - Tree search of feasible solutions.
    - QP formulation to find a solution which minimizes a given criteria (modify as less as possible the initial flight plans).
  - Complexity reduction for a distributed collision avoidance system.
Connectivity and deployment

--Funke’s algorithm to centrally detect routing holes

• Principle: create iso-hop clusters, detect border nodes

- Mission: the UAV has to drop three nodes in different locations:
  - wp1 at time 30.
  - wp4 at time 60.
  - wp3 at time 90.

- Available paths and costs computed by the plan refining toolbox module.

- At the beginning the helicopter is hovering at “home” location.
Load transportation

\[ \dot{q}_i = f(q_i, u_i, \gamma_i) \quad \gamma_i \neq 0 \quad \dot{\gamma}_i = h(\gamma_i, q_i, \bar{q}_i) \quad \bar{q}_i = h(q_{i_1}, q_{i_2}, \ldots, q_{i_{nc}}) \]
\[ u = g(q_i, \bar{q}_i, \tau_i) \]

- Translation: Consideration of the translation dynamic of whole system (mass points approximation to produce): coupled and decoupled control
- Orientation: Consideration of the complete dynamics of the whole system (coupled helicopters and load).

Rope force sensing for decoupling.

The orientation controller becomes independent of number of helicopters

\[ u_i = g(q_i, F_{ri}, \tau_i) \]
Load transportation using an autonomous small size helicopter

Technische Universität Berlin
Department of Computer Science
Institute for Technical Computer Science
Real Time Systems & Robotics
Laboratory for autonomous flying robots

Three helicopters: Joint transportation
Cooperative tracking

- Objectives:
  - Localize and track the position of targets (mobile nodes)
  - The motion of the targets is completely unknown.
- Main problems using images: Visibility, Image processing, Reliability.
- Main problems using the RSSI: Delayed RSSI measures, RSSI/distance is an inaccurate model, Non-gaussian initial estimation.
- Approach: Decentralized perception (One perception software for each aware entity (GCNs, UAVS and WSN).
  - Allow reducing requirements on data transmission.
  - Divide the processing load among different nodes.
  - Increase the robustness.
- Implementation based on Extended Information Filter (EIF): easy to integrate measurements, including delayed, low computation.
Actuation: Fire extinguishing

AWARE USER GROUP

Members
- Media industries.
- IT industries, including developers and vendors SMEs.
- Members of the Academia.

Objectives
- Specification of the system.
- Evaluation of the involved technologies and project results.
- Information for the Exploitation plan.

http://www.aware-project.net
Conclusions and further developments

- Cooperation of multiple aerial vehicles offers many application possibilities
  - Load transportation
  - Cooperative detection, localization and tracking
  - Cooperation with ground robots and autonomous systems in general.

- Integration of UAVs and WSN technologies very promising:
  - Coverage,
  - Deployment, Cooperative detection, localization and tracking,
  - Integration is in its early stages: New integration paradigms.
  - Self-deployment needs more attention: many future possibilities

- Further developments are required: Reliable networking, safety, security, scalability.

- New applications: security, environment monitoring, air traffic control, ………

Cooperating aerial platforms

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