Crowdsourcing Arctic Navigation

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(Adapted from Wikimedia Commons)
Introduction

- Summer Arctic sea ice extent has decreased by more than 50% since 1980.
- There is estimated to be a large amount of untapped natural resources in the Arctic, particularly oil (13% of the world’s undiscovered reserves) and gas (30%).
- Many motivators such as tourism, fishing, resource exploration/exploitation, and shipping are attracting operations in the Arctic; our aim is that it is done safely to avoid loss of life and environmental disasters.
- Arctic navigation at sea is plagued by many obstacles such as:
  - Poor sea chart quality
  - GNSS and other navigational aid challenges
  - **Sea ice hazards**
Summer Sea Ice

>2 Collisions / Year

1/6 Ships Lost / Collision
**New Ice/Nilas**
- <10 cm thick
- Not a danger to ships

**Young Ice**
- 10 to 30 cm thick
- Potential hazard to non-strengthened ships

**First-Year Ice**
- 30 cm to 2 m
- Hazard to non-strengthened ships

**Multi-Year Ice**
- 2m to 4m thick
- Usually covered by thick First-Year Ice
- Polar Class ship for sustained operation

**Glacial Ice**
- Anywhere from <1m to 5m+
- Danger to all ships
Current Detection Method Breakdown

Figure 9. Breakdown of Icebergs by detection method.

Proposed System

Ship Based Monitoring

Path Planning

Ship to Ship Aiding

Safety Level
40 km

AQUA/TERRA Satellite Imagery
What is the path of safest approach?
Google driving to be driverless

Google’s modified Toyota Prius uses an array of sensors to navigate public roads without a human driver. Other components, not shown, include a GPS receiver and an inertial motion sensor.

Laser-guided mapping
A rotating sensor with lasers called a LIDAR on the roof scans more than 200 feet in all directions to generate a precise three-dimensional map of the car’s surroundings.

Video camera
A camera mounted near the rear-view mirror detects traffic lights and helps the car’s onboard computers recognize moving obstacles—such as pedestrians and bicyclists.

Position estimator
A sensor mounted on the left rear wheel measures small movements made by the car and helps to accurately locate its position on the map.

Radar
Four standard automotive radar sensors, three in front and one in the rear, help determine the positions of distant objects.

Source: Google

NEW YORK TIMES; PHOTOGRAPHS BY RAMI RAHIMIAN FOR THE NEW YORK TIMES
Multi-Frequency System


http://www2.hawaii.edu/~jmaurer/albedo/
Multispectral Sensing

Radar | Lidar | Image Processing | GNSS

Ship Based Monitoring

Ship to Ship Aiding

Path Planning

Safety Level
Reflectance

Finding Patterns

- *k*-Means Clustering is a Machine learning algorithm used for finding patterns (clusters) in large data sets.
- Cluster points based on similar reflectance.
Classification Results

FRESH SNOW
OLD SNOW
OLDER SNOW
FIRN
ICE
GLACIER (DIRTY)
REFREEZING ICE
OLDER SNOW
OLD SNOW
FRESH SNOW

200m
Crowd Sourcing

- Radar
- Lidar
- Image Processing
- GNSS

Ship Based Monitoring

Ship to Ship Aiding

Path Planning

Safety Level
What is the path of safest approach?
Maximizing the cumulative reward can be used to find the optimal set of actions to achieve a final desired state.
Markov Decision Process (MDP) Example

States

Actions

Rewards

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>+100</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>-50</td>
</tr>
</tbody>
</table>

Start State

Desired State

N

-3

E

W

S
Value Function

Want to maximize the total cumulative reward along the selected path.
Use greedy algorithm to find the path.
What is the path of safest approach?
Conclusion

- This system could offer improvements in ice classification by making use of advancements in sensing technology found in autonomous vehicles.

- Need to crowd source the information and tie it together with GNSS to achieve ship to ship consistency. This allows ships to plan paths far ahead of their current position safely and economically.

- Our ultimate if to offer safer ice navigation in the hopes of preventing catastrophic accidents in the future.
Acknowledgements

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Lidar Data:

- **David Finnegan**, Environmental Research Scientist at the Cold Regions Research and Engineering Lab (CRREL) of the USACE

- **Gordon Hamilton**, Assoc. Professor at the Climate Change Institute and School of Earth and Climate Scientists at the University of Maine

- **Leigh Stearns**, Assistant Professor, Department of Geology at the University of Kansas.

Ship Collision Database:

References (1)

References (2)

Back Up Slides
Radar Introduced, Reduction in Collisions With Large Icebergs

*Based on data from Dr. Brian T. Hill of the National Research Council of Canada*
Bergy bits & Growlers

<table>
<thead>
<tr>
<th>Description</th>
<th>Height Above Sea-Level [m]</th>
<th>Relative Size</th>
<th>Mass [tonnes]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iceberg</td>
<td>&gt; 5</td>
<td>Merchant Ship</td>
<td>&gt; 180,000</td>
</tr>
<tr>
<td>Bergy Bit</td>
<td>1 – 5</td>
<td>Small House</td>
<td>&gt; 5,400</td>
</tr>
<tr>
<td>Growler</td>
<td>&lt; 1</td>
<td>Grand Piano</td>
<td>&gt; 120</td>
</tr>
</tbody>
</table>

Shipping Routes

Northern Sea Route
13,800 km

Suez Canal
21,200 km

Source: Wikimedia Commons
Total Ship Traffic in The Canadian Arctic

Ship Collision Breakdown by Ice Type
1980-2011

*Based on data from Dr. Brian T. Hill of the National Research Council of Canada
Ice Collision Breakdown by Latitude
1980-2011

*Based on data from Dr. Brian T. Hill of the National Research Council of Canada*
Location of Ice Collisions
1980-2011

*Based on data from Dr. Brian T. Hill of the National Research Council of Canada
Collisions

<table>
<thead>
<tr>
<th>Collision Rate*</th>
<th>&gt; 2 Collisions Per Year</th>
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<tbody>
<tr>
<td>Likelihood of Ship Being Lost*</td>
<td>1/6</td>
</tr>
<tr>
<td>Probability of Collision**</td>
<td>1/2000</td>
</tr>
<tr>
<td>Probability of Ship Being Lost</td>
<td>1/10,000</td>
</tr>
</tbody>
</table>

* Based on data from 1980-2011
**Based on cargo shipping data over the Grand Banks to and from US and Canadian Ports on the east coast. (B. Hill, "Ship Collisions with Iceberg Database. Report to PERD: Trends and analysis," TR-2005-17, 2005.)
Ice Patrol Coverage

Typical Report
Figure 7: NAIS Iceberg Limit (left panel) and excerpt from MiFC LANT Analysis for 14-16 May 2012 (right panel).
Iceberg Report Breakdown

<table>
<thead>
<tr>
<th>Season</th>
<th>Summer/Autumn</th>
<th>Year Round</th>
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<tbody>
<tr>
<td>Ice Type</td>
<td>First-Year</td>
<td>Second-Year</td>
</tr>
<tr>
<td>Min Ice</td>
<td>0.15 m</td>
<td>0.25 m</td>
</tr>
<tr>
<td>Polar Class</td>
<td>PC 7</td>
<td>PC 6</td>
</tr>
<tr>
<td>Baltic Class</td>
<td>IC</td>
<td>IB</td>
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</table>

### Icebreaker Examples

- **AHTS Balder Viking** (2000) PC 7  
  83 m, 13 MW, 6ktonnes

- **CCGS-Henry Larsen** (1987-) PC 4/5  
  100 m, 12 MW, 6ktonnes

- **Sevmorput** (1988-) PC 6  
  260 m, 30 MW (N), 62ktonnes

- **MS Norilskiy Nickel** (2006-) PC 4/5  
  170 m, 13 MW, 30ktonnes

- **NS 50 Let Pobedy** (2007-) PC 1  
  160 m, 55 MW (N), 26ktonnes

- **USCGC Polar Star** (1976-2011) PC 2  
  122 m, 56 MW, 13ktonnes
Data Collection Location

Helheim Glacier