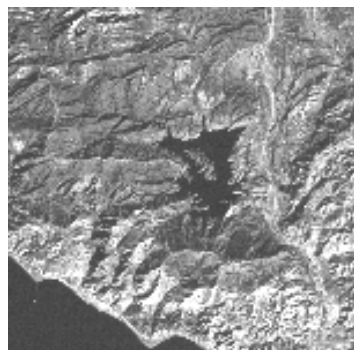


Dynamic Image Registration for Elevation Map Fusion



Sponsor

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Some Background: what we want to do with the technology

Testbed : Alice

Background

Alice is equipped with a number of sensors, of particular interest are the

- Ladar
- Stereo vision

which are used to create an elevation map of the terrain around the vehicle.

Each sensor creates a separate Digital Elevation Map (DEM) from its range measurements.

Data from these multiple sensors is fused into a single cost (or speed) map for the path-planning algorithm.



Problem

- As the vehicle moves across the terrain, the sensors (eg. stereo cameras) may get misaligned, making the original calibration invalid. Thus errors are introduced in the elevation maps, such as specific locations of obstacles, etc.

Proposed Approach

- To apply image registration techniques to correct for errors in this dynamic environment.

Note: what ALICE sees as the “environment” is completely sensor dependant—in other words, no filtering is taking place. Recent work (Lars Cremean) has recast this problem as an estimation problem (remember for later)

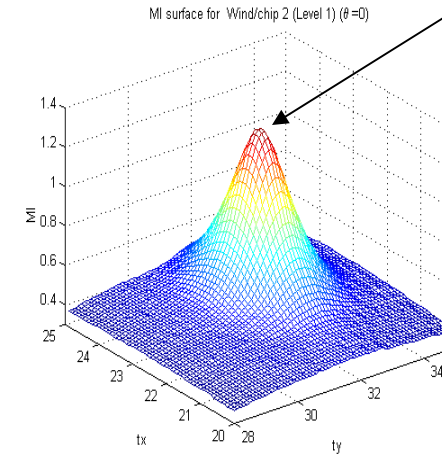
More Background: Information Theory

Underlying technology: Image Registration using Mutual Information (MI)

For two images A and B the Mutual Information, $I(A,B)$ can be computed from their joint histogram, $h_{AB}(a,b)$ by:

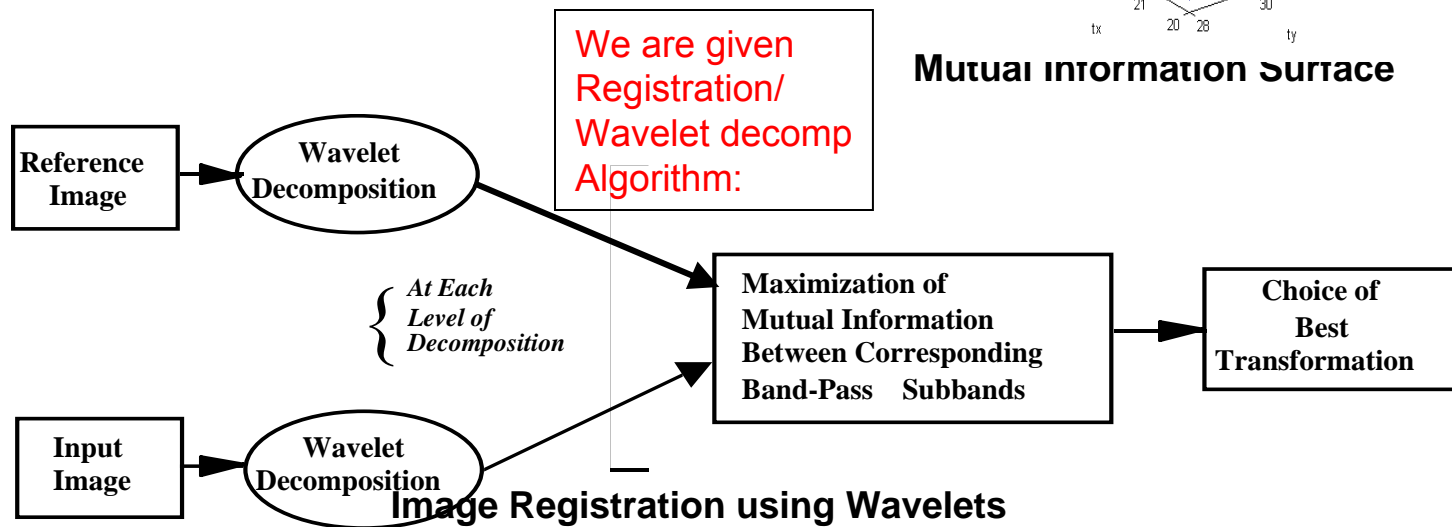
$$I(A,B) = (1/N) \sum_{a,b} h_{AB}(a,b) \cdot \log \frac{N \cdot h_{AB}(a,b)}{h_A(a) \cdot h_B(b)}$$

where N is the number of pixels in image.



Transform until Peak is found

Mutual information surface



Global View of the project: Sensor Fusion Using Images

(An ALICE centric view)

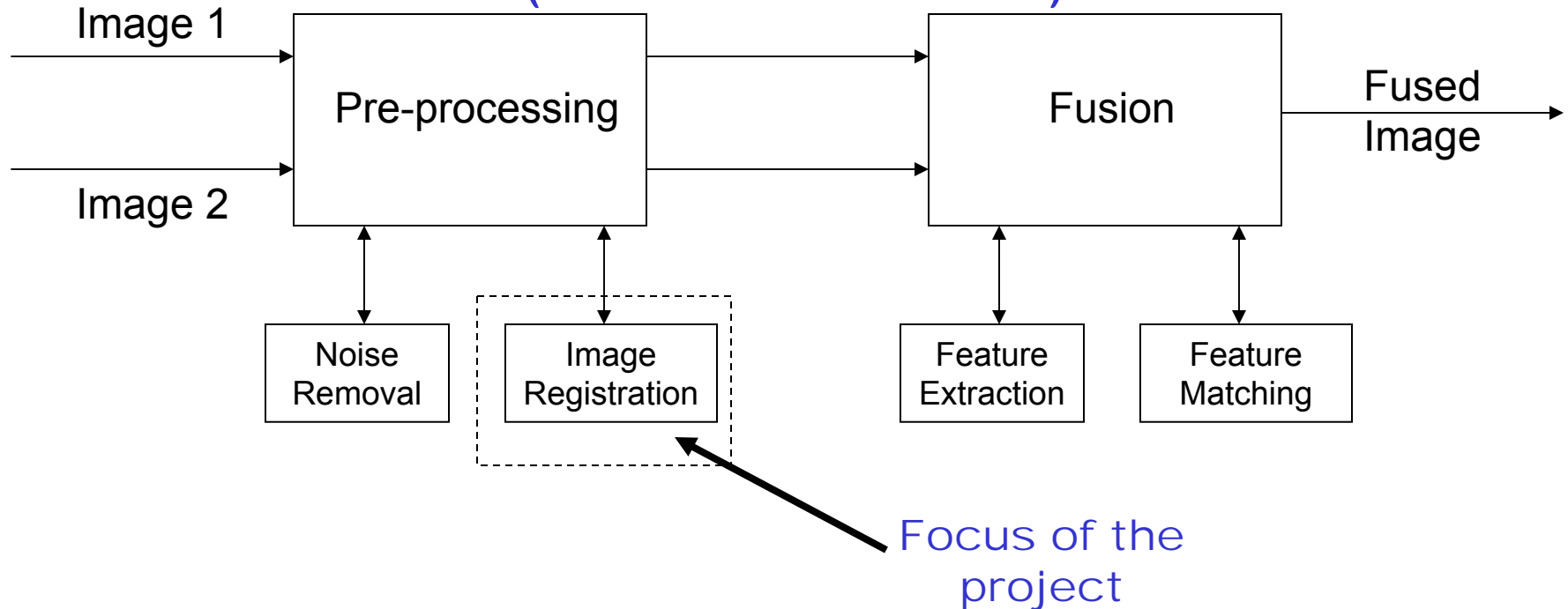


Image Registration is the process of establishing point-by-point correspondence between two images of a scene. Used in applications like remote sensing, medical image fusion and so on.

1. Feature based methods: Identify features and try to align. Case specific.
2. Intensity based methods: Maximize covariance, mutual information etc.

Specific GOALS

**Use image registration techniques for elevation map fusion (Alice)
(instead of fusing cost maps)**

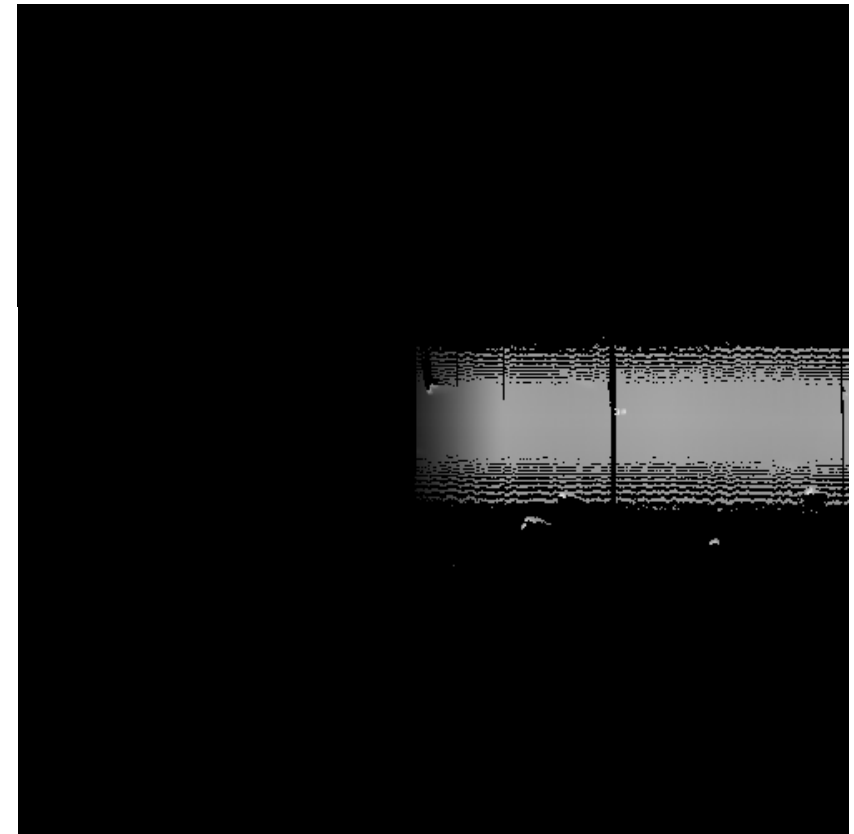
1. Combine data from multiple Ladar sensors
2. Build one final speed map
3. → Correct errors of misalignment

Dynamic image registration (we need fast techniques)

Preliminary results: what we've done

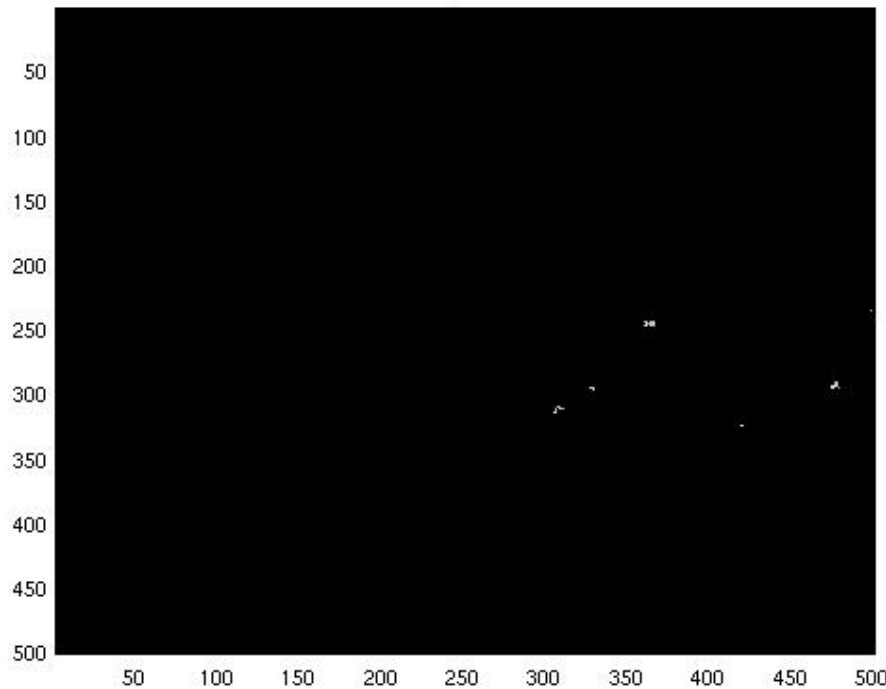
- **Given the original data (1)**
 - We threshold (noise removal)(2)
 - Run through decomposition (3)
 - Register (get tx, ty, theta)
 - Output—fuse images (4)
 - Produce a speed map (5)

Raw ladar data



Thresholded ladar data

input



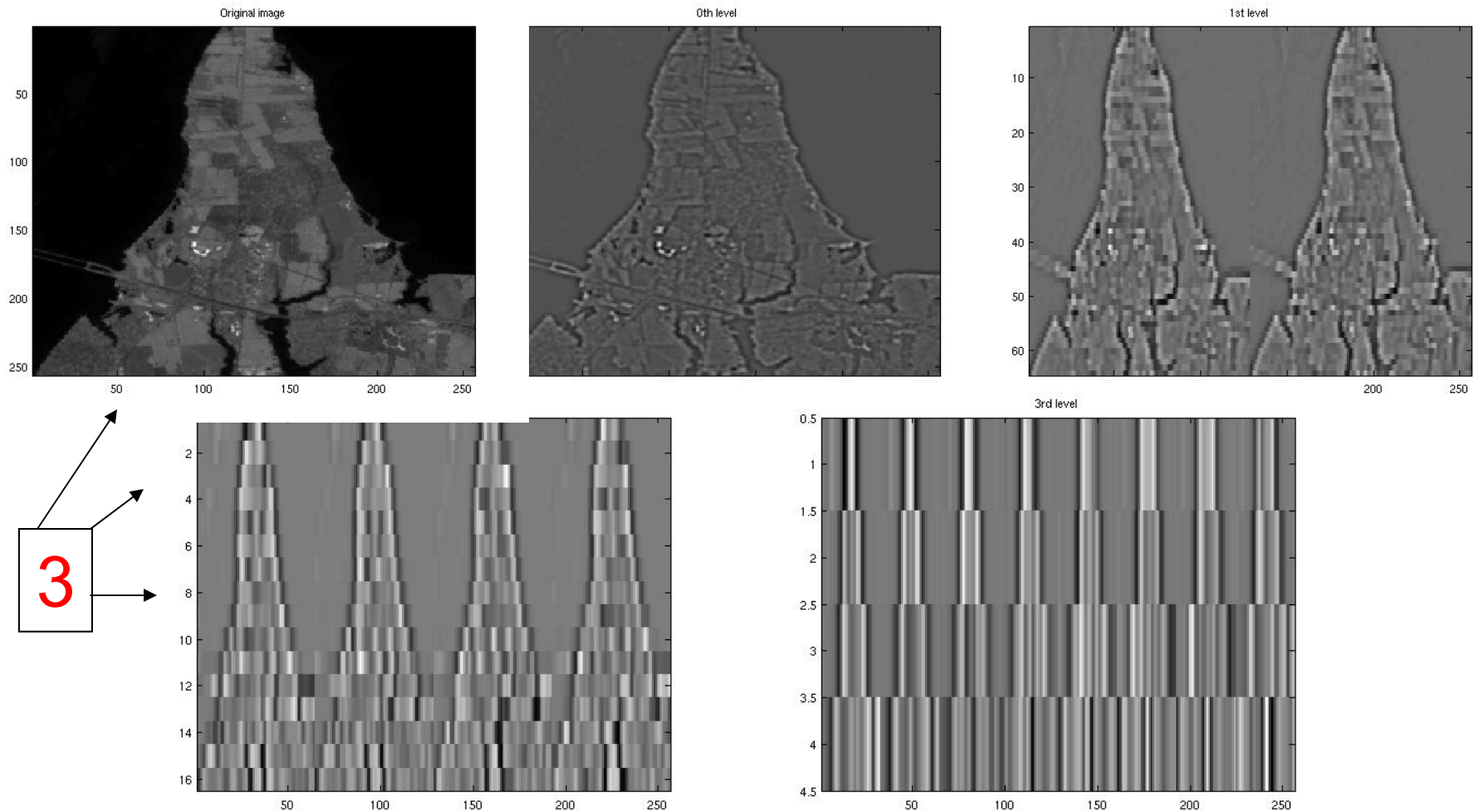
2

1

Preliminary results: what we've done

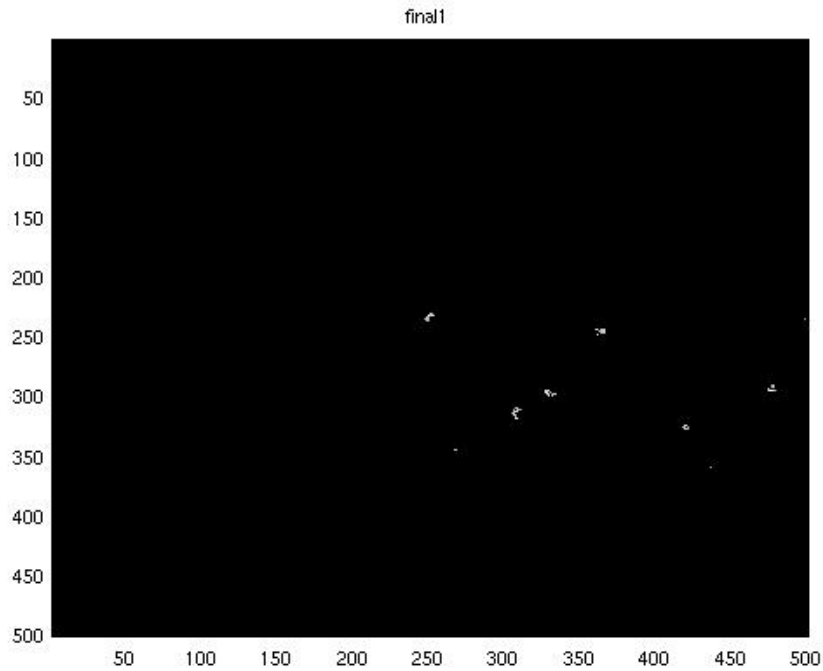
- Run through decomposition (Wavelet based, Simoncelli)

- Provided matlab code
- Registration works up through the decomposition, starting with 3rd level



Preliminary Results: what we've done

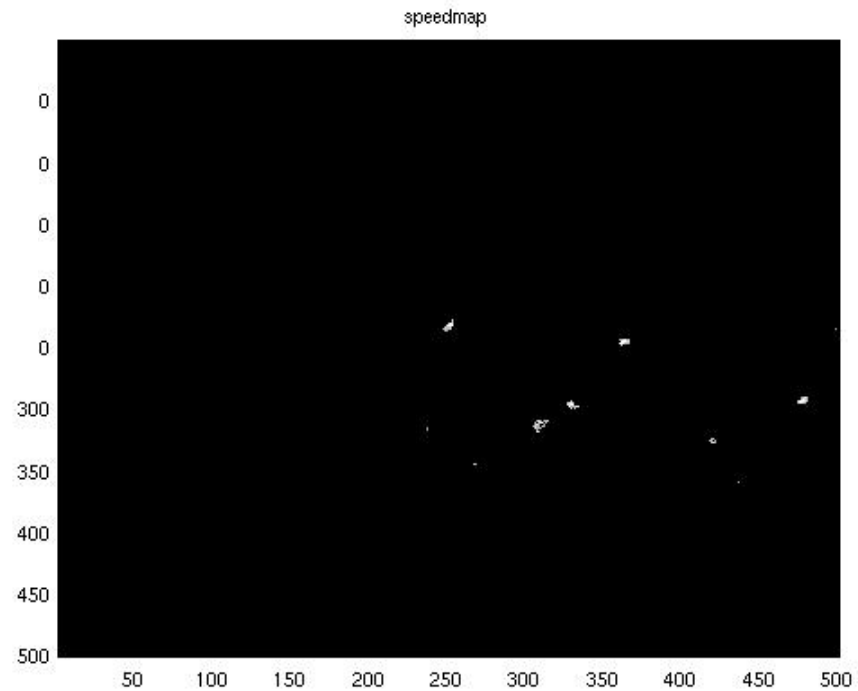
- Output: combine (fuse) registered images by simple averaging



Difference between
Front and Roof
Ladars

Average of all three maps
After being registered

4,5

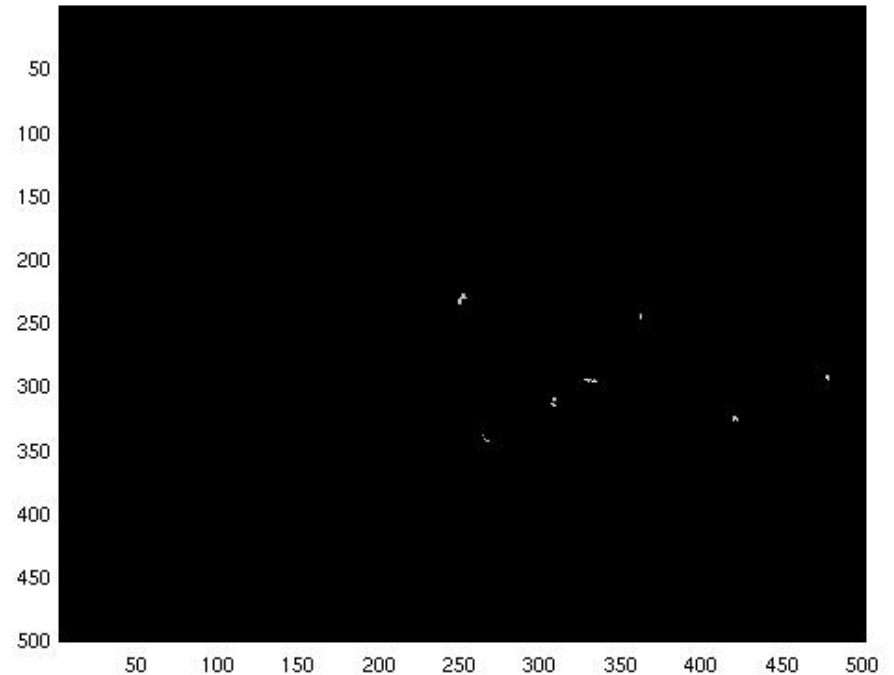


Preliminary Results: what we have found

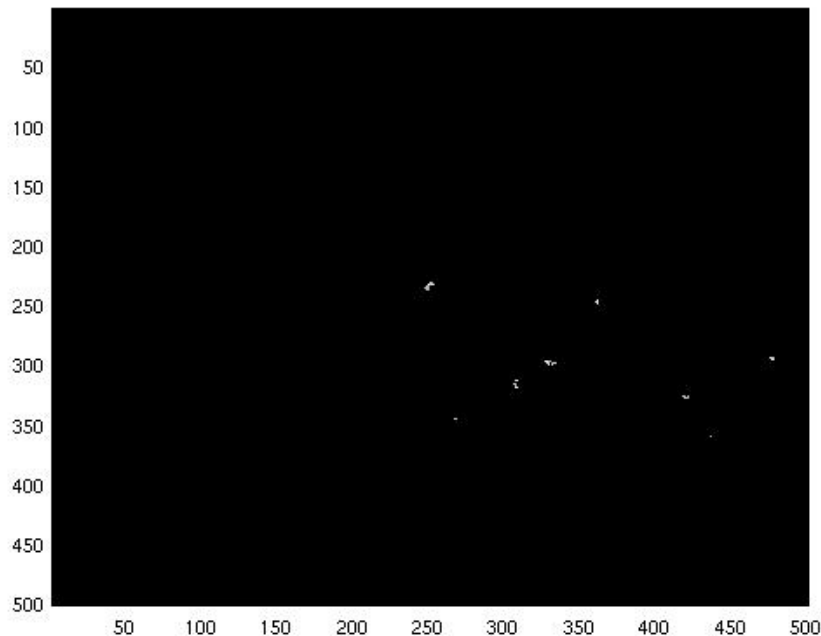
- Very slow at registration level
- Registration usually on the order of a pixel—is this reasonable, given the errors of the other sensors? (i.e., why not just fuse the data?)
 - We know that registration is local, in the sense that it is highly dependant on initial guess

Front ladar before Transformation

ref1



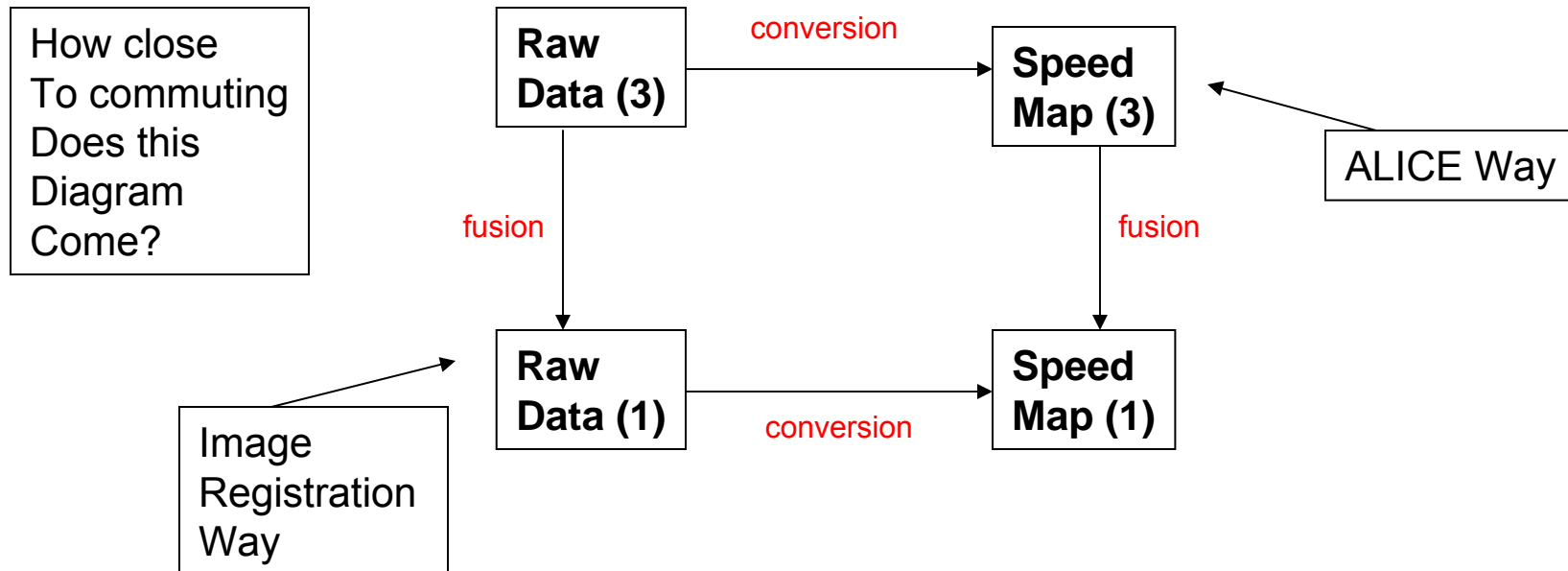
ref1transrot



Front Ladar after Transformation

Plan for the Remainder of the term

- Make Faster (real time, ~10 Hz)—perhaps tinker with Registration?
- Put in C++, connect with 3Register so we can go from input images to registered output
- Right now thresholding determined via histogram of pixel values (or guessing)...is there a better way?
- We combine transformed images by averaging—does a more sophisticated fusion method exist?
- Compare with current methods used on ALICE (see below)—is there a difference?
Is registration better?



Plan for the remainder of the term

- **Collect more data, with more/better features (allows registration to run more reliably)**
- **Is the registered and fused map a good representation of reality? (compare with ground truth)**

Plan for the Remainder of the Term

- **Possible alternative to “full” image registration:**
 - Within particle filtering framework, and thinking in terms of “road estimation” (right now, we are just relying on fused data—no filtering):
 - Add registration parameters ($tx(i)$, $ty(i)$, $theta(i)$) to each particle $x(i)$ (since $(tx, ty, theta)$ varies over a small interval, this wouldn't Add too much computation to particle filter--hopefully)
 - Factor likelihood into data part and Mutual information part, i.e.
 1. $p(y|x(i)) = p(\text{Ladar}|x(i)) * MI(A, T(B))$, where $T(B) = (tx(i), ty(i), theta(i))(B)$
 2. Thus, over time you would expect the particles with the correct registration to converge (i.e., most particles would have the same $(tx, ty, theta)$)
 3. Reasonable alternative since full registration very costly, and only slightly beneficial—this approach would only be slightly more costly, but gain (partial) benefits of registration
- **This approach has been implemented in the very similar FastSLAM algorithm, with good results**

Plan for the Remainder of the Term

• **Similarly, perhaps this problem could be framed as one of data association (and use “traditional” techniques (e.g., nearest neighbor)**

Instead of calculating mutual information

- Thresholded ladar data tends to have strong features—just doing assignment might be less computationally expensive, and more reliable (at the cost of not having a sound theoretical basis)

Dynamic Image Registration for Elevation Map Fusion

Approach to Solution

Using pairs of Elevation Map images from

- Ladar (from 3 units)
 - *Front, Roof, Small* (taken at the same time instant), and
- Stereo vision cameras.

At position (i,j) , of image **A**, the pixel intensity a_{ij} denotes the *elevation (or height)* at that pixel location.

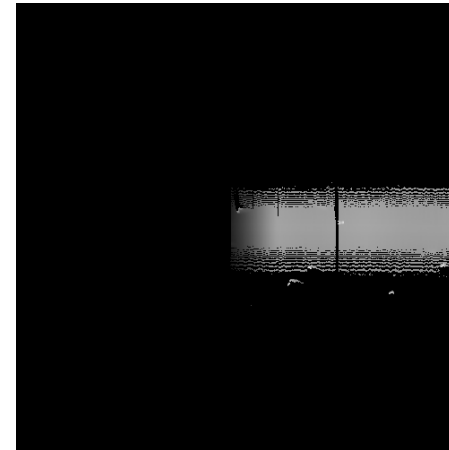
The image, **A** is registered to the image **B** to determine the parameters (tx,ty,θ) which align image **A** to **B**.

Currently

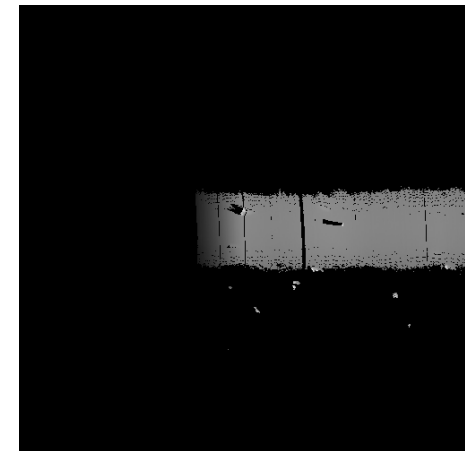
Individual Elevation Map=> Individual Speed Map;
Fuse individual speed maps from sensors => Final Speed Map.

Alternatively

Register new Elevation maps from sensors =>
From *Fused* Elevation maps => Final Speed Map, and
Keep updating Speed map over time, using the new registration.



**Front
Ladar**



**Roof
Ladar**