Aalto University
School of Electrical
Engineering

Coverage Path Planning

Wide Area Coverage!!

Dr. Kshitij Tiwari

Dept. of Electrical Engineering and Automation
kshitij.tiwari@aalto.fi

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Overview

Motivation

Intuition

Coverage Path Planning (CPP)

- Travelling Salesman
- Lawnmower
- Piano Mover
- Art Gallery
- Watchman Route
- Orienteering
- Random Exploration
- Frontier-based Exploration
- Adaptive Voronoi Exploration

Challenges

Summary

Readings

Motivation

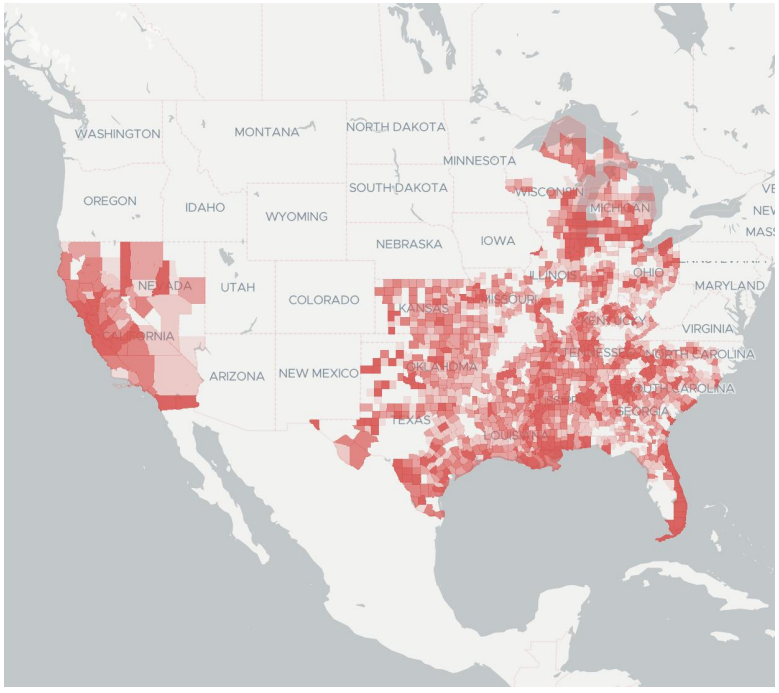
- Definition of a robot ✓
- Robot positioning (Localization) ✓
- Path planning
  - Graph-based ✓
  - Information-based ✓
  - Area-Coverage . . .

Applications:

- Area surveillance
  - Forest, disaster site, *etc.*
- Patrolling
  - Event crowd, enemy territory, *etc.*

Let's get to business!!!

Intuition



- AT&T Internet Availability Map.[1]
- To be a monopoly, tap maximal regions asap.
- Higher Coverage $\rightarrow$ lower competition.

Intuition (cont.)

In a robotic setting:

- Operation environment $\rightarrow$ unknown.
- Unknown $\propto$ Risk.
- Minimize risk by acquiring maximal observations until mission termination.

[1] Image taken from https://broadbandnow.com/ATT

Coverage Path Planning (CPP)-Travelling Salesman

Mission:

- Maximize Sales $\rightarrow$ visit ***all*** locations.
- ***Shortest*** possible route.

Coverage Path Planning (CPP)-Travelling Salesman (cont.)

Figure: 8 cities across USA[2] for selling a product. Salesman has 5040 possible ways of covering these cities.

Coverage Path Planning (CPP)-Travelling Salesman (cont.)

Possible route selection strategies:

- **Greedy:**
  - Choose next closest city.
  - Produces sub-optimal routes.

Coverage Path Planning (CPP)-Travelling Salesman (cont.)

- 2 **Opt Swap:**
  - Prevents route cross-overs
  - Select 2 edges and reconnect to form new paths

Methods for selecting edges for swapping:

Coverage Path Planning (CPP)-Travelling Salesman (cont.)

- ◇ *Local Search:*
  - Start with a random route.
  - Select arbitrary pair of edges.
  - If swapping reduces path length, retain and repeat.

Coverage Path Planning (CPP)-Travelling Salesman (cont.)

- Suffers from local minima

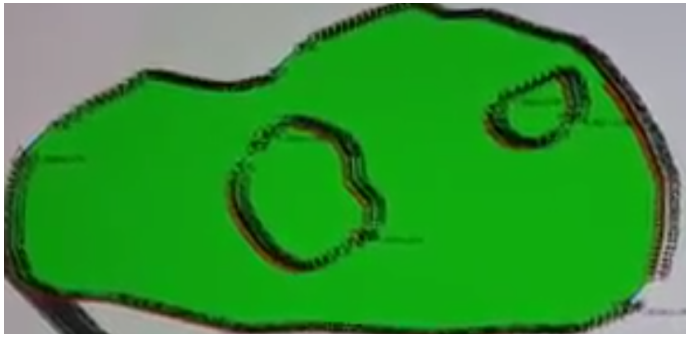
Coverage Path Planning (CPP)-Travelling Salesman (cont.)

- ◇ *Simulated Annealing:*
  - Probabilistically accept worse solutions early on.
  - Define temperature $\propto$ affinity for "bad" solution.
  - ▶ Hot $\rightarrow$ Accept Bad Solutions
  - ▶ Cold $\rightarrow$ Reject
  - ▶ Start with Hot

[2] Image from https://www.youtube.com/watch?v=SC5CX8drAtU

Coverage Path Planning (CPP)-Lawnmower

Mission:



- Lawn with 2 static stones[3].
- Mow ***whole*** lawn.
- Avoid ***static*** obstacles.

Coverage Path Planning (CPP)-Lawnmower (cont.)

Figure: Showcasing the progress of Lawn Mower algorithm. **N.B.:** Notice the exhaustive nature of this approach.

[3]Taken from https://www.youtube.com/watch?v=c_8d5sY455o

Coverage Path Planning (CPP)-Piano Mover

Mission:

- Move piano from shop to buyer's house
- Find ***shortest*** path through city

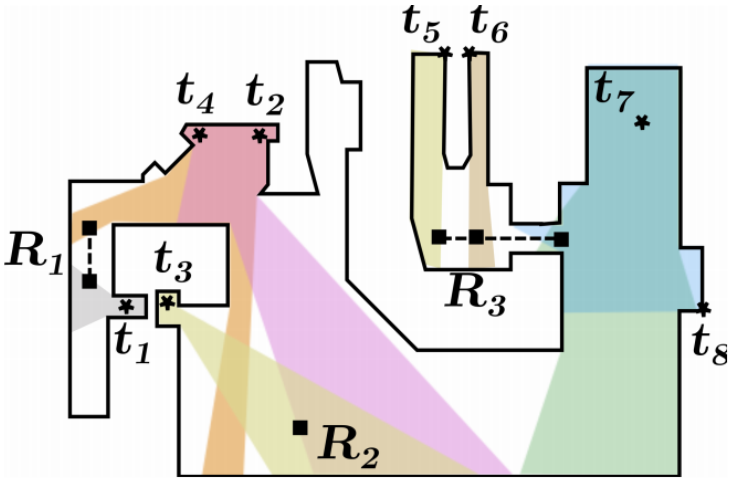
Coverage Path Planning (CPP)-Art Gallery

Mission:

- Art gallery with expensive exhibits
- Hire security personnel to monitor gallery at all times
- *How many guards are enough to patrol a gallery with n walls?*

Coverage Path Planning (CPP)-Watchman Route

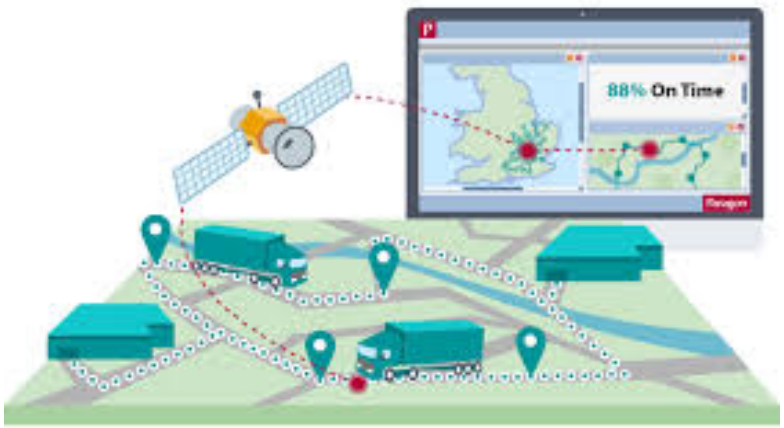
Mission:



- Consider a set of target points (denoted by $\star$) in a polygonal environment as shown.
- The objective of the watchmen denoted by $R_1, \ldots, R_3$ is to find paths (denoted by $- - -$) such that each target $(\star)$ is seen from at least one viewpoint $(\blacksquare)$.
- In this setup, watchman R_1 can observe t_1 and t_2, R_2 can monitor t_3 and t_4 while R_3 can see $t_5 - t_8$.

Coverage Path Planning (CPP)-Orienteering

Mission:



- Given a start, goal and set of intermediate nodes like a truck with depots[4].
- Find a subset of nodes:
  - Maximize net reward
  - Remain within time budget
    - *E.g.,* imagine delivering dairy products which perish as time passes
- Well known for vehicle routing problems

[4] Image from http://tinyurl.com/yxhn9o53

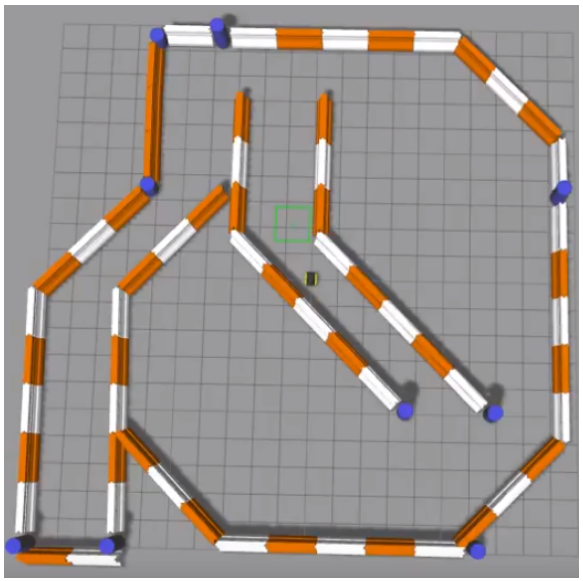
Coverage Path Planning (CPP)-Random Exploration

Mission:

- Pick a direction as per whim
- Rinse-and-repeat

Coverage Path Planning (CPP)-Frontier-based Exploration

Mission:

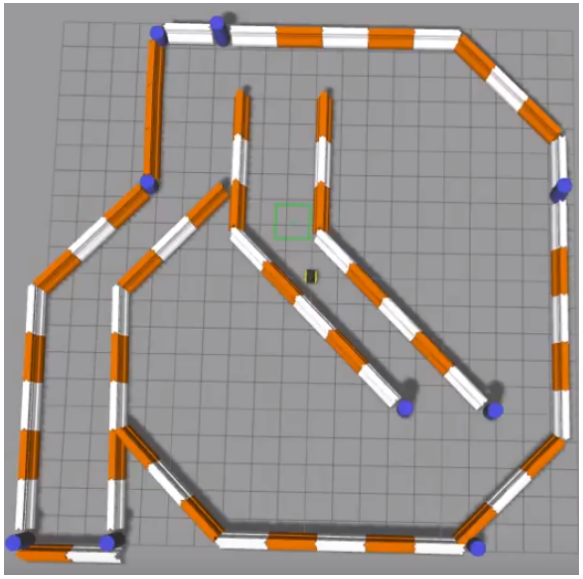


- Identify the frontier
  - Barrier between *known* and *unknown*
  - Function of sensing range
- Move to a candidate on frontier
- Rinse-and-repeat until all area is observed.

Coverage Path Planning (CPP)-Frontier-based Exploration (cont.)

Figure: Illustration of frontier-based expansion of civilization in a strategy game[5].

Coverage Path Planning (CPP)-Frontier-based Exploration (cont.)



- *Grey:* Unobserved region; *White:* Observed region; *Blue:* Frontier
- Expansion using laser scanning

[5] Image from http://www.indieretronews.com/2015/03/freeciv-open-source-inspired.html

Coverage Path Planning (CPP)-Adaptive Voronoi Exploration

Primer on Voronoi Tesselation:

- Encodes proximity information between object pairs
  - Each object is called a *site*
  - Set of pts. in ND that are closer to each site than to any other site form a *Voronoi Cell*
  - Convex hull of all cells gives a *Voronoi Diagram*.

Coverage Path Planning (CPP)-Adaptive Voronoi Exploration (cont.)

Mission:

- Generate Voronoi tesselation
- adapt Voronoi cells to faulty hardware[6]
  - Robot 1 has a faulty actuator. Note how its voronoi cell shrinks.

[6] Presented in https://www.youtube.com/watch?v=qyYt3frZ7aw

Coverage Path Planning (CPP)-Challenges

- These methods are exhaustive in nature
- Computationally challenging as size of area increases
- Hard to define an optimal termination condition
  - Robot resources vs exhaustivity

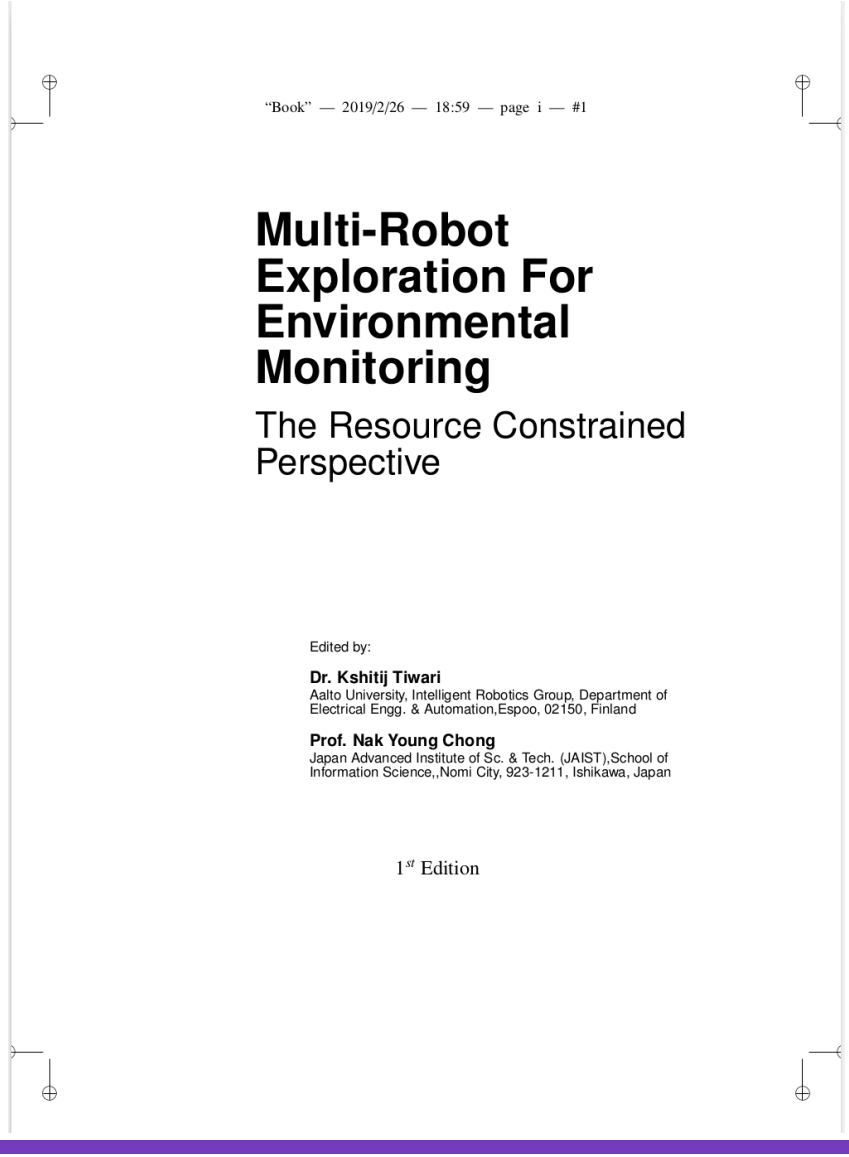
Summary

Over the span of last 2 days:

- Presented Graph-based path planning
  - Best-first search
  - Sampling-based search
- Brief intro to Informative path planning
- Per request, presented Coverage path planning
- All these 3 classes cover vast majority of well-known planners

You have a path, can you execute it?

Books



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Multi-Robot Exploration For Environmental Monitoring

The Resource Constrained Perspective

Edited by:

Dr. Kshitij Tiwari
Aalto University, Intelligent Robotics Group, Department of Electrical Engg. & Automation,Espoo, 02150, Finland

Prof. Nak Young Chong
Japan Advanced Institute of Sc. & Tech. (JAIST),School of Information Science,,Nomi City, 923-1211, Ishikawa, Japan

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Thank You!!