Perception, Navigation and Target Localization for Autonomous Robots

COllaboration Based Robotics and Automation (COBRA)

University of New Brunswick
Department of Electrical and Computer Engineering
http://www.unb.ca/cobra

Cairo 2015

Perception, Navigation and Target Localization for Autonomous Robots

COllaboration Based Robotics and Automation (COBRA)

University of New Brunswick
Department of Electrical and Computer Engineering
http://www.unb.ca/cobra

Cairo 2015

Outline

About
COBRA

- COllaboration Based Robotics and Automations is a collection of inspired researchers developing robotics applications located at the University of New Brunswick in beautiful Fredericton.
- http://www.unb.ca/cobra

UNB

COBRA

About

Current and Recent Team Members

Team Members

1. Carl Thibault, MEng
2. Sajad Saeedi, Post-Doc
3. Amr Nagaty, MSc
4. Liam Paull, PhD
5. Faris Mahboob, BEng
6. Howard Li, Associate Professor, PhD, PEng

Team

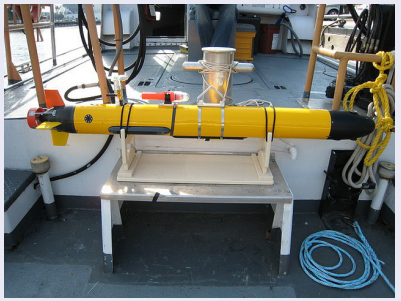
About

Liam Paull

Education and Experience

- Post-Doc at MIT
- PhD at UNB
- BEng (Computer) from McGill
- Path planning for AUVs
- MAS framework with MOOS-IvP
- Control of water heaters
- Control strategies for power inverters
- AI for load forecasting
- Image Processing

Sample Work



About

Amr Nagaty

Education and Experience

- Engineer at Pratt & Whitney Canada
- MSc at UNB
- BScE in Mechatronics Engineering, German University in Cairo (GUC)
- Bachelor project at the Institute of Flight Mechanics and Control (iFR) at Stuttgart University
- Modeling of helicopter equipped with active trailing edge flaps during air resonance
- Eurocopter Deutschland GmbH

Sample Work

About

Sajad Saeedi G.

Education and Experience

- Research Engineer at 2G Robotics
- Post-doc and PhD at UNB
- MSc in Electrical Engineering, TMU with Control
- BEng in Electrical Engineering, KNTU with Electronics
- 4 years of hardware developing and programming
- 3 years of metropolitan optical network design

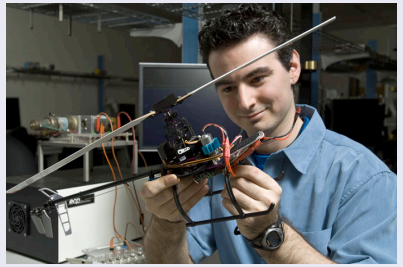
Sample Work

About
Carl Thibault

Education and Experience

- Research Engineer, MSc at UNB
- BEng in Mechanical Engineering, UNB with Mechatronics option
- Forestry Protection Ltd; ADI Ltd
- Wind tunnel application of a 3D laser interferometer system
- UVS Canada 2009 UAV competition pilot
- 19 years of radio control cars
- 12 years of radio control aircraft
- 9 years with model helicopters
- Computer aided design software
- Computer aided machining

Sample Work



About

Howard Li, PhD, PEng, Associate Professor

Experience

- Atlantis Systems International
- F/A-18 Hornet (Boeing, Royal Australian Air Force, Canadian Forces)
- EH-101 Helicopter (Royal Danish Air Force)
- Alt Software Inc.
- Christie Digital Systems Inc.
- Applied AI Systems Inc.
- UOIT
- University of Waterloo
- University of Guelph

Sample Work

Outline

History

Unmanned Aerial Vehicles

- On Oct. 9, 1903, **New York Times** - "*it might be assumed that the flying machine which will really fly might be evolved by the combined and continuous efforts of mathematicians and mechanicians in from one million to ten million years . . .*".
- On Decc 17, 1903, bicycle repairmen, the **Wright brothers** tested their flying machine.
- On July 20, 1969, the United States's **Apollo 11** was the first manned mission to land on the Moon.
- In 2009, the **Ontario Provincial Police** used UAVs to collect evidence in a homicide investigation.
- In 2009, the **Saskatoon Police Service** became the first urban police service in North America to use UAVs for aerial forensic purposes within city limits.
- By Sept 2015, civilian UAVs will be integrated into the national airspace in North America.

UAV Platforms

Fixed Wing

Quad Rotor

Helicopter

UAV Platforms

Conventional Helicopter

Helicopter

1. Common collective pitch model helicopters
2. Known for their excellent maneuverability
3. Complex system

Flight Test

UAV Platforms

Multi Rotor Aircraft

Quad Rotor

1. Have the ability to hover
2. Neutrally stable and durable
3. Easy to coordinate with slower ground vehicles

Flight Test

UAV Platforms

Draganfly X8

The X8

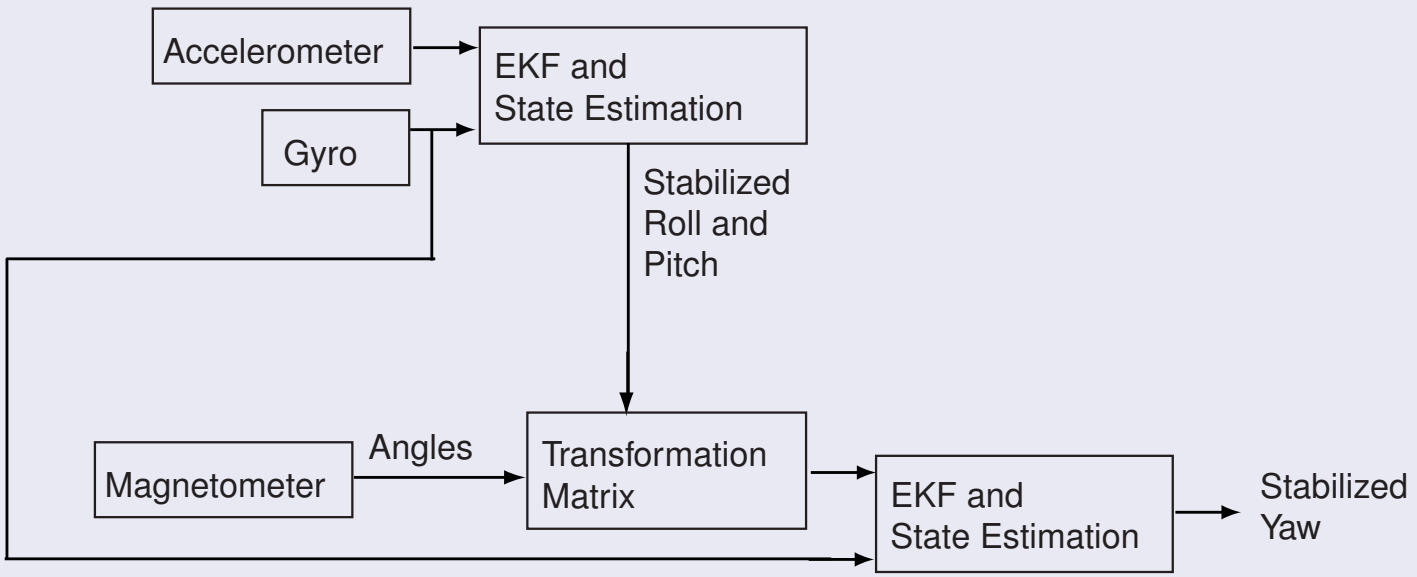
1. Eight rotor aircraft
2. Same stability as a Quad
3. Built-in redundancy
4. Higher payload
5. Lower efficiency

Draganfly X8

AHRS and Navigation

Automatic Heading Reference System

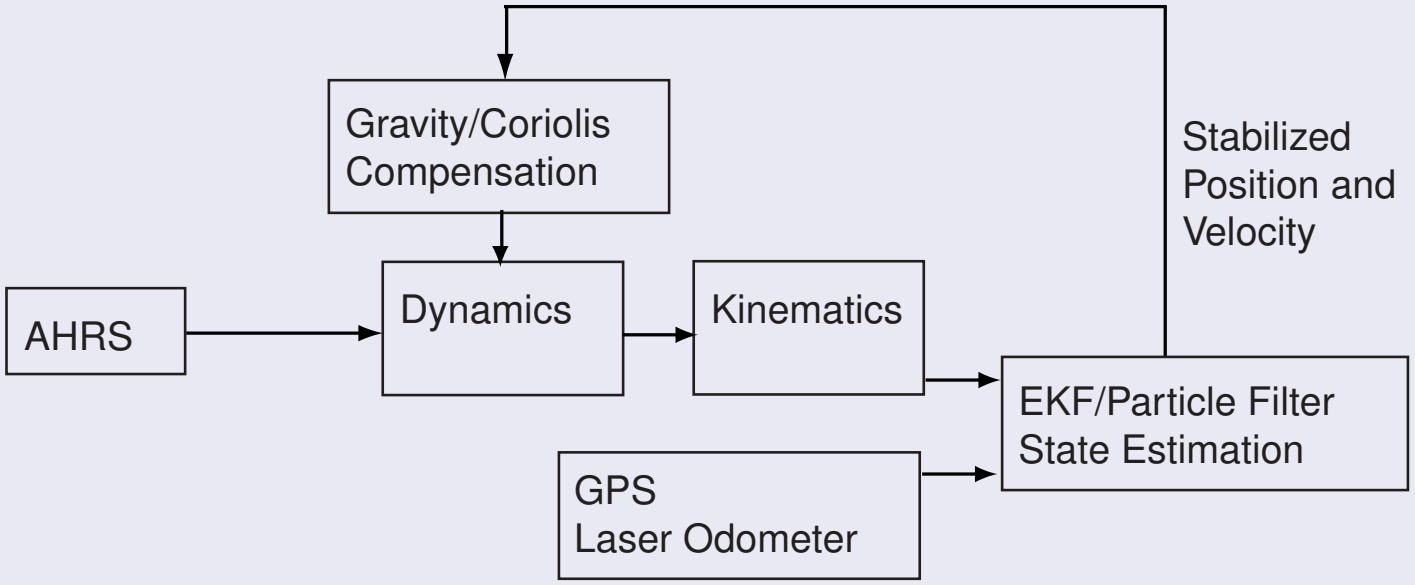
AHRS



AHRS and Navigation

Navigation System

Navigation System



Flight Simulator

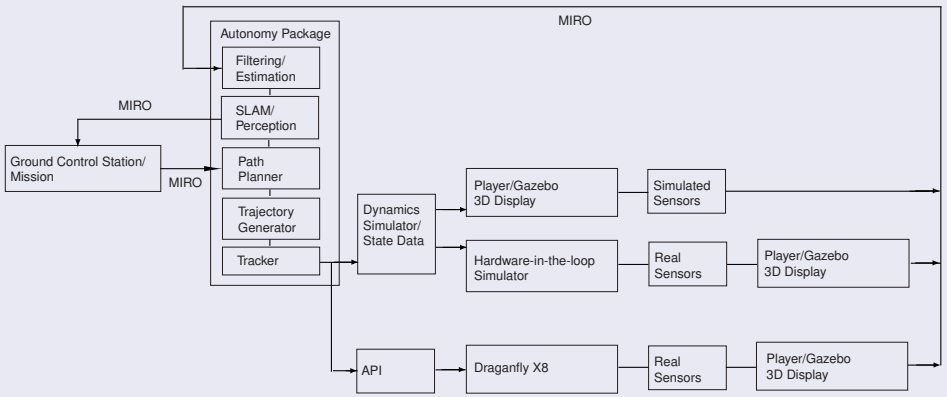
Flight Simulator and Visualization

Gazebo Quadrotor Sim

Flight Simulator

Hardware-in-the-Loop Simulator

Hardware-in-the-Loop Simulator



Flight Simulator

Simulator Operation

Simulator Operation

- We can fly the following settings using the same ground control station, 3D display, and joystick:
  - The real UAV with the real "autonomy package" hardware;
  - The real "autonomy package" hardware using state data from the dynamics simulator (the airframe is not moving);
  - The simulated UAV and the dynamics simulator on the ground control station PC using a joystick;
  - The real UAV using the UAV handheld transmitter while the status is displayed using the same ground control station and 3D display.

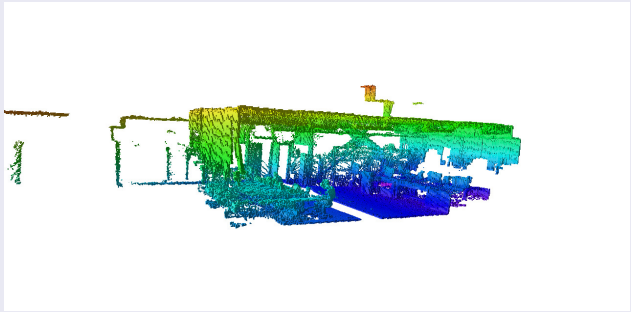
Mapping and Localization

Types of Maps

Types of Maps

- Occupancy grid map
- Feature map
- Topology map
- Hybrid map

SLAM



Mapping and Localization

Localization

Localization

- Ground/Air
  - GPS - Absolute position
  - Laser - Scan matching; Feature detection
  - Vision - Feature detection

Mapping and Localization

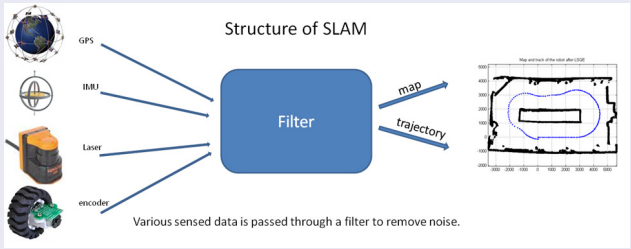
Feature Based Simultaneous Localization and Mapping

Feature Based SLAM

- Extended Kalman Filter
- Information Filter
- Particle Filter (FastSLAM)

- Pros: Static features improve correlation
- Cons: Feature extraction, state size grows over time

Fusion and Filtering



Mapping and Localization

View Based SLAM

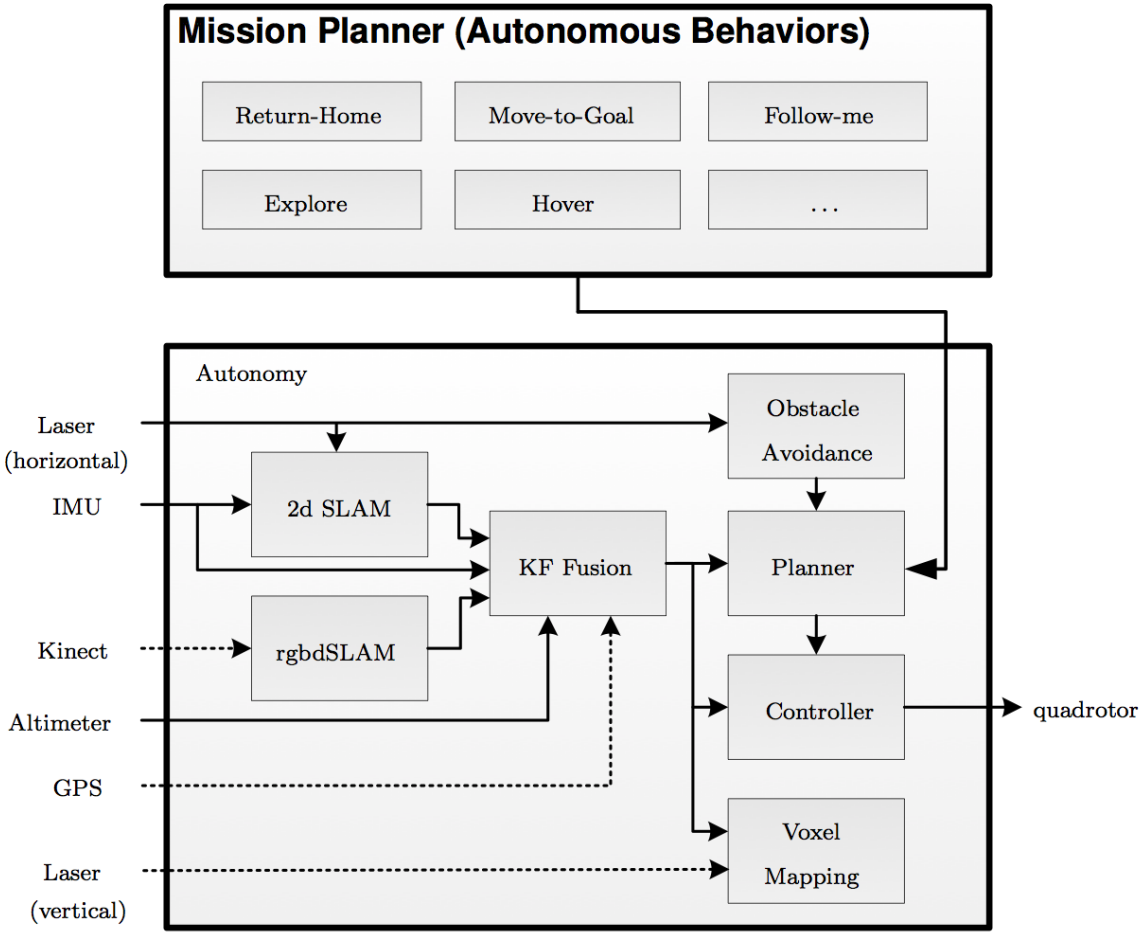
View Based SLAM

- Dense range and bearing
- Data association: scan matching or scan registration: ICP (Iterative Closest Point)
- Pros: No loss of data, no feature extraction
- Cons: Difficult for loop closure, error accumulation, slow

SLAM

Rotorcraft SLAM and Autonomy

Rotorcraft Autonomy



Rotorcraft SLAM and Autonomy

Development of Autonomous Behaviours, Perception and Navigation Strategies

- Waypoint following: waypoint navigation
- Obstacle avoidance: obstacle avoidance while navigating between waypoints
- SLAM: map building for avoiding obstacles and moving between waypoints
- Path planning/behaviours: autonomous behaviours such as, follow me, return to me, and wall following, entailing some level of path planning, and go home, involving planning within the generated world model and rapid egress
- Target detection/sensor driven exploration: exploration of unknown space

Rotorcraft SLAM and Autonomy

Autonomous Rotorcraft Results

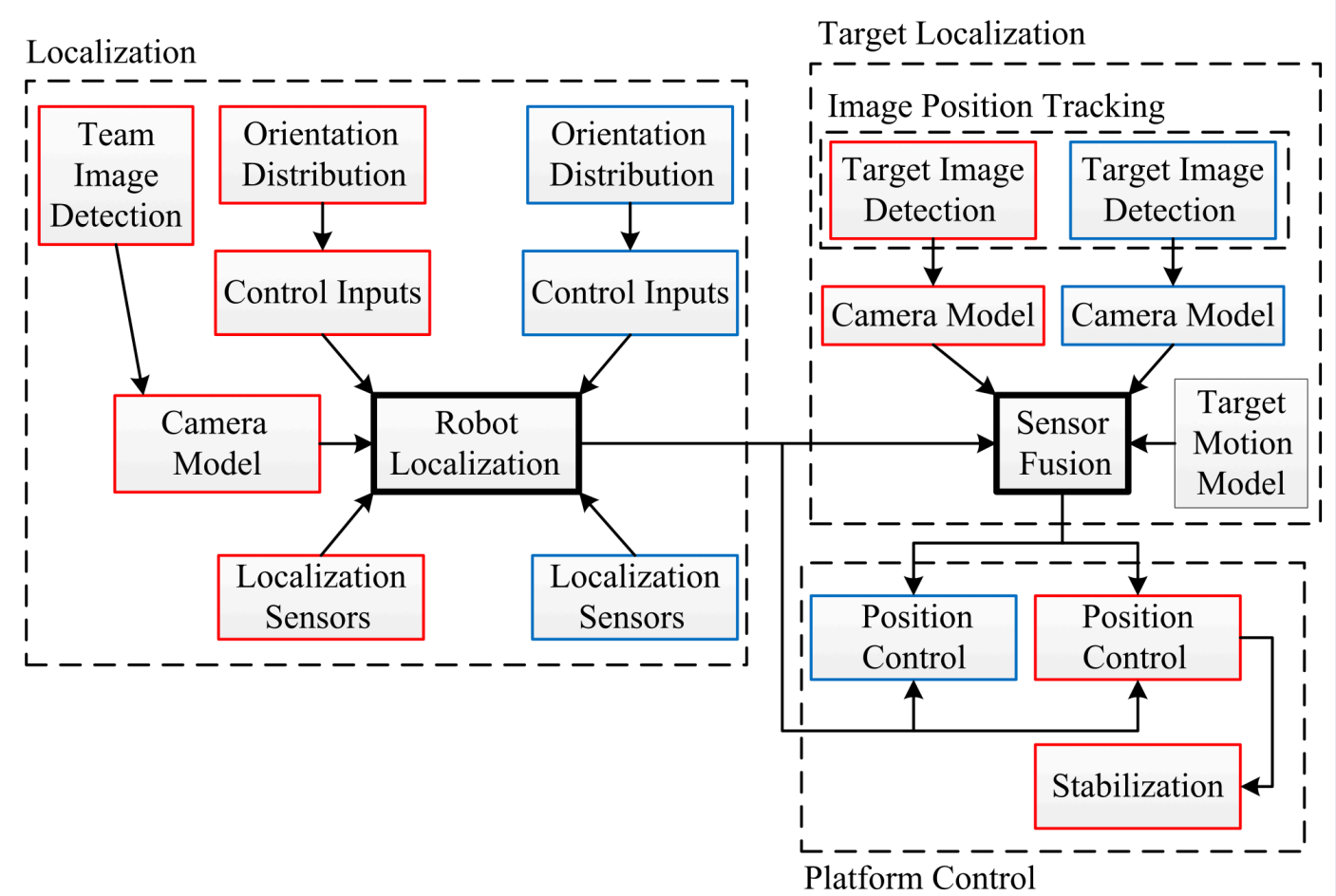
Results

Outline

Aerial and Ground Robot Cooperative Localization

System Overview

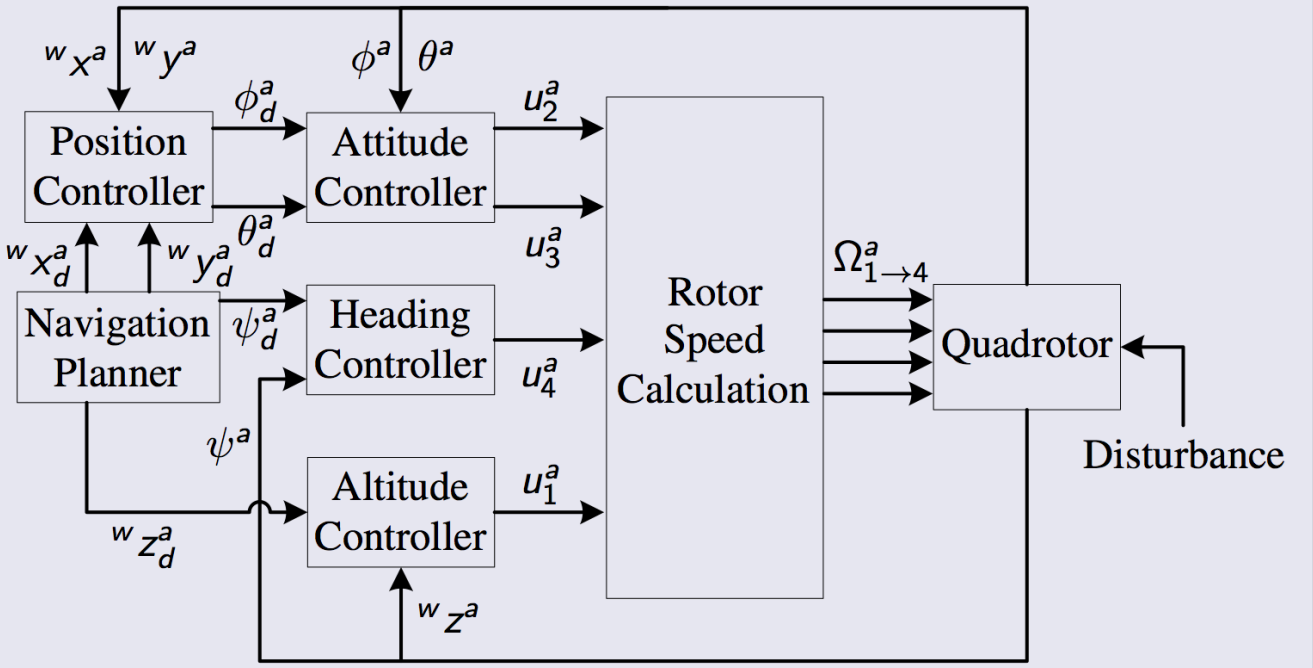
System Overview



Aerial and Ground Robot Cooperative Localization

Quadrotor Control

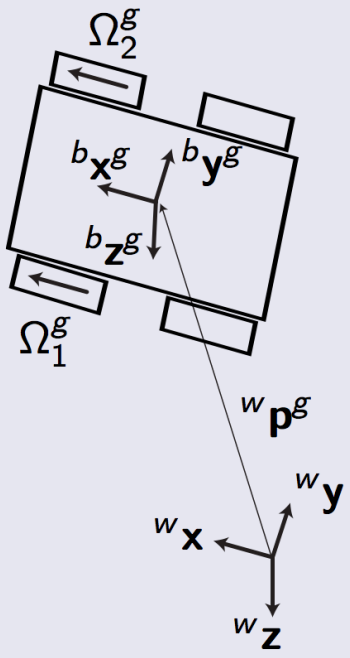
Cascaded Control Architecture



Aerial and Ground Robot Cooperative Localization

Ground Vehicle Control

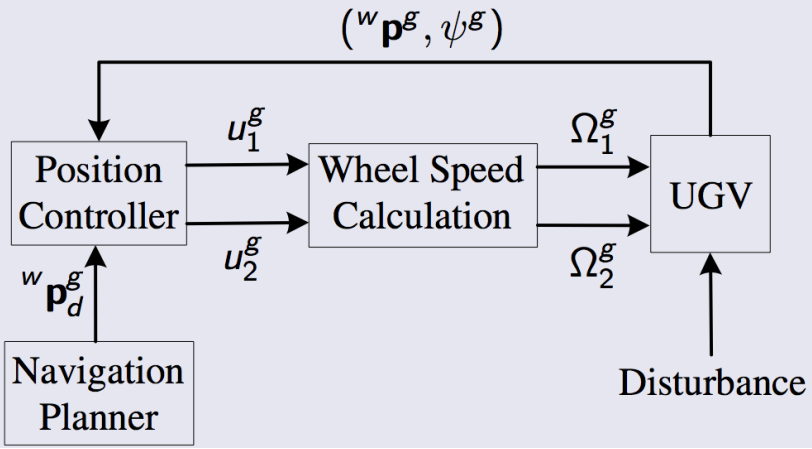
UGV Frame Definition



Control Speeds

Rate	Ω_1^g	Ω_2^g
Forward	+	+
Turn	+	-

Control Architecture



Aerial and Ground Robot Cooperative Localization

Localization Problem Definition

- Estimation of the positions and velocities of both robots in the terrestrial system

$$\mathbf{x} = \left[\begin{array}{cccccccccc} \varphi^a & \lambda^a & h^a & \upsilon_N^a & \upsilon_E^a & \upsilon_D^a & \varphi^g & \lambda^g & \upsilon_N^g & \upsilon_E^g \end{array} \right]^T$$

- Odometry measurements

$$\mathbf{u}_t = \left[\begin{array}{ccc} \mathbf{a}_t^a & \omega_1 & \omega_2 \end{array} \right]^T$$

- Global localization measurements $\mathbf{z}_t$
- Relative localization measurement $\mathbf{z}_t^{a/g}$
- Posterior distribution of the joint robots' positions and velocities

$$\mathrm{bel}\left(\mathbf{x}_t\right) = p\left(\mathbf{x}_t | \mathbf{x}_{t-1}, \mathbf{u}_t, \mathbf{z}_t, \mathbf{z}_t^{a/g}\right)$$

Aerial and Ground Robot Cooperative Localization

Localization Algorithm

Algorithm for Localization of the Aerial and Ground Robots

1: Perform state prediction$\leftarrow$ Step 1
2: Perform measurement update using global localization measurements $\mathbf{z}_t \leftarrow$ Step 2
3: **if** Relative position measurement $\mathbf{z}_t^{a/g}$ received **then**
4: Update the relative position subspace $\left({}^{w}\mathbf{p}_t^a, {}^{w}\mathbf{p}_t^g\right) \leftarrow$ Step 3
5: **end if**

Aerial and Ground Robot Cooperative Localization

Baysian Algorithm

Step 1 - Prediction

$$\overline{\mathrm{bel}}\left(\mathbf{x}_t\right) = \int_{\mathbf{x}_{t-1}} p\left(\mathbf{x}_t | \mathbf{x}_{t-1}, \mathbf{u}_t\right) \mathrm{bel}\left(\mathbf{x}_{t-1}\right) d\mathbf{x}_{t-1}$$

Step 2 - Global Measurement Update

$$\mathrm{bel}\left(\mathbf{x}_{t-}\right) = \eta\, p\left(\mathbf{z}_t | \mathbf{x}_t, \mathbf{u}_t\right) \overline{\mathrm{bel}}\left(\mathbf{x}_t\right)$$

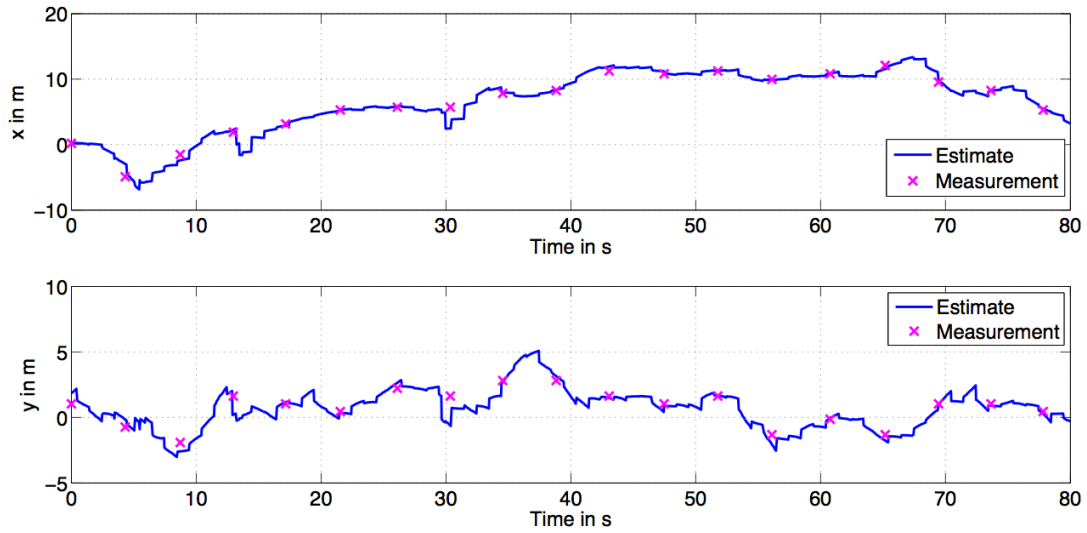
Step 3 - Relative Measurement Update

$$\mathrm{bel}\left(\mathbf{x}_t\right) = \eta\, p\left(\mathbf{z}_t^{a/g} | \mathbf{x}_{t-}, \mathbf{\Theta}_t^a\right) \mathrm{bel}\left(\mathbf{x}_{t-}\right) \mathrm{bel}\left(\mathbf{\Theta}_t^a\right)$$

Aerial and Ground Robot Cooperative Localization

Localization UAV Results

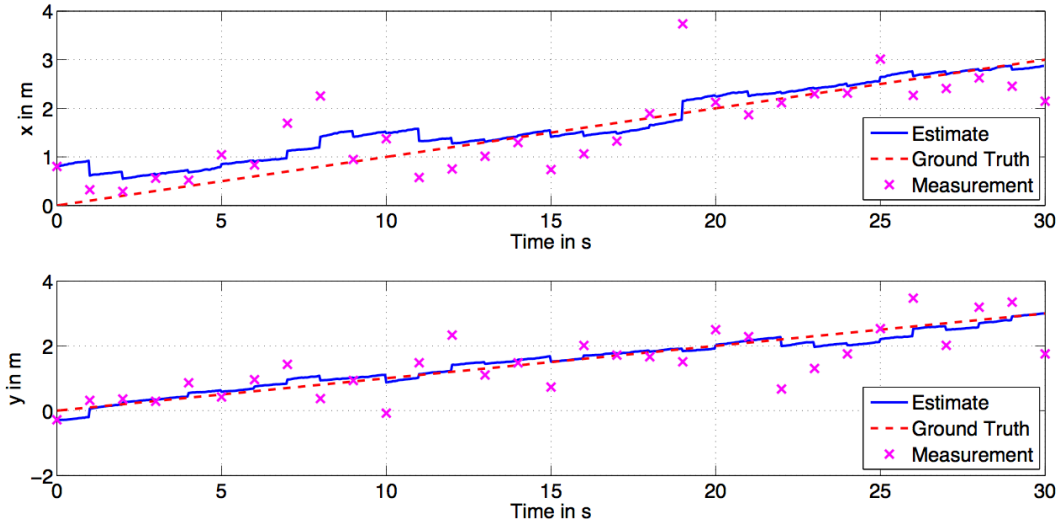
UAV Localization Results



Aerial and Ground Robot Cooperative Localization

Localization UGV Results

UGV Localization Results



Target Localization

Target Localization Problem Definition

- Estimation of the target's position and velocity

$$\mathbf{x}^0 = \begin{bmatrix} {}^w\mathbf{p}^0 & {}^w\dot{\mathbf{p}}^0 \end{bmatrix}^T$$

- Estimated poses of the robots $\mathbf{y}_t$
- Aerial $\mathbf{\Delta}_t^{a/0}$ and ground $\mathbf{\Delta}_t^{g/0}$ camera measurements
- Posterior distribution of the target's position and velocity

$$\mathrm{bel}\left(\mathbf{x}_t^0\right) = p\left(\mathbf{x}_t^0 | \mathbf{x}_{t-1}^0, \mathbf{y}_t, \mathbf{\Delta}_t^{a/0}, \mathbf{\Delta}_t^{g/0}\right)$$

Target Localization

Target Localization Algorithm

Algorithm for Target Localization

1: Perform target state prediction
2: Compute target measurement model for each robot that observes the target
3: Impose the epipolar constraint
4: Update the target state

Target Localization

Target Localization Baysian Algorithm

Step 1 - Prediction

$$\overline{\mathrm{bel}}\left(\mathbf{x}_t^0\right) = \int_{\mathbf{x}_{t-1}^0} p\left(\mathbf{x}_t^0 | \mathbf{x}_{t-1}^0\right) \mathrm{bel}\left(\mathbf{x}_{t-1}^0\right) d\mathbf{x}_{t-1}^0$$

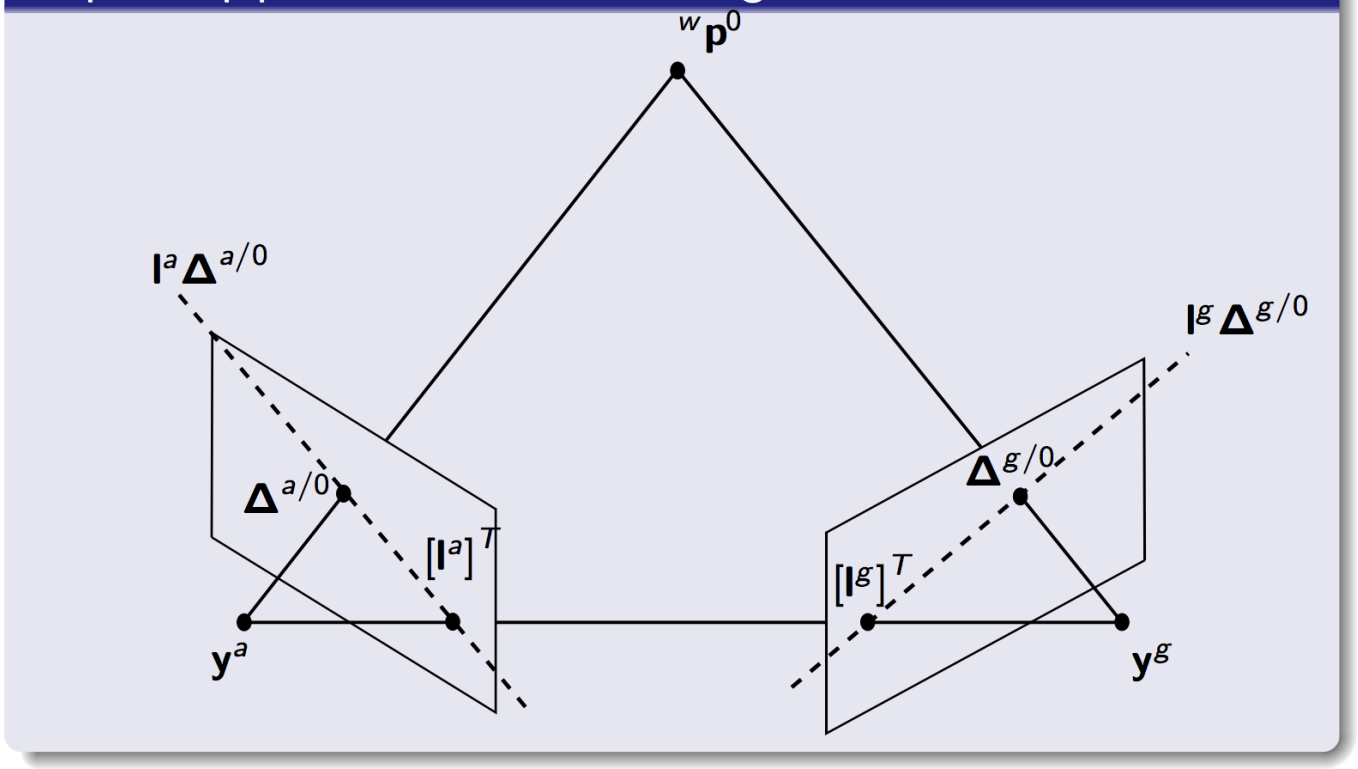
Step 2 - Target Measurement Likelihood (Camera Geometry)

$$p\left(\mathbf{\Delta}_t^{a/0}, \mathbf{\Delta}_t^{g/0} | \mathbf{x}_t^0, \mathbf{y}_t\right) = p\left(\mathbf{\Delta}_t^{a/0} | \mathbf{x}_t^0, \mathbf{y}_t^a\right) p\left(\mathbf{\Delta}_t^{g/0} | \mathbf{x}_t^0, \mathbf{y}_t^g\right)$$

Target Localization

Target Localization Epipolar Constraint

Step 3 - Epipolar Constraint Modeling



Target Localization

Target Localization Update

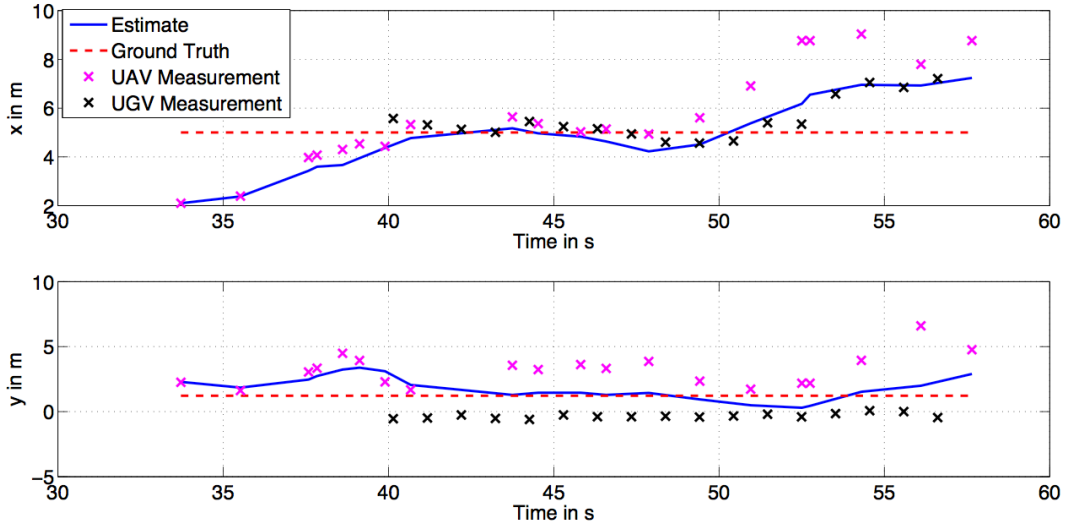
Step 4 - Update Target State

$$\mathrm{bel}\left(\mathbf{x}_t^0\right) = \eta\, p\left(\mathbf{\Delta}_t^{a/0}, \mathbf{\Delta}_t^{g/0} | \mathbf{x}_t^0, \mathbf{y}_t\right) \overline{\mathrm{bel}}\left(\mathbf{x}_t^0\right)$$

Target Localization

Target Localization Results

Target Localization



Target Localization

Localization Results

Results

Outline

Summary

Summary

1. Perception, SLAM, sensor fusion, control, and autonomy for UAVs and UGVs are implemented
2. Cooperative localization and target localization using multiple UAVs and UGVs
3. AUVs for mine countermeasure

Acknowledgement