Urban Robotics Lab.

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Urban Robotics Lab
“IT & Robotics for smart cities”

**Robot Navigation**
- Vision / LiDAR / Magnetic field / RF-based 3D SLAM
- Low-cost self-driving
- Autonomous valet parking
- Mole-bot

**Structural Health Monitoring**
- 6-DoF SHM robot system
- CAROS (Climbing Aerial Robot System)
- FAROS (Fireproof Aerial Robot System)

**Environmental Robotics**
- JEROS (Jellyfish Elimination RObotic Swarm)
- Oil spill protection robot
- Green algae removal robot
AI & Robot Intelligence

- Autonomous robot navigation
  - Vision, LiDAR, Magnetic field-based SLAM (Simultaneous Localization And Mapping)
  - Indoor, Outdoor (Ground, Underwater, Underground, Aerial) SLAM

- Object recognition
  - UAV image-based jellyfish recognition, green algae recognition, underwater jellyfish recognition
  - Object recognition using low-resolution aerial images

- Human behavior recognition for HRI (Human Robot Interaction)
  - Human pose estimation
  - Sequence-based human behavior recognition

- Developed robot system in our lab
  - JEROS (Jellyfish removal robot), ARROS (Green algae removal robot)
  - CAROS, FAROS (Wall climbing drones)
Autonomous Robot Navigation
Core technologies of autonomous navigation

Mapping
• Feature map
• Grid map

Localization
• Localization
• Relocation

Integrated Approach
• Active SLAM

Exploration

Motion
• Path Planning
• Reactive Control

SLAM

(Source: Makarenko et al. '02)
KAIST’s technology

- Graph-based sensor fusion for dynamic and feature-poor environment
  - False constraints removal in dynamic environment (low + high dynamic)
  - SLAM performance improvement using low-cost sensor fusion
    - ex1) 2D LiDAR + 2D camera = 3D matching for robustness
    - ex2) Magnetic feature + 2D LiDAR = minimize planar localization error
GP-SLAM for low-dynamic environment

- **Grouping nodes**
  - Normalized covariance values of the odometry edges.
  - Error metric (average Mahalanobis distances of the edges) based on the grouped nodes.

- **Pruning false constraints**
  - Edges btw. groups 2 & 6 can be pruned
  - Result obtained after grouping the nodes
  - Optimized trajectory after pruning false constraints
GP-SLAM for low-dynamic environment

Mobile robot system with a RGB-D sensor and a marker for measuring the ground truth position.

(a) Camera installed on the ceiling. (b) Global positioning result is displayed. A 3-DOF robot pose is obtained.

SLAM in dynamic environment (LiDAR sensor)

- Real-time recognition of high dynamic (human) and low dynamic objects
- Graph-based SLAM using 3D feature matching & LRF scan matching
- Tested on KAIST Geocentrifuge center building (10 × 10m) with 2 low dynamic and 5 high dynamic objects
3D SLAM for autonomous driving

Stereo camera + GPS + Odometry = 3D point cloud map
Robust localization for autonomous driving


Velodyne, GPS, IMU, and wheel odometry

Mean error ≤ 0.1 m
3D SLAM using a tilted 2D LiDAR sensor

- 3D localization and mapping (SLAM) using a tilted 2D LiDAR sensor
- Improving accuracy through hierarchical graph optimization
3D SLAM using a tilted 2D LiDAR sensor
3D SLAM using a tilted 2D LiDAR sensor
Earth’s magnetic field-based SLAM

Motivation

- Feature-poor (Vision/LiDAR) environment
- Anomaly of earth’s magnetic field (20~80 μT) is used as features

<3-axis magnetic field distribution>
Magnetic sequence-based graph SLAM

- Cyan: reference (SICK Gmapping)
- Magenta: wheel odometry
- Blue: optimized pose graph

Mole-bot
Directional drilling for shale gas extraction requires:

- Underground localization
- RSS (Rotary Steerable System) mechanism
- Control algorithm

Source: Katie Mazerov, “New directional drilling system combines improved mud motor, MWD technologies”, Drilling Contractor (2011), Halliburton Hompage
Mole-bot

As-is

To-be

Underground comm. & monitoring system

• Embedded directional drilling
• Underground localization
Mole-bot

Digging mechanism

Source: NY Times ([https://youtu.be/toARdZKs-IE](https://youtu.be/toARdZKs-IE))
Mole-bot

Front part

- Forelimbs
- Cone type drill bit

Rear part

- Locking
- Direction & Shrinkage
- Locomotion
Mole-bot

Forward drilling

Directional drilling

x15

x10
The magnetic sensor can measure similar features again
Designed for loop closing at both direction movement
Underground localization using Graph SLAM

Results

Comparison of RMSE

<table>
<thead>
<tr>
<th></th>
<th>Position</th>
<th>Orientation</th>
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<tbody>
<tr>
<td>Dead reckoning</td>
<td>77.8cm</td>
<td>10.2°</td>
</tr>
<tr>
<td>Proposed algorithm [1]</td>
<td>12.5cm</td>
<td>84.0%↓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.4° 76.5%↓</td>
</tr>
</tbody>
</table>

Structural Health Monitoring
SLAM in aerial environment

- Bridge inspection using UAVs
UAV SLAM Framework

GPS + Camera + IMU + 3D LiDAR

- GPS
- Camera + IMU
- 3D LiDAR
- Normal Distribution Transform
- Generalized ICP with voxels
- Visual Inertial Odometry

Node generation

Constraint

Graph optimization

Pose estimation

3D point cloud
NDT
3D point cloud (2.6s/frame)
Voxel of 3D point cloud (0.7s/frame)

Pose (only if it is available)

pose

node

pose

node
UAV SLAM

Downward camera

Upward camera

Playback speed x3
CAROS: Wall-climbing drone (robust to wind)
Tilt-rotor-based low-impact perching

- Significant decrease of impact in perching
Applications of a wall-climbing drone

FAROS (MBC News, Apr. 2016)
Environmental Robotics
JEROS (Jellyfish Elimination RObotic Swarm)

**PROBLEM**
- Damage by jellyfish in South Korea: over 300M USD/year (fishery: 230M, power plants: 70M)

**DEVELOPMENT**
- USV (unmanned surface vehicle) + Jellyfish shredding device
- Autonomous navigation
- Formation control: leader-follower
- Vision-based jellyfish detection & distribution recognition
- Jellyfish removal performance: 216 kg/hour
Jellyfish distribution recognition

Jellyfish images using drones
- Coverage path planning
- ASV launching and docking

Jellyfish images

Jellyfish distribution recognition
- Deep learning
- GPS/IMU aided image-based localization

Localized Jellyfish distribution

Jellyfish removal

JEROS formation control

ASV launching and docking
Jellyfish distribution recognition using DNN

<table>
<thead>
<tr>
<th>Proposed network</th>
<th>LeNet-5</th>
<th>AlexNet</th>
<th>GoogLeNet</th>
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<tbody>
<tr>
<td>Accuracy [%]</td>
<td>94.06</td>
<td>95.11</td>
<td>95.60</td>
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<tr>
<td>Average frame rate [Hz]</td>
<td>8.23</td>
<td>4.89</td>
<td>0.01</td>
</tr>
</tbody>
</table>

ARROS (Algal bloom Removal RObot System)

Thanks!

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