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A Robotic Mobile Sensor Network for Achieving Scientific Measurements in Challenging Environments

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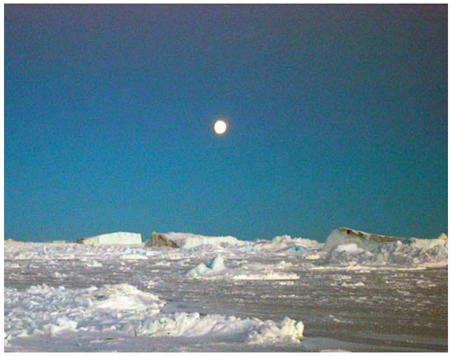
Motivation

- Weather data from glacial regions is considered important and valuable to global climate change.
  - Must be measured at surface.
- Human expeditions can be sent to collect this data.
  - Short duration, limited area, slow and dangerous.
- Fixed weather stations.
  - Continuous data feed. But low spatial resolution.
- Our proposed solution => Mobile robotic sensor network.
  - Dense data around an area of choosing (dynamic resolution)
  - Safe for the scientists.

Scientist

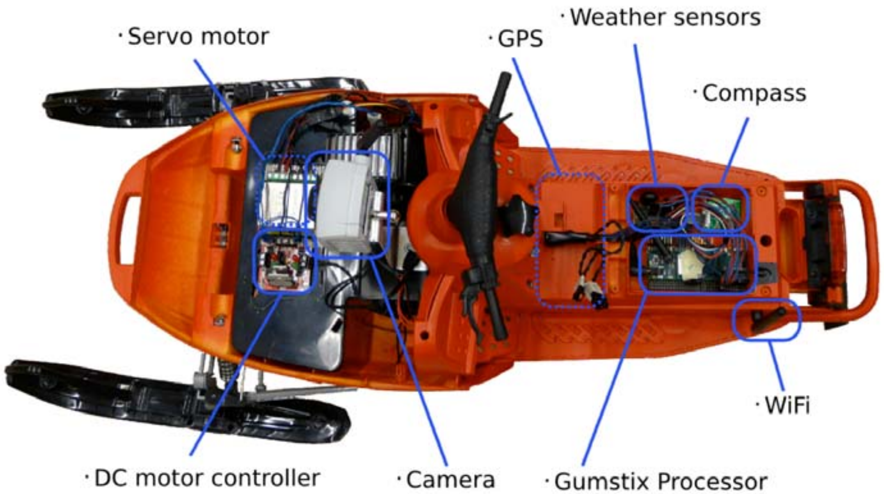
Project Overview

- Deploy robotic devices to move (or function as) sensor devices in Antarctica
- Key Components
  - Robotic Deployment
    - Robot and Science Instrument Platform
    - Mobility in Hazardous Environments
    - Operation at Test Site - Analogous and Actual
  - Scientist-Robot Collaboration
    - How, when, and what to communicate (transmit/receive data)
    - How to specify science formations to robot team
    - How and when to ask for help from scientist
  - Multi-Robot Formation Control
    - Formation Initialization
    - Formation Reconfiguration
    - Formation Keeping/Maneuvering



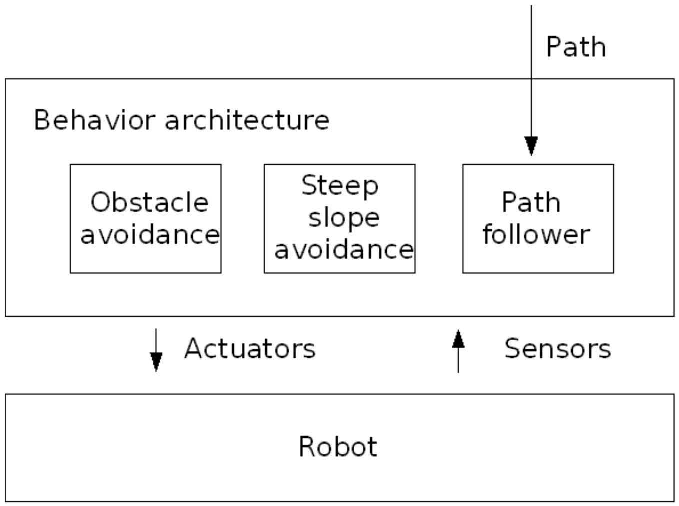
Robot Platform

- RC snowmobile chassis.
- Linux computer.
  - Wireless communications.
  - I2C communications with microcontroller for low level control.
- DC drive motor.
- GPS unit.
- Color camera.
- Weather sensors suit.



Navigation scheme

- Based on behaviors.
  - Path follower.
  - Obstacle avoidance.
  - Steep slope avoidance.
    - Slope estimation
    - Navigation controller.

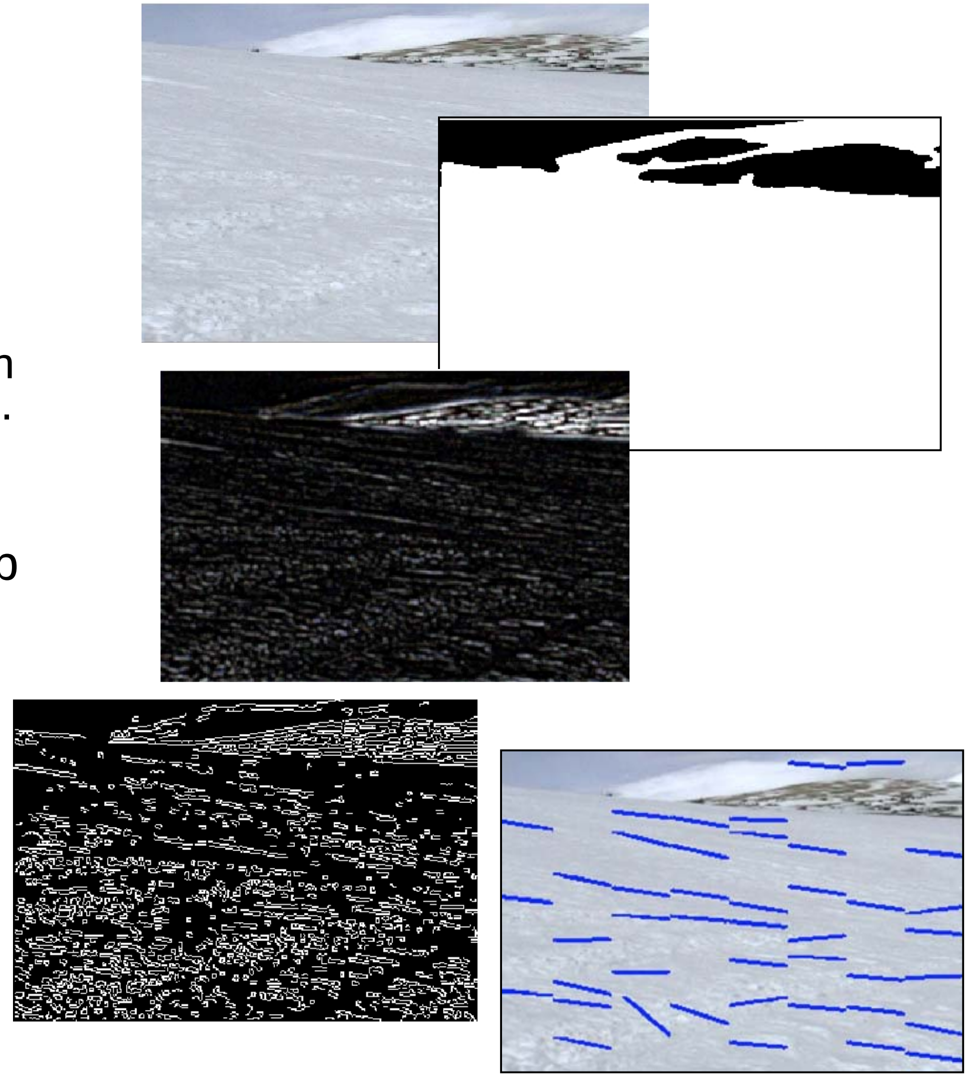


Slope estimation

- Visual clues.
  - Humans can estimate slope from a single image.
  - High winds sculpt the snow surface into dune-like formations.
  - Vertical cracks called crevasses.
  - Mountain peaks present obstacles.

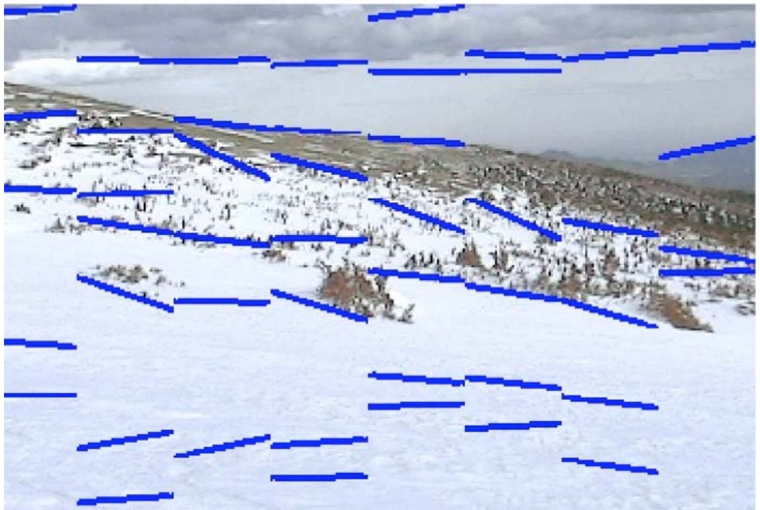
Slope estimation

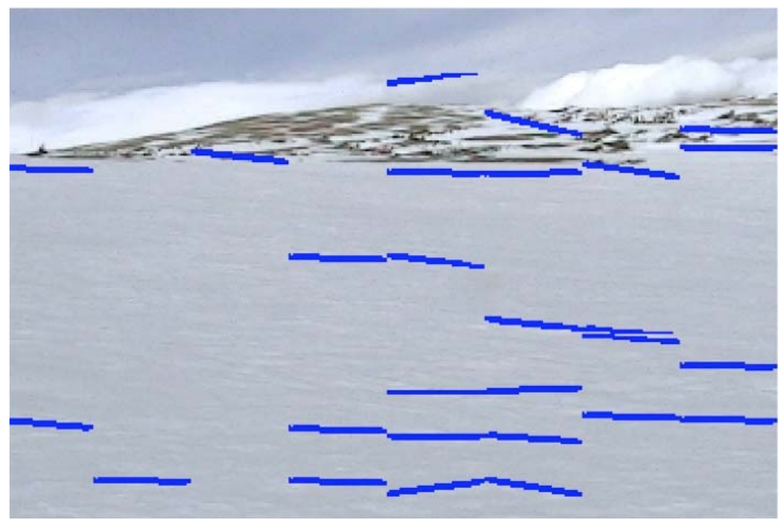
- Algorithm
  - Adaptive histogram threshold.
  - Texture extraction.
    - A bandpass filter is applied to isolate the surface texture.
    - A Canny Edge Detector is then used to create a binary image.
  - Slope estimate is obtained by fitting a line to the texture map
    - Employs Hough transform to select the “strongest” line in an image region.



- Questions to Stephen Williams (swilliams8@gatech.edu)

Real Image Results





Slope navigation controller

- Fuzzy Logic controller selected for robust performance in the face of measurement error.

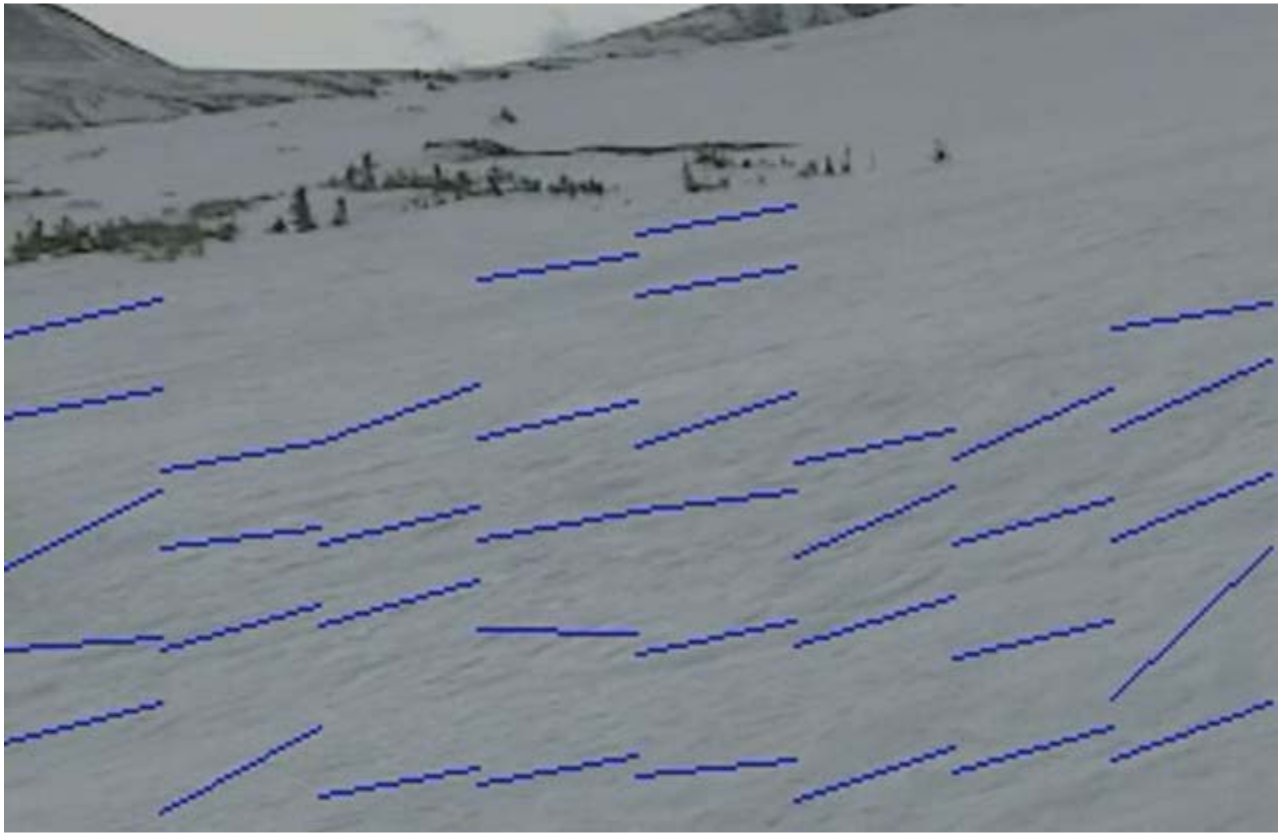
- Goal is to maintain the rover on level ground using only the slope estimates.

- Slope estimates converted into linguistic set.
  - 0º-5º => not steep slope.
  - 5º-15º => medium steep slope.

- Heuristic navigation rules created by observing a human driver.

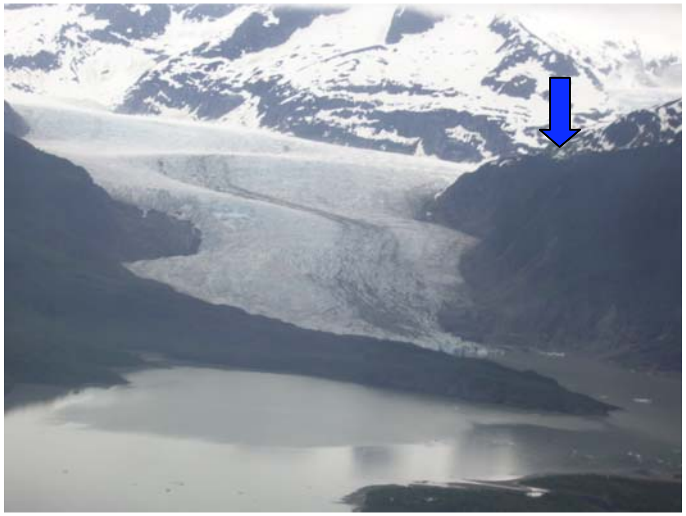
Steep slope avoidance behavior

- Video.



Field experiments

- We went to Juneau (Alaska) two weeks ago.
  - Thanks to Matt Heavner (University of Alaska Southeast).
- Navigation and vision algorithm were tested.

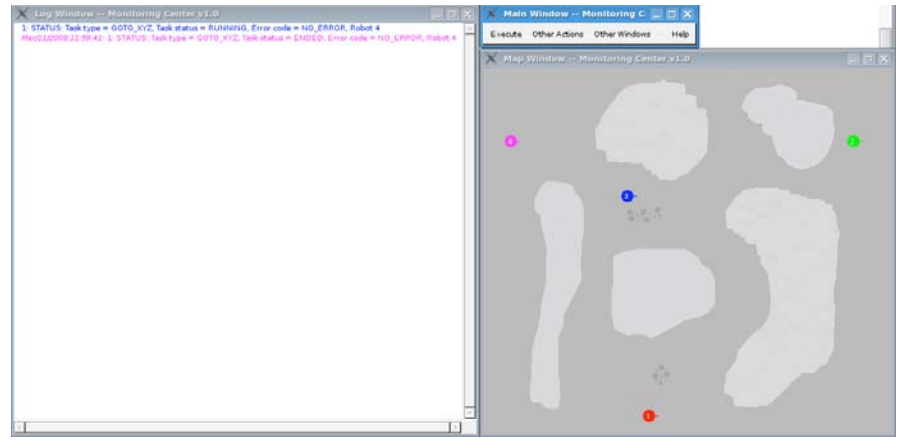


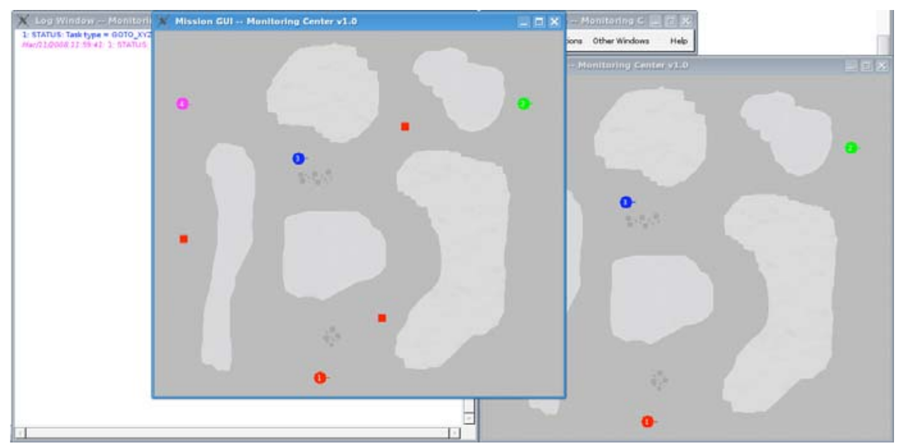
Field experiments

- Video.

Scientist interface

- Simple GUI to allow scientists to specify desired sensor locations.
- Main window:
  - Aerial view of the area.
    - Current location of robots.
    - Specified positions to get measurements from.
- Log window:
  - Current state of each task.
  - Weather related data.
  - Log with timestamp.
- Specification of tasks:
  - Graphically.
  - Script files.

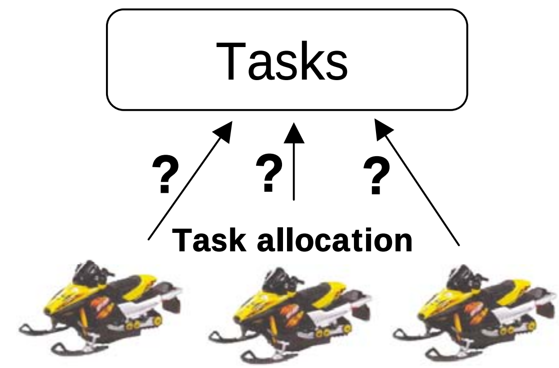




Multi-robot coordination

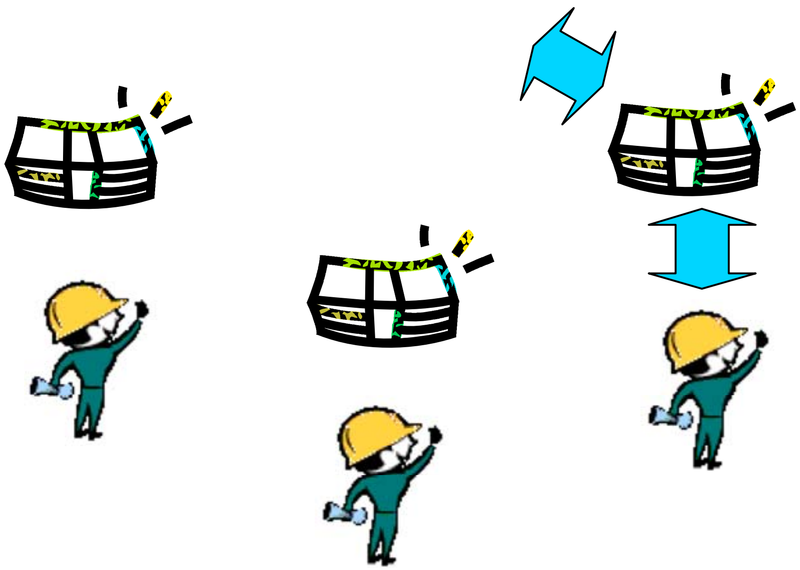
- The desired locations must be allocated to the different robots.

- Initial Formation Problem:
  - Given a number of tasks and a team of robots, and a cost function, find the assignment that allocates one task per robot and tries to minimize the global cost (sum of all the executed tasks).



Market-based algorithm

- Based on two roles:
  - Auctioneer:
    - Announce the tasks.
    - Select the best bid.
  - Bidder:
    - Send a bid for each announced task.
- Played dynamically by the different robots.
- Algorithm:
  - Auctioneer announces a task.
  - Bidders send their bids.
  - The task is allocated to the robot with the best bid.
  - If a robot wins more than one task, it keeps the one with the lowest cost and re-announces the other one.

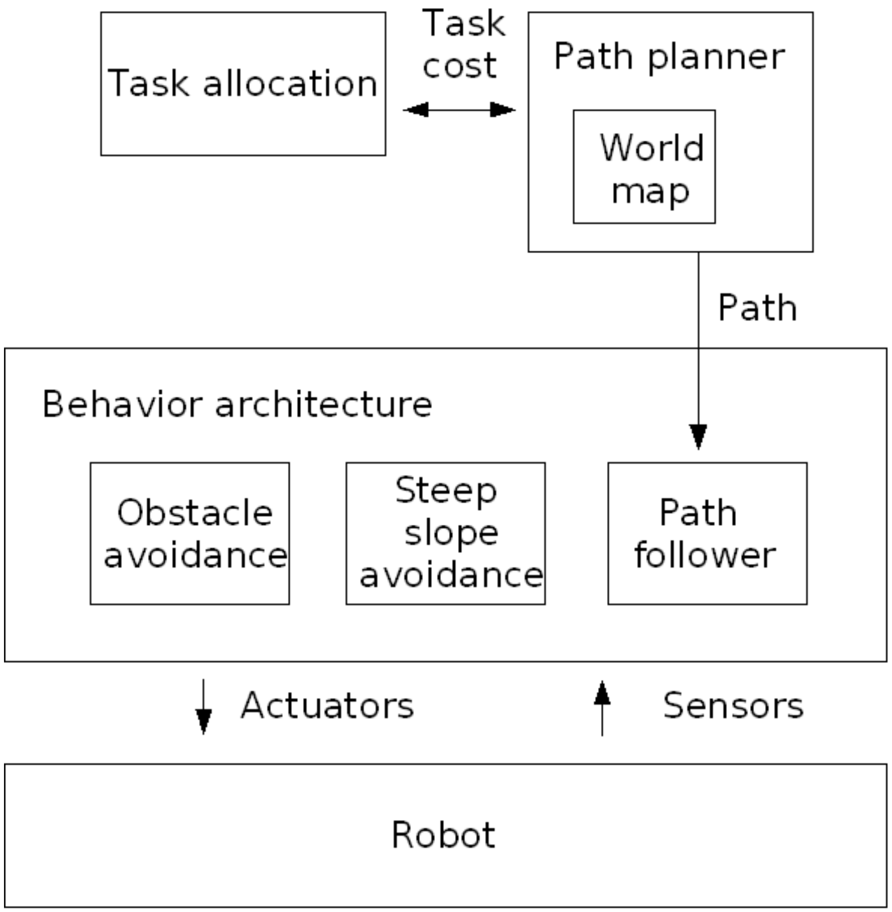


Multi-robot coordination

- Market-based algorithm
  - Efficiency: try to obtain solutions as close as possible to the optimal one.
- Distributed:
  - Fault tolerance: no single point of failure.
  - Fast response to dynamic environments.
  - Low computational complexity.

Integration task allocation within a robotic system

- Cost calculation using path planning.
- Use of a map to specify non-navigable areas.
- Task allocation can ask for the cost of the same task several times.
  - Path and cost is saved to reduce computation power and calculation time.
- Task execution: path follower receives the path from path planner.

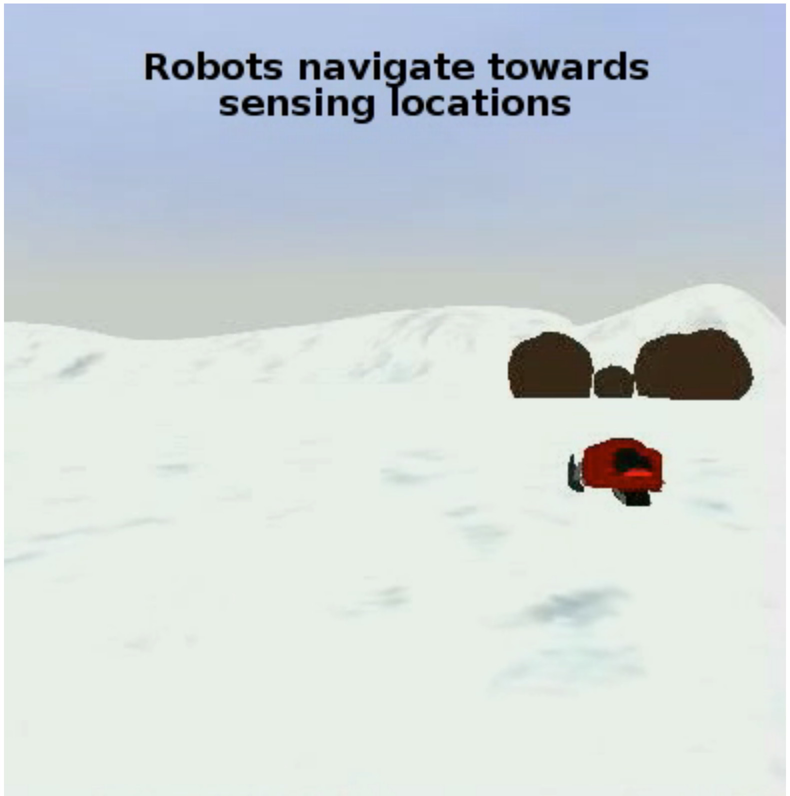


Simulation environment

- Expeditions to the Arctic are time consuming and expensive.
- Having a realistic simulator to test is beneficial.
- Based on Player/Gazebo open source suite.
  - Used to test slope estimator.
  - Navigation and coordination of multiple robots.

Integrated simulation

- Video.



Conclusions

- Robotic sensor networks should be considered as a viable, alternative data collection methodology.
  - Mitigate the cost, effort and danger of human presence.

- We have presented solutions for some of the main technological challenges for autonomous robotic sensor networks.
  - Robust arctic locomotion.
  - Navigation architecture for arctic environments.
  - Distributed task allocation method.
  - Scientist interface.

Thank for your attention!

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