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
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Cairo 2015
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
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
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
## 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
# 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

1. Introduction

2. Autonomous Unmanned Aerial Vehicles
   - History
   - UAV Platforms
   - AHRS and Navigation
   - Flight Simulator
   - Mapping and Localization
   - Rotorcraft SLAM and Autonomy

3. Aerial and Ground Robot Cooperative Localization

4. Questions
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 Dec 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
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
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
AHRS and Navigation
Automatic Heading Reference System

AHRS

Accelerometer → EKF and State Estimation

Gyro → Stabilized Roll and Pitch

Magnetometer → Angles → Transformation Matrix → EKF and State Estimation → Stabilized Yaw
AHRS and Navigation

Navigation System

- AHRS
- Gravity/Coriolis Compensation
- Dynamics
- Kinematics
- GPS Laser Odometer
- EKF/Particle Filter State Estimation
- Stabilized Position and Velocity
Flight Simulator
Flight Simulator and Visualization

Gazebo Quadrotor Sim
Flight Simulator
Hardware-in-the-Loop Simulator

- Autonomy Package
- Filtering/Estimation
- SLAM
- Perception
- Path Planner
- Trajectory Generator
- Tracker
- Dynamics
- Simulation State Data
- AI
- Dragonfly X8
- Real Sensors
- Player/Gazebo 3D Display

- MIRO
- Simulated Sensors
- Hardware-in-the-loop Simulator
- Player/Gazebo 3D Display
- Real Sensors
- Player/Gazebo 3D Display

Ground Control Station/Mission
Hardware-in-the-loop Simulator
3D Display
3D Display
Player/Gazebo
Flight Simulator

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

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

SLAM
Mapping and 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
Mapping and Localization

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
Rotorcraft SLAM and Autonomy

Rotorcraft Autonomy

Mission Planner (Autonomous Behaviors)
- Return-Home
- Move-to-Goal
- Follow-me
- Explore
- Hover
- …

Autonomy
- Laser (horizontal)
- IMU
- Kinect
- Altimeter
- GPS
- Laser (vertical)

2d SLAM
KF Fusion
Obstacle Avoidance
Planner
Controller
Voxel Mapping

quadrotor
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
Results
Outline

1. Introduction
2. Autonomous Unmanned Aerial Vehicles
3. Aerial and Ground Robot Cooperative Localization
   - Aerial and Ground Robot Cooperative Localization
   - Target Localization
4. Questions
Aerial and Ground Robot Cooperative Localization

System Overview

Localization
- Team Image Detection
  - Orientation Distribution
    - Control Inputs
      - Camera Model
        - Localization Sensors
          - Robot Localization
            - Image Position Tracking
              - Target Image Detection
                - Target Image Detection
                  - Camera Model
                    - Sensor Fusion
                      - Target Motion Model
                        - Position Control
                          - Stabilization
                            - Platform Control
              - Camera Model
                - Control Inputs
                  - Localization Sensors
                    - Robot Localization
                      - Image Position Tracking
                        - Target Image Detection
                          - Camera Model
                            - Sensor Fusion
                              - Target Motion Model
                                - Position Control
                                  - Stabilization
                                    - Platform Control
Aerial and Ground Robot Cooperative Localization
Quadrotor Control

Cascaded Control Architecture

- Position Controller
- Attitude Controller
- Navigation Planner
- Heading Controller
- Altitude Controller
- Rotor Speed Calculation
- Quadrotor
- Disturbance
Aerial and Ground Robot Cooperative Localization

Ground Vehicle Control
Aerial and Ground Robot Cooperative Localization

Localization Problem Definition

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

\[
\mathbf{x} = \begin{bmatrix}
\varphi^a & \chi^a & h^a & v_N^a & v_E^a & v_D^a & \varphi^g & \chi^g & v_N^g & v_E^g
\end{bmatrix}^T
\]

- Odometry measurements

\[
\mathbf{u}_t = \begin{bmatrix}
\mathbf{a}_t^a & \omega_1 & \omega_2
\end{bmatrix}^T
\]

- Global localization measurements \( \mathbf{z}_t \)
- Relative localization measurement \( \mathbf{z}_{t}^{a/g} \)
- Posterior distribution of the joint robots’ positions and velocities

\[
\text{bel} (\mathbf{x}_t) = p \left( \mathbf{x}_t | \mathbf{x}_{t-1}, \mathbf{u}_t, \mathbf{z}_t, \mathbf{z}_{t}^{a/g} \right)
\]
Aerial and Ground Robot Cooperative Localization

Localization Algorithm

Algorithm for Localization of the Aerial and Ground Robots

1. Perform state prediction ← Step 1
2. Perform measurement update using global localization measurements \( z_t \) ← Step 2
3. if Relative position measurement \( z_t^{a/g} \) received then
4. Update the relative position subspace \( (w_p^a, w_p^g) \) ← Step 3
5. end if
Aerial and Ground Robot Cooperative Localization

Baysian Algorithm

**Step 1 - Prediction**

$$
\overline{\text{bel}}(x_t) = \int_{x_{t-1}} p(x_t | x_{t-1}, u_t) \text{bel}(x_{t-1}) \, dx_{t-1}
$$

**Step 2 - Global Measurement Update**

$$
\text{bel}(x_{t-}) = \eta \, p(z_t | x_t, u_t) \overline{\text{bel}}(x_t)
$$

**Step 3 - Relative Measurement Update**

$$
\text{bel}(x_t) = \eta \, p(z_{t|g}^a | x_{t-}, \Theta_t^a) \text{bel}(x_{t-}) \text{bel}(\Theta_t^a)
$$
Aerial and Ground Robot Cooperative Localization

Localization UAV Results

UAV Localization Results

![Graph showing localization results for UAVs.](image-url)
Aerial and Ground Robot Cooperative Localization

Localization UGV Results
Target Localization

Target Localization Problem Definition

- Estimation of the target’s position and velocity
  \[ x^0 = \begin{bmatrix} w p^0 & w \dot{p}^0 \end{bmatrix}^T \]

- Estimated poses of the robots \( y_t \)

- Aerial \( \Delta^a_t/0 \) and ground \( \Delta^g_t/0 \) camera measurements

- Posterior distribution of the target’s position and velocity
  \[ \text{bel} (x^0_t) = p \left( x^0_t | x^0_{t-1}, y_t, \Delta^a_t/0, \Delta^g_t/0 \right) \]
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
\[
\text{bel} (x_t^0) = \int_{x_{t-1}^0} p (x_t^0 | x_{t-1}^0) \, \text{bel} (x_{t-1}^0) \, dx_{t-1}^0
\]

Step 2 - Target Measurement Likelihood (Camera Geometry)
\[
p (\Delta_t^{a/0}, \Delta_t^{g/0} | x_t^0, y_t) = p (\Delta_t^{a/0} | x_t^0, y_t^a) \, p (\Delta_t^{g/0} | x_t^0, y_t^g)
\]
Target Localization
Target Localization Epipolar Constraint

Step 3 - Epipolar Constraint Modeling

$w p^0$

$[I^a]_T$

$[I^g]_T$

$\Delta^g_{/0}$

$\Delta^a_{/0}$

$\Delta^a_{/0}$
Target Localization

Target Localization Update

Step 4 - Update Target State

\[ \text{bel} (x_t^0) = \eta p \left( \Delta_t^{a/0}, \Delta_t^{g/0} | x_t^0, y_t \right) \frac{\text{bel} (x_t^0)}{} \]
Target Localization

Target Localization Results

[Graph showing target localization results with time in seconds on the x-axis and distance on the y-axis, comparing estimate, ground truth, UAV measurement, and UGV measurement.]
Target Localization

Localization Results

Results
Outline

1 Introduction

2 Autonomous Unmanned Aerial Vehicles

3 Aerial and Ground Robot Cooperative Localization

4 Questions
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