IEEE/RSJ International Conference on Intelligent Robots and Systems IROS

IROS 2016 Workshop on

State Estimation and Terrain Perception

Daejeon Convention Center - Daejeon, Korea

Multi-Sensor State Estimation on Dynamic Quadruped Robots

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ADVANCED ROBOTICS

Summary

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1) Hydraulic Quadruped (HyQ)
   - Description
   - Characteristic motions
   - Sensors
2) State Estimation
   - Overview
   - Modules
   - Applications
3) Mapping
   - Definition
   - Applications

Hydraulic Quadruped (HyQ)

Specifications

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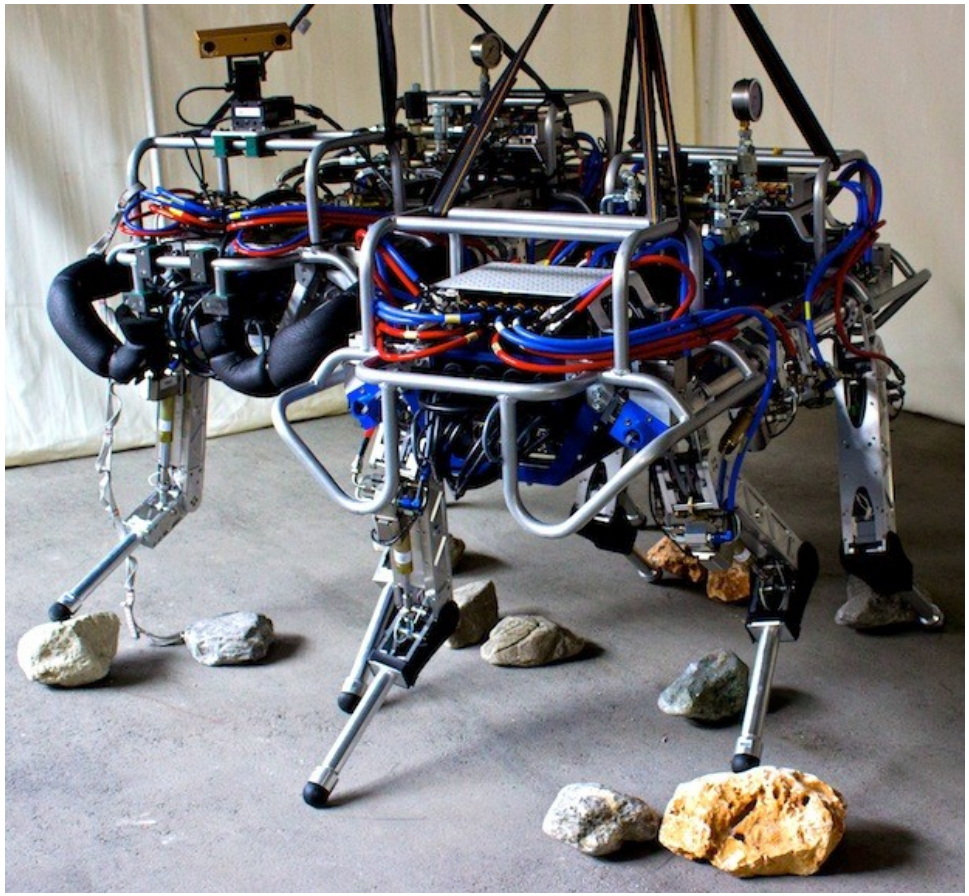
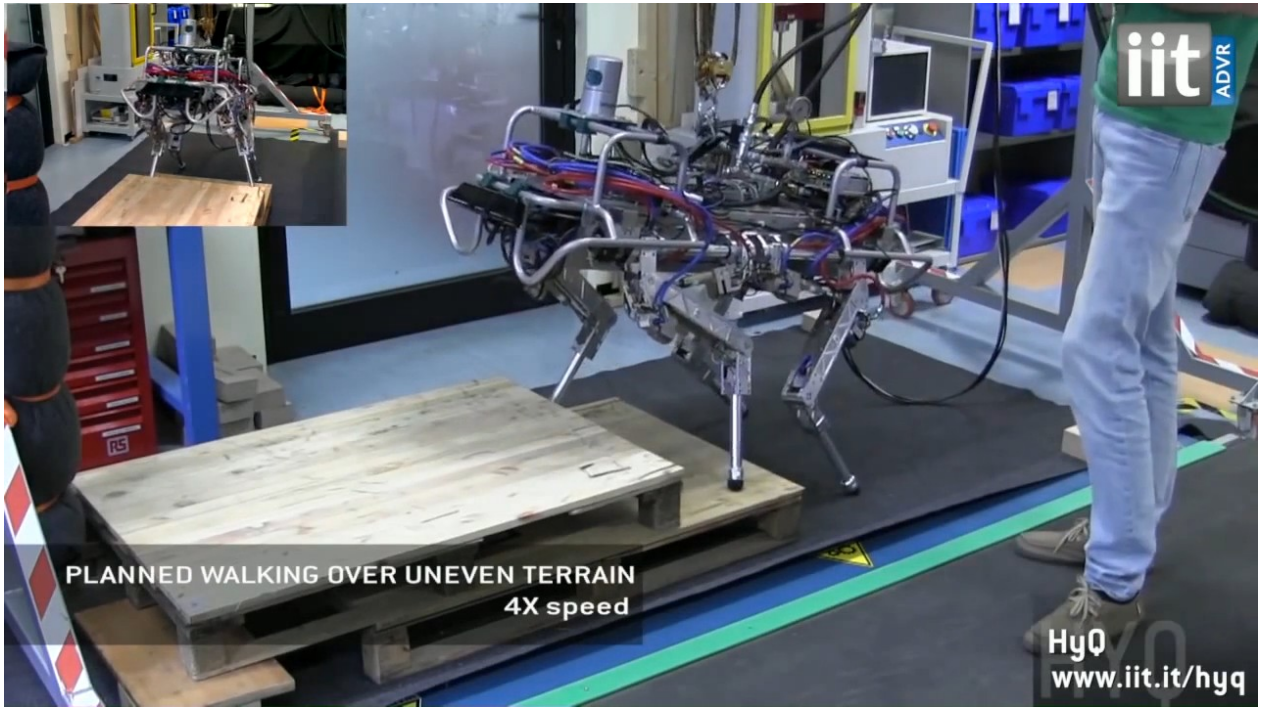
- 12 Degrees of Freedom
- ~80 kg
- 1 m x 0.5 m x ~0.8 m
- Fully torque controlled
- Fully hydraulic
- 145 Nm (at 16 MPa)



http://www.iit.it/hyq

Characteristic Motions



- Planned crawl
- Trot
- Flying trot
- Chimney Climb

https://www.youtube.com/HydraulicQuadruped

MiniHyQ, HyQ2Max, and...

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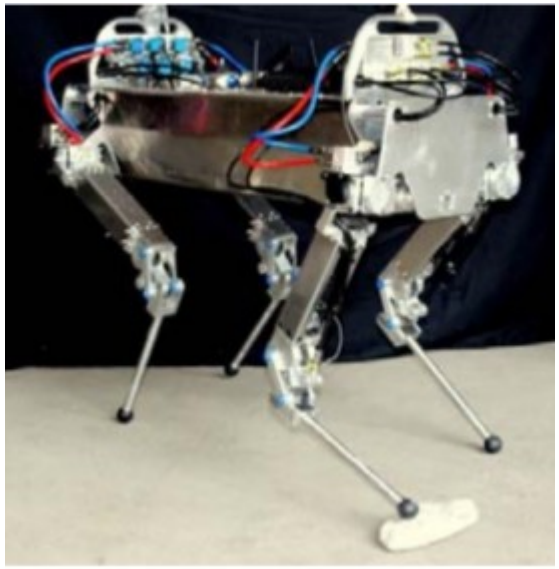


MiniHyQ

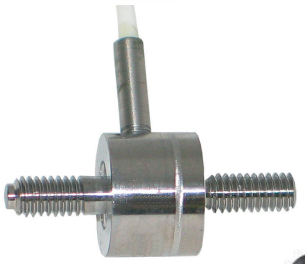
HyQ2Max (source: Reuters)

MOOG

MOOG @ IIT Joint Lab
Integrated Servo Actuators

`http://moog.iit.it`

Sensors



- Microstrain GX3-25
- Optical encoders
- Load cells
- ASUS Xtion
- Multisense SL
- Hokuyo URG-04LX

State Estimation

Pronto

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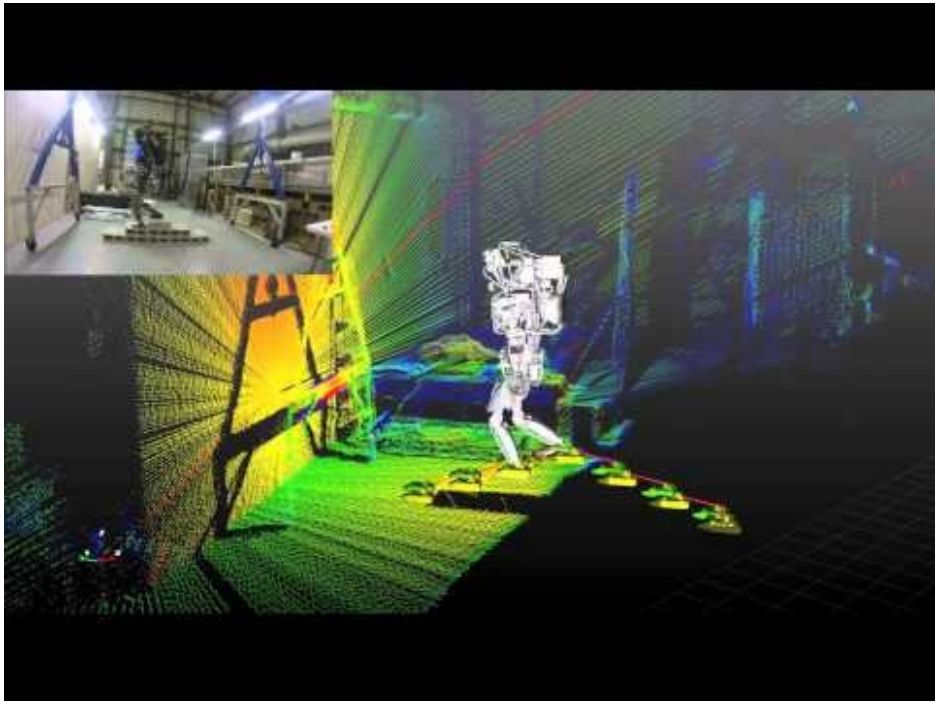
- Modular
- EKF-based
- History of meas.
- Open Source*
- Used/tested for the DRC (MIT, ViGIR, ...)
- LCM§ based



Drift-free humanoid state estimation fusing kinematic, inertial and LIDAR sensing
M. Fallon, M. Antone, N. Roy and S. Teller
2014 IEEE-RAS International Conference on Humanoid Robots, Madrid, 2014

§ https://lcm-proj.github.io/

*https://github.com/ipab-slmc/pronto-distro

Modules

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- **Proprioceptive:**
  - IMU (prediction)
  - Leg Odometry
- **Exteroceptive:**
  - Visual Odometry (FOVIS)
  - Gaussian Particle Filter (GPF)
  - Fast and Robust Scan Matcher (FRSM)
  - Vicon (ground truth)
  - …

Modules

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- **Proprioceptive:**
  - IMU (prediction) → bias, drift
  - Leg Odometry → drift, slippage, leg compliance
- **Exteroceptive:**
  - Visual Odometry (FOVIS) → featureless areas
  - Gaussian Particle Filter (GPF) → pre-acquired map
  - Fast and Robust Scan Matcher (FRSM) → only planar
  - Vicon (ground truth)
  - …

State Estimation Scheme

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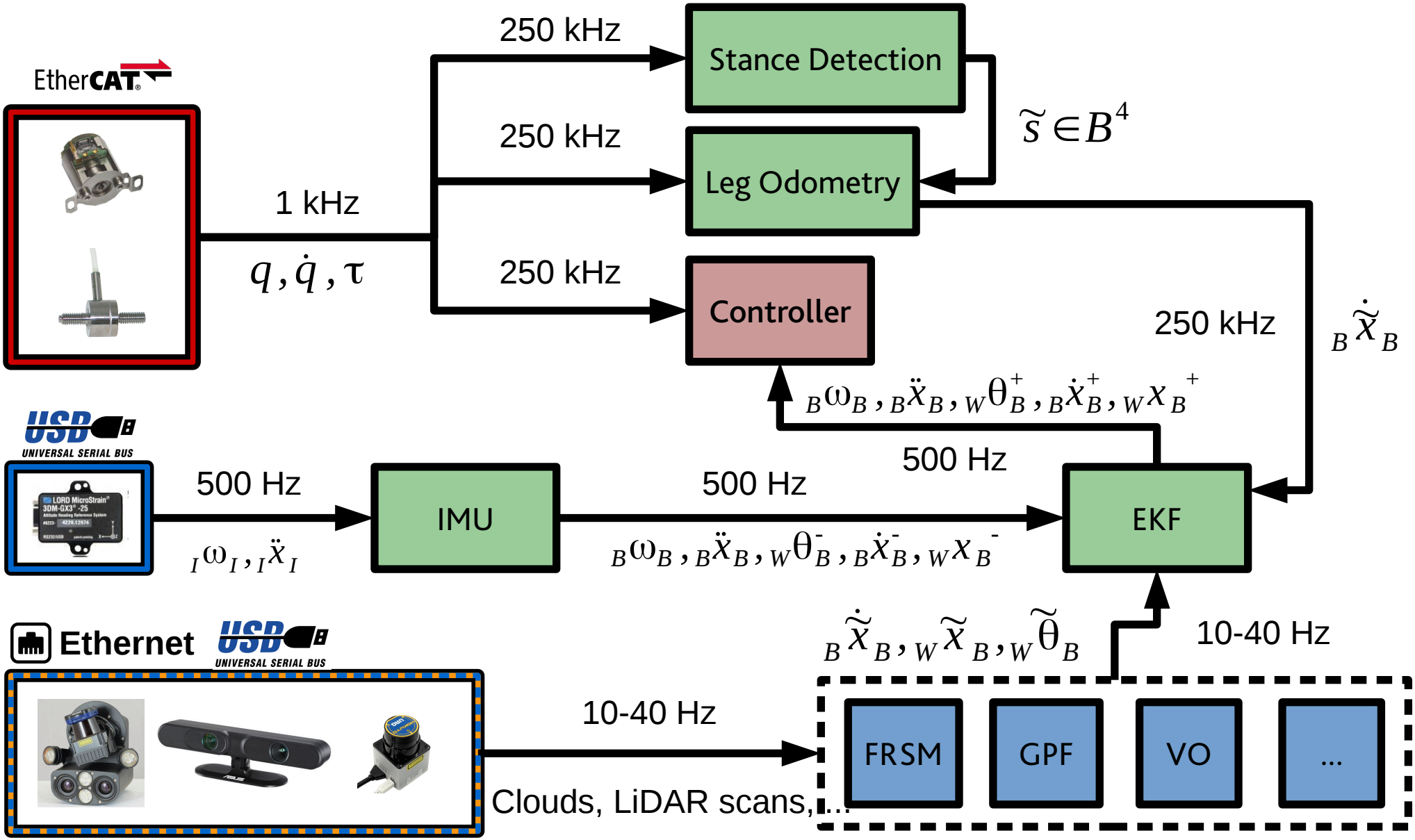

Leg Odometry

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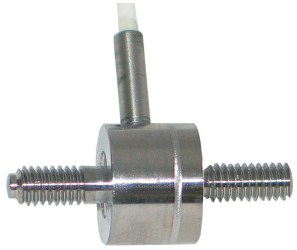
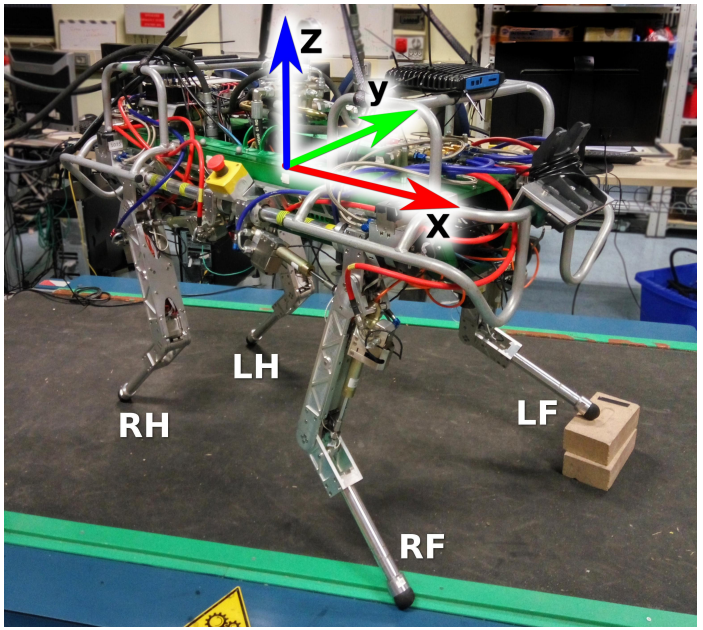
- Ground Reaction Forces estimation
- Stance Detection
- Velocity computation
- Covariance estimation





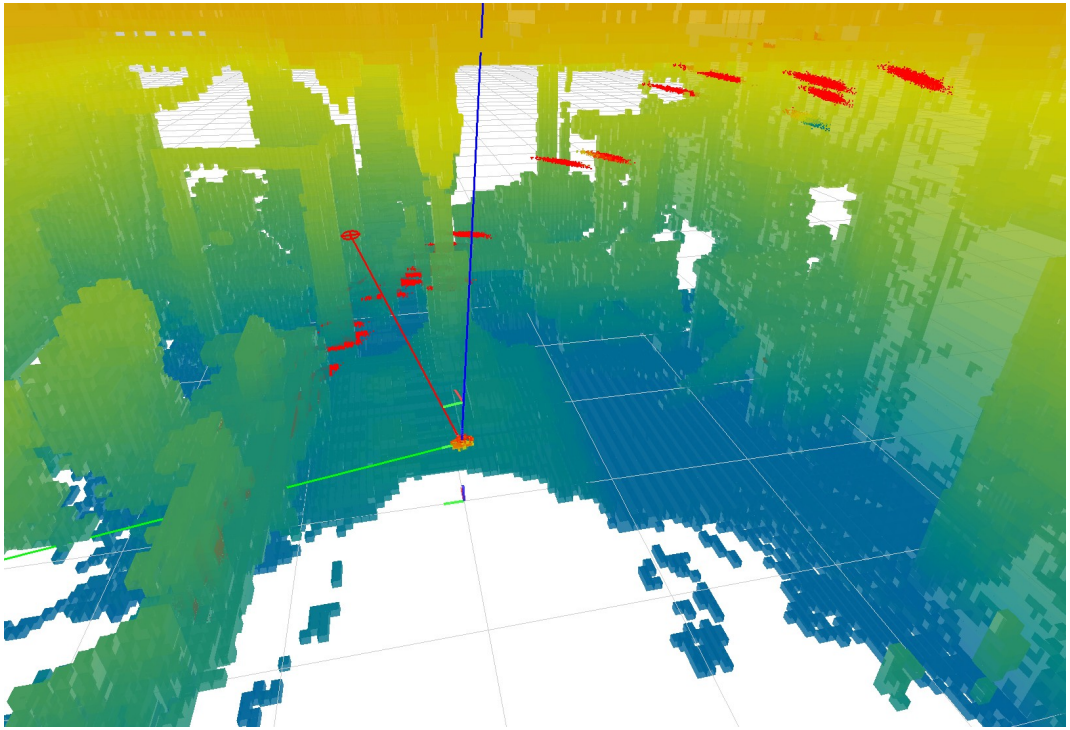
FRSM and Trunk Control

- RCF with push recovery
- Robot controlled to stay on target position
- Hokuyo URG 04-LX

RANGE - Robust Autonomous Navigation in GPS-denied Environments
Abraham Bachrach, Samuel Prentice, Ruijie He Nicholas Roy
Journal of Field Robotics, 2011

A reactive controller framework for quadrupedal locomotion on challenging terrain
Victor Barasuol, Jonas Buchli, Claudio Semini, Marco Frigerio, Edson R De Pieri, Darwin G Caldwell
2013 IEEE International Conference on Robotics and Automation (ICRA)

Gaussian Particle Filter



- Tested on Atlas/Drones
- Suitable for aggressive motions
- High Quality map required

State estimation for aggressive flight in GPS-denied environments using onboard sensing
A. Bry, A. Bachrach and N. Roy
2012 IEEE International Conference on Robotics and Automation (ICRA), Saint Paul, MN, 2012

Gaussian Particle Filter

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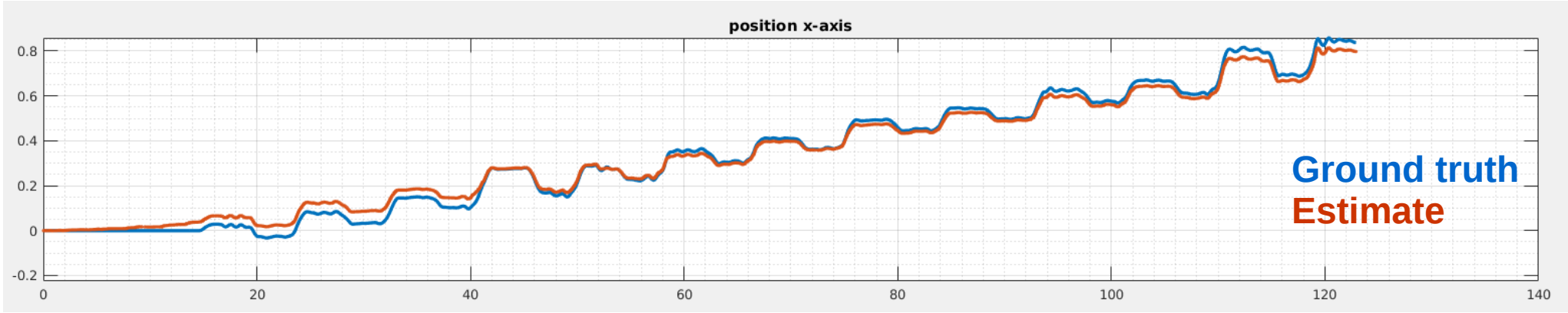
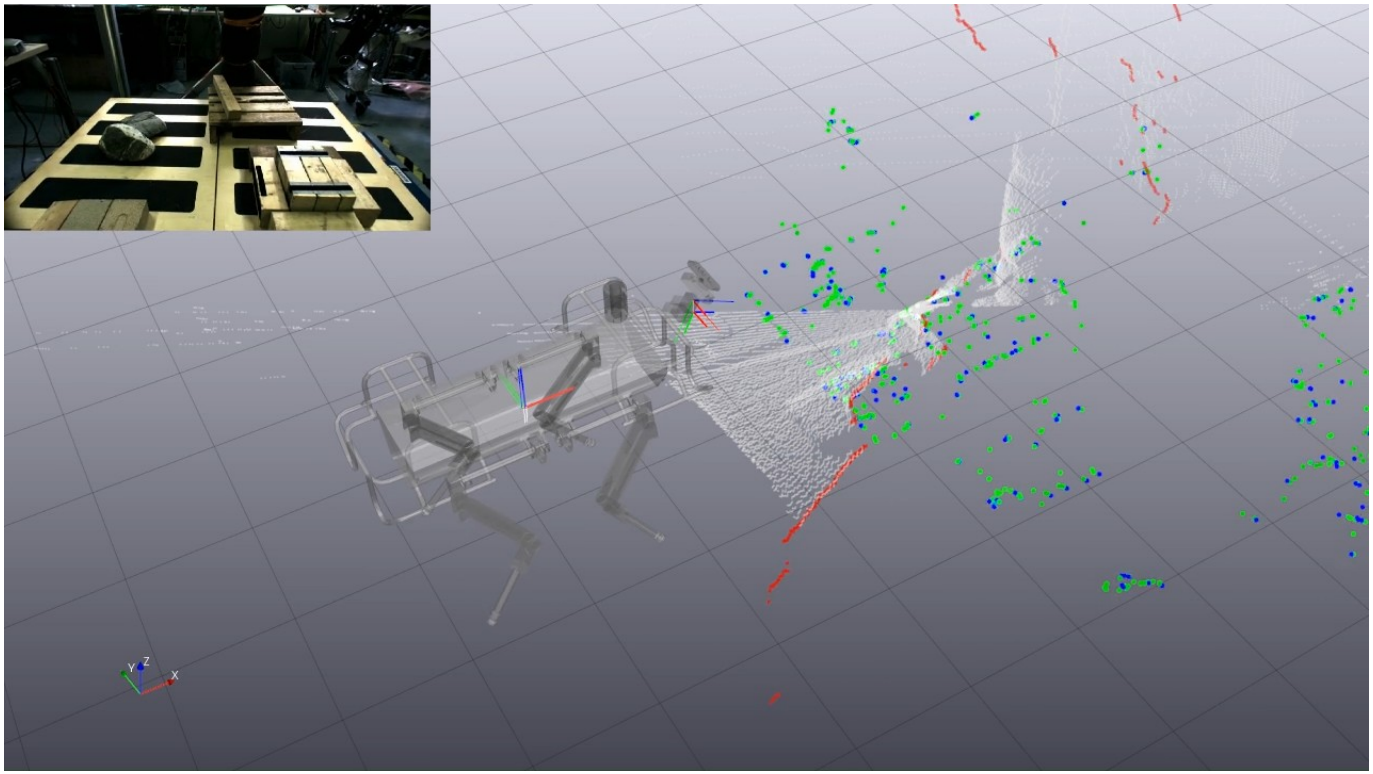
IMU+Leg Odometry

IMU+Leg Odometry+Gaussian Particle Filter

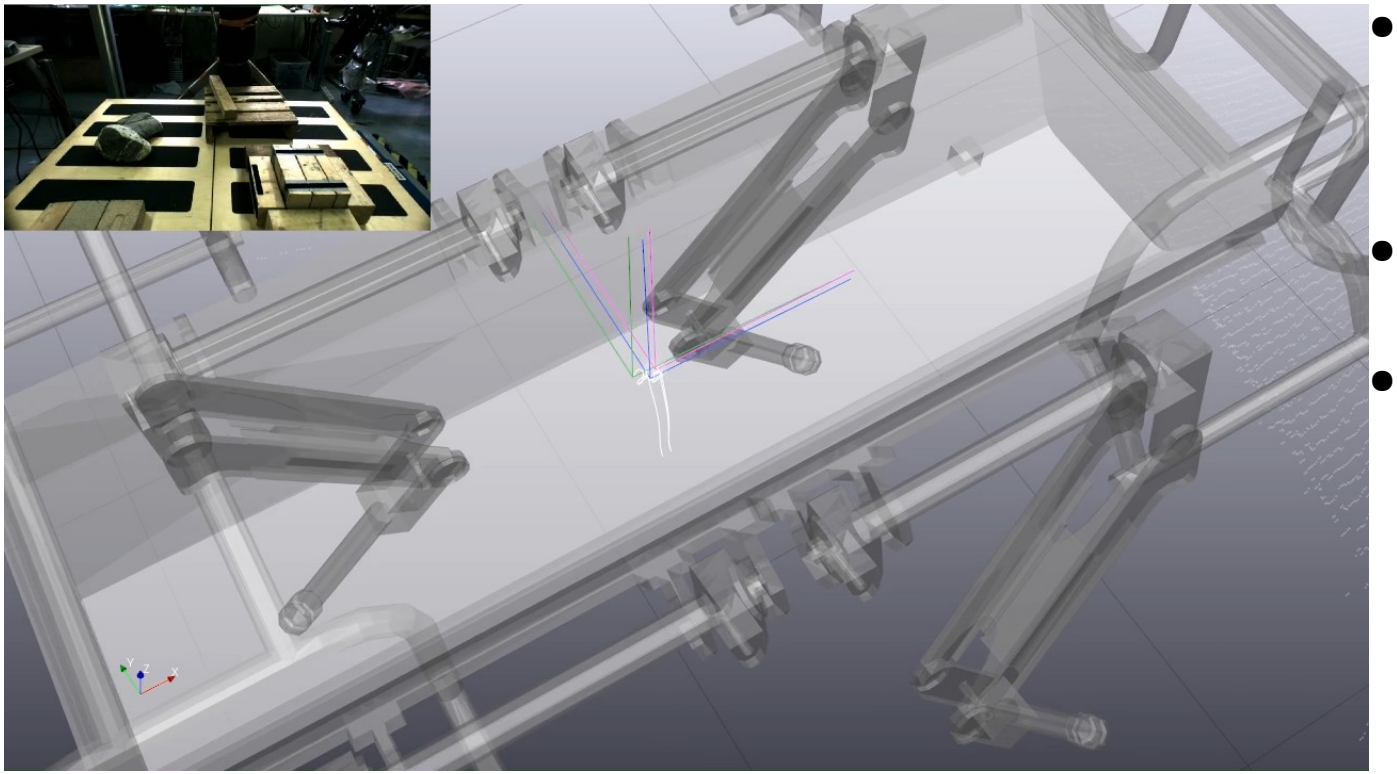


FOVIS



- Tested on Atlas/Drones
- Lightweight
- Position or velocity measure

Visual Odometry and Mapping for Autonomous Flight Using an RGB-D Camera.
Albert S. Huang, Abraham Bachrach, Peter Henry, Michael Krainin, Daniel Maturana, Dieter Fox, and Nicholas Roy.
Int. Symposium on Robotics Research (ISRR), Flagstaff, Arizona, USA, Aug. 2011



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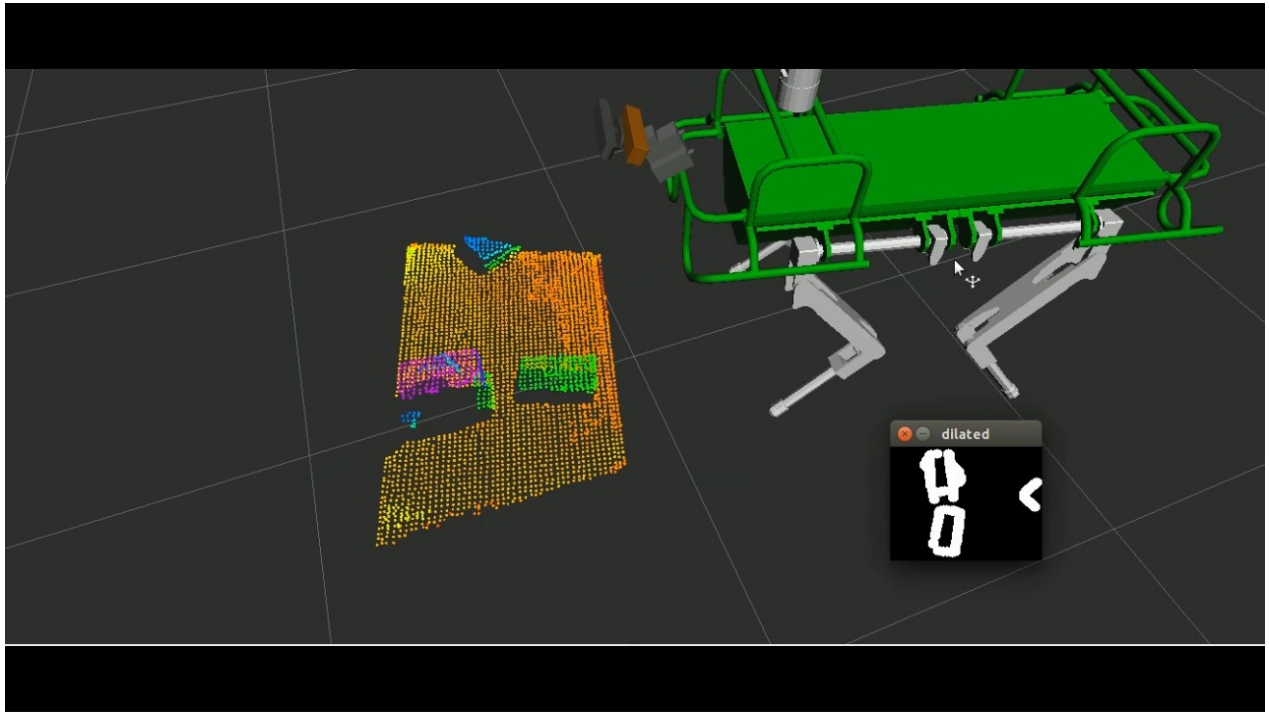
Selective ICP

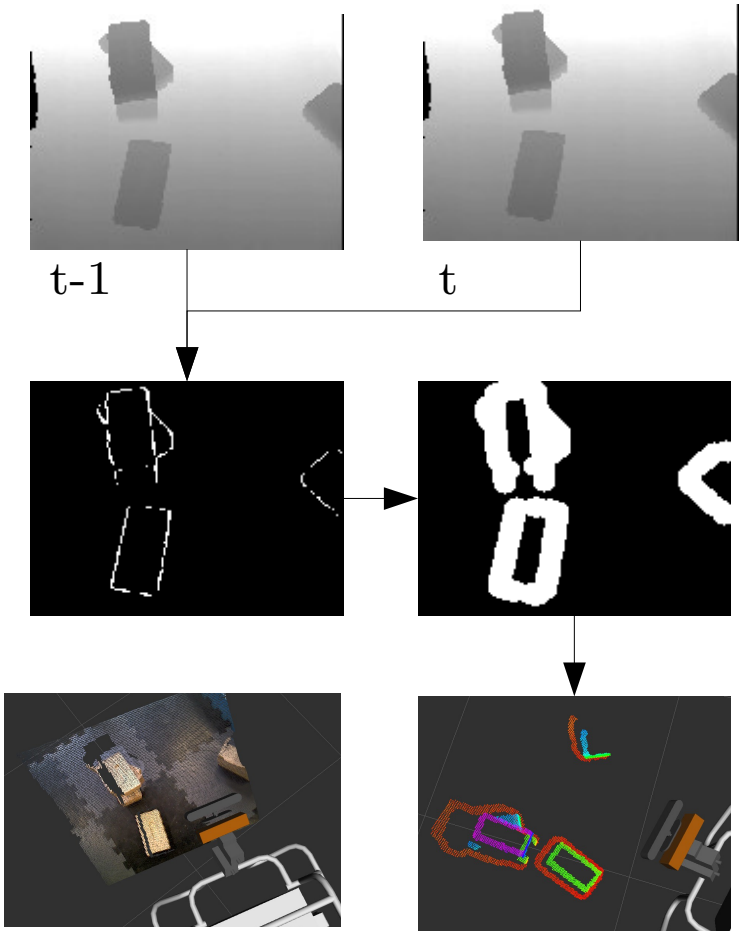


- Selective ICP: register only the points in motion, geometrically relevant
- Fuse with IMU

Real-time depth and inertial fusion for local slam on dynamic legged robots.
M. Camurri, S. Bazeille, C. Semini, and D. G. Caldwell
IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI), 2015

Selective ICP

- Frame-to-frame background subtraction
- Morphologic dilation
- Point cloud selection
- Iterative Closest Point (ICP) registration
- Black image (no edges)→ no motion



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Mapping

Robocentric Mapping

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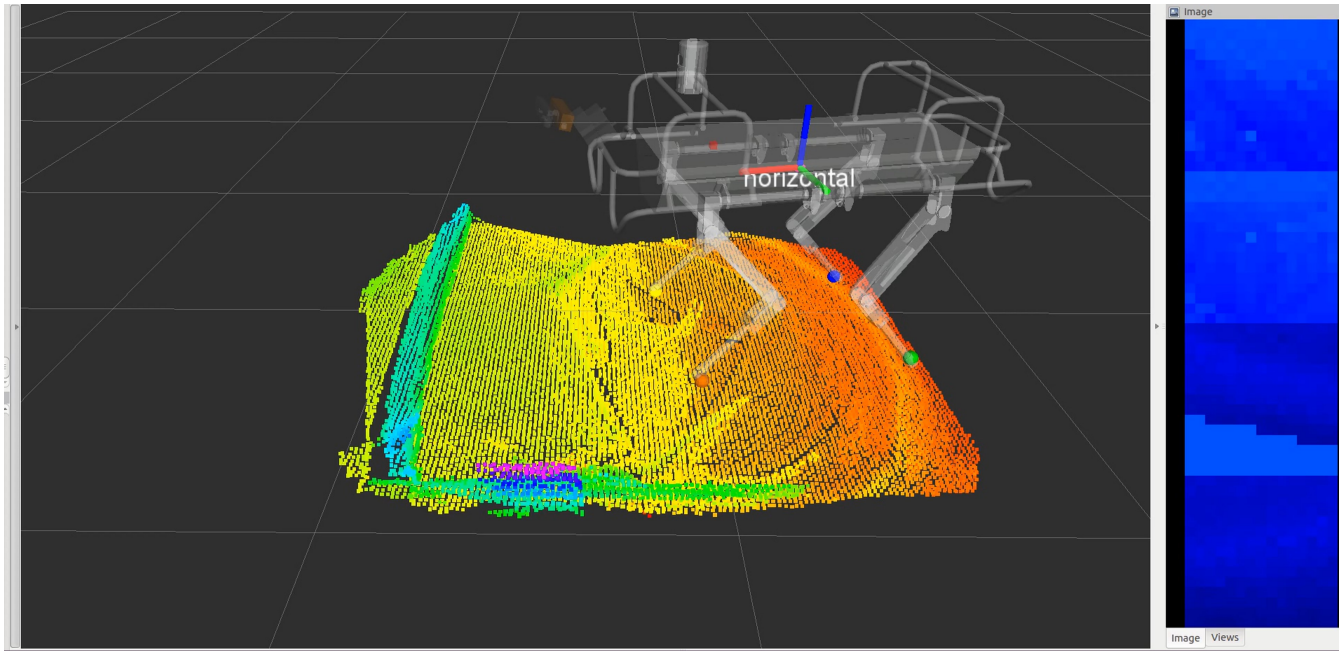
- Current sensed cloud is the most trustworthy
- Current map should accumulate drift backwards

$$M_n = M_{(n-1)} + {}_{(n-1)}T_n \cdot C_n$$

- Current map is the newest cloud plus previous map aligned to the current cloud
- Less accurate data is the oldest, and automatically discarded when out of scope

Real-time depth and inertial fusion for local slam on dynamic legged robots.
M. Camurri, S. Bazeille, C. Semini, and D. G. Caldwell
IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI), 2015

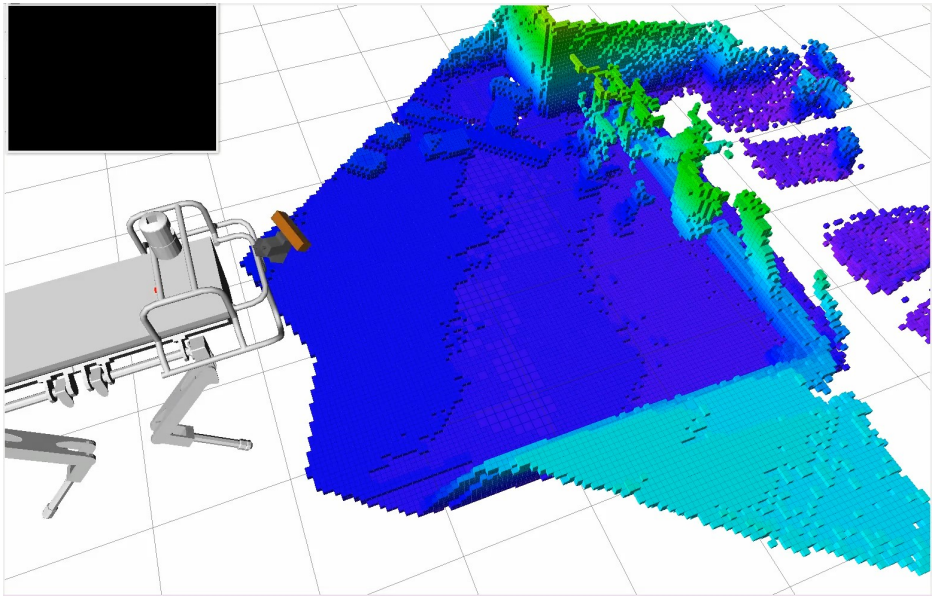
Visual Pattern Classification



- Local heightmap around target footholds
- Each heightmap is classified to select an offset correction on the touch down coordinate

Reactive trotting with foot placement corrections through visual pattern classification
V. Barasuol, M. Camurri, S. Bazeille, D. G. Caldwell and C. Semini
Intelligent Robots and Systems (IROS), 2015 IEEE/RSJ International Conference on, Hamburg, 2015

Octomap and planning



- Scan with PTU
- Scan Merging with Octomap
- Feature extraction
- Reward computation
- Planning from reward map

On-line and On-board Planning and Perception for Quadrupedal Locomotion
C. Mastalli, I. Havoutis, A. W. Winkler, D. G. Caldwell and C. Semini
IEEE International Conference on Technologies for Practical Robot Applications (TEPRA) 2015

Conclusions

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- State Estimation is crucial for robot control, mapping and planning
- Multiple sources help being robust against more scenarios
- Local mapping helps keeping uncertainty away from where you want to operate

The Dynamic Legged System Lab and friends:


Claudio Semini


Marco Frigerio


Victor Barasuol


Michele Focchi

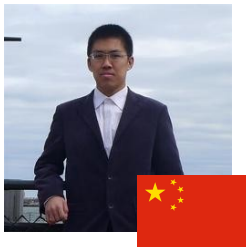

Romeo Orsolino


Andreea Radulescu


Alex Posatskiy

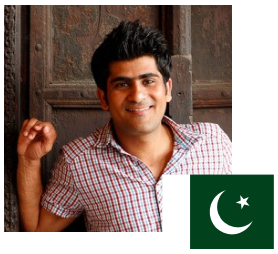

Jose Colmenares


Marco Camurri


Yifu Gao


Janne Koivumaki


Elco Heijmink


Bilal Ur Rehman


Carlos Mastalli


Roy Featherstone


Sep Driessen

Thanks for your attention!

Questions?

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