Reconstructing Textured Urban 3D Object by Fusing Ground-based Laser Range Image and CCD Image

レンジ画像とCCD画像を併用した３次元都市空間モデルの自動構築手法

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Study Background

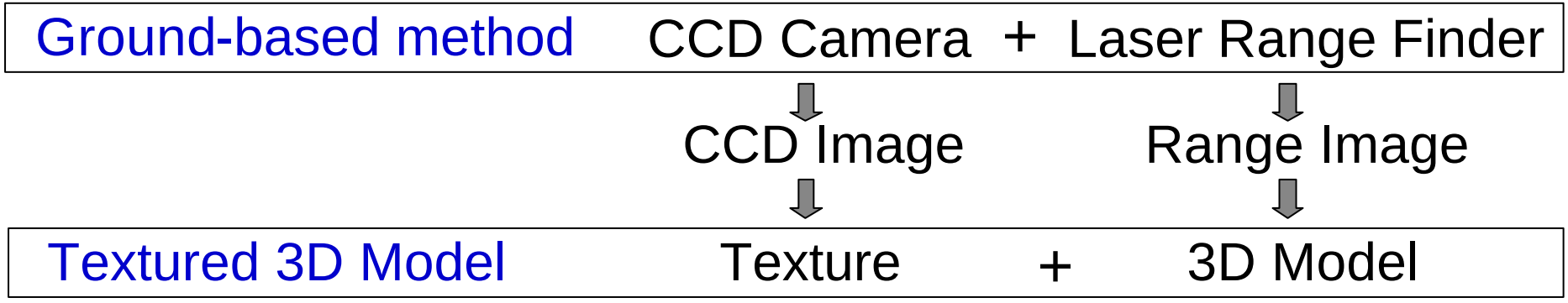
1. Methods for Automated reconstructing Urban 3D Object

- Aerial-based method ⋯⋯> Loss of details of urban objects
- Ground-based method

2. Sensors for Ground-based Acquisition

- Optical Camera ⋯⋯> Unreliable Stereo Matching
- Range Finder ⋯⋯> Measuring Discrete Points

3. In this research

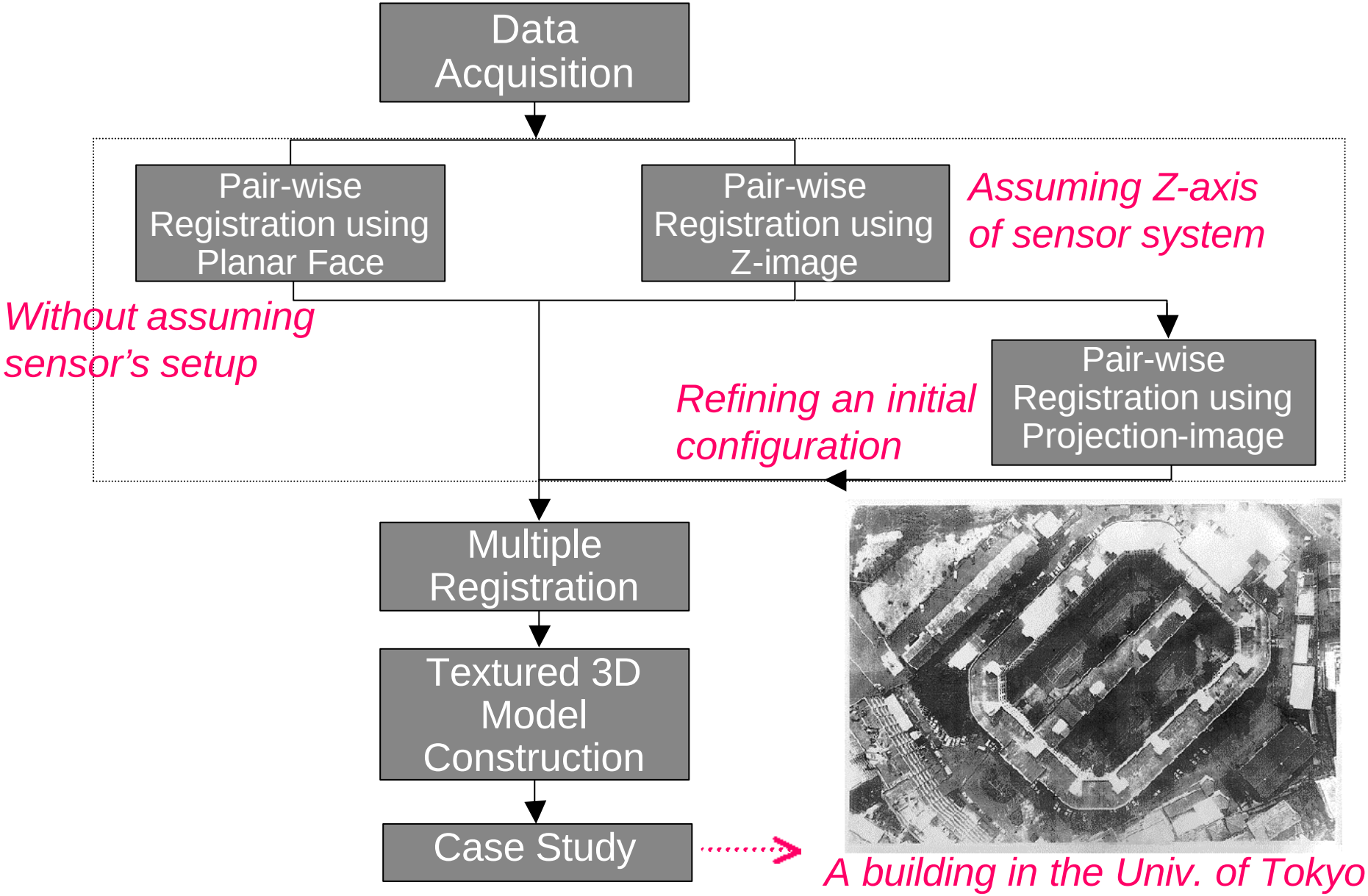


Study Objectives

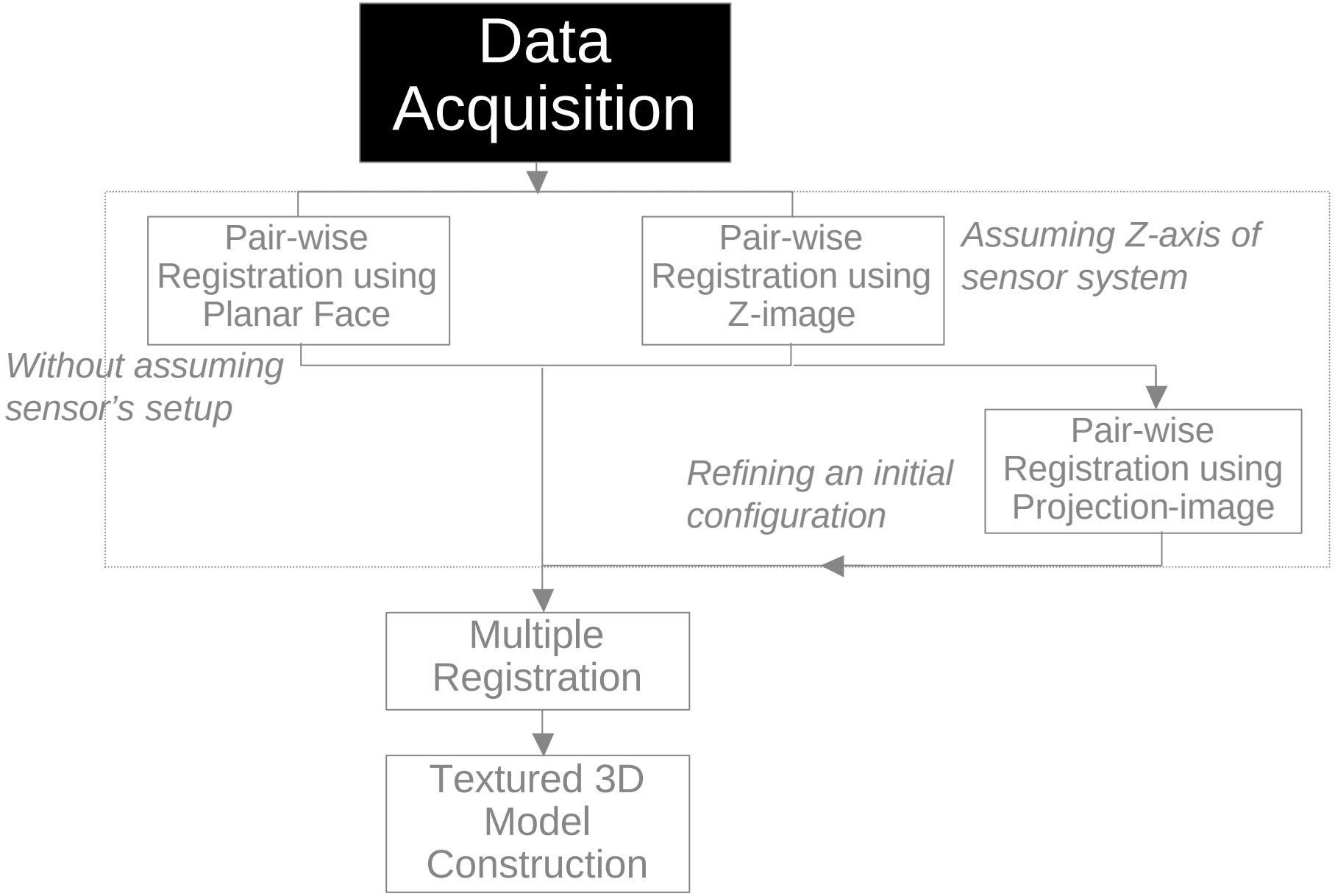
Developing a framework for the reconstruction of textured 3D urban object using ground-based laser range and CCD images

- Developing a data acquisition system for simultaneously acquiring range and CCD images
- Developing methods for pair-wise registration
  - without assuming sensor's setup
  - assuming sensor's posture
  - refining an initial configuration
- Developing a multiple registration method to solve error accumulation in pair-wise registration
- Developing a method for textured 3D model construction from the data sets of duplication and erroneous measurement

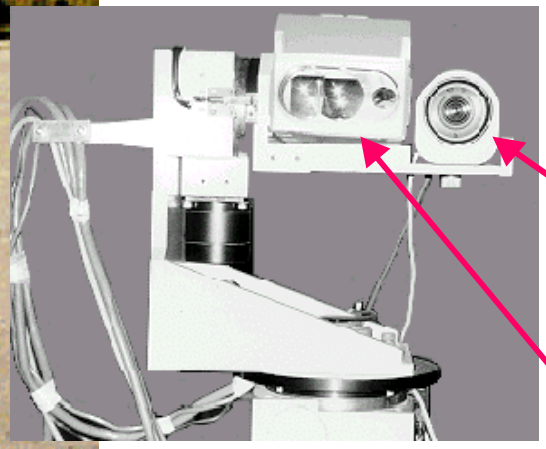
Flow of the Research



Flow of the Research

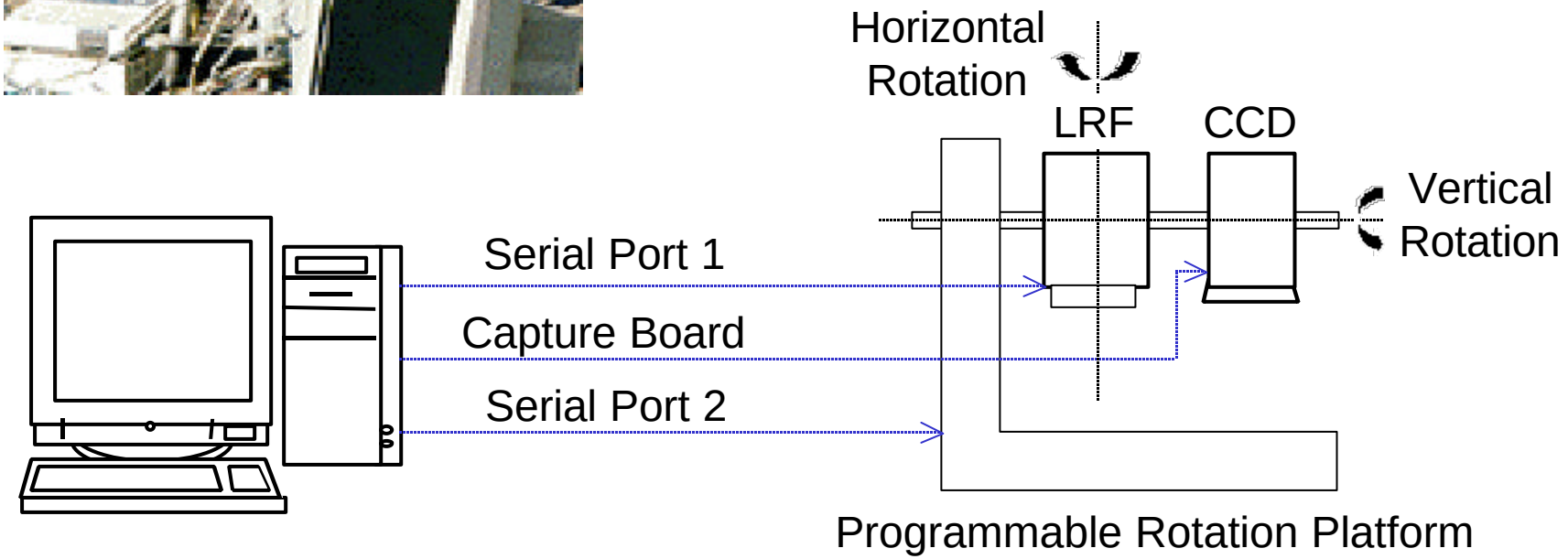


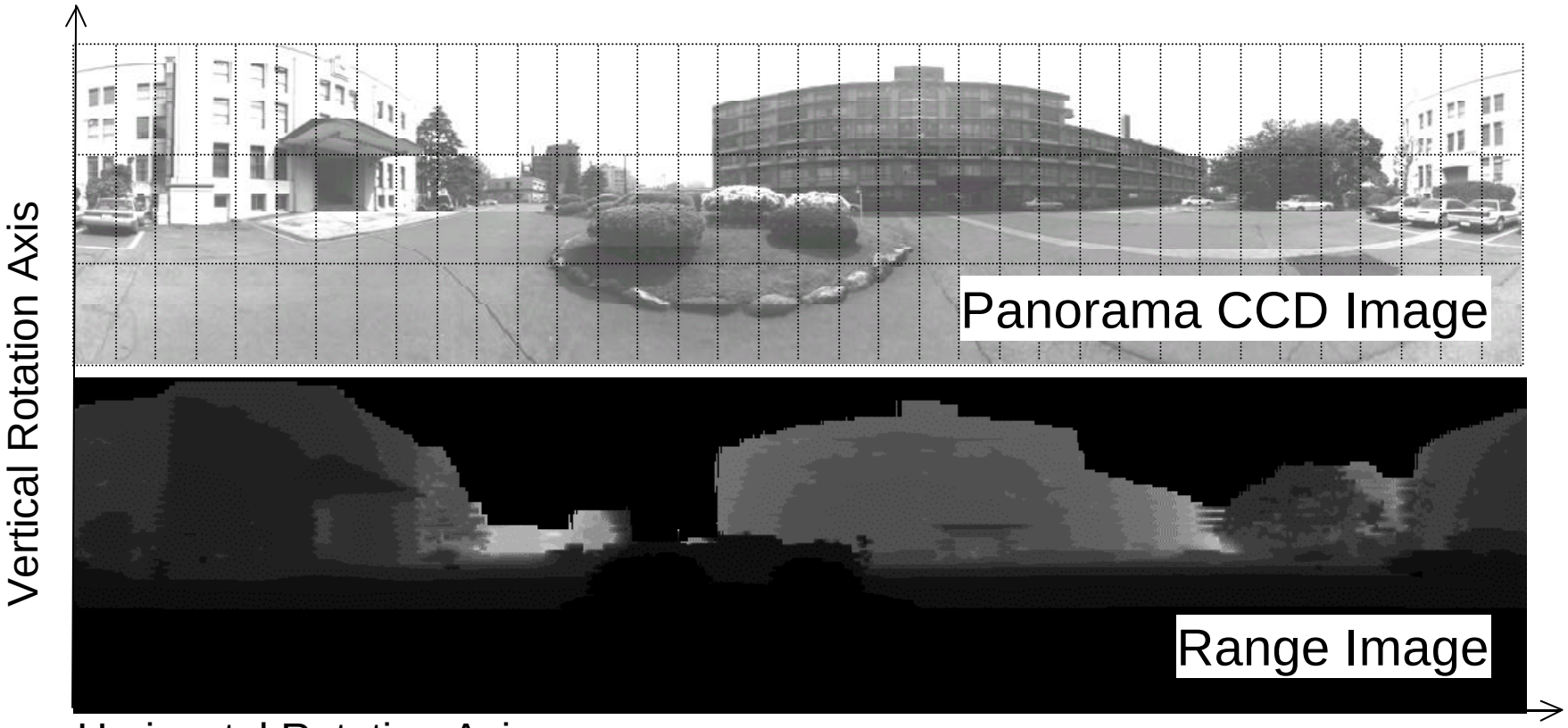
Ground - based Sensor System

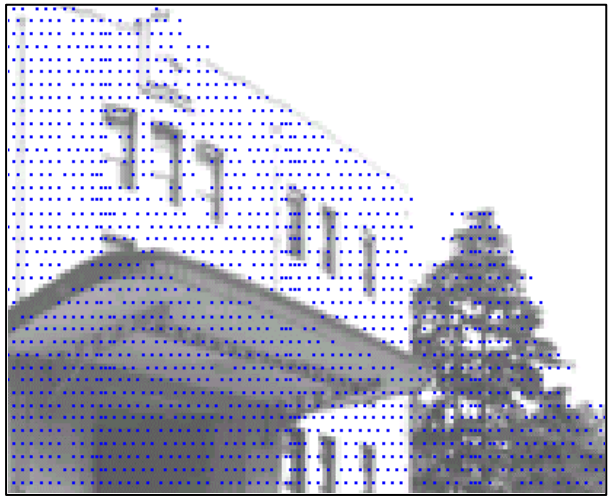


CCD Camera

Laser Range Finder

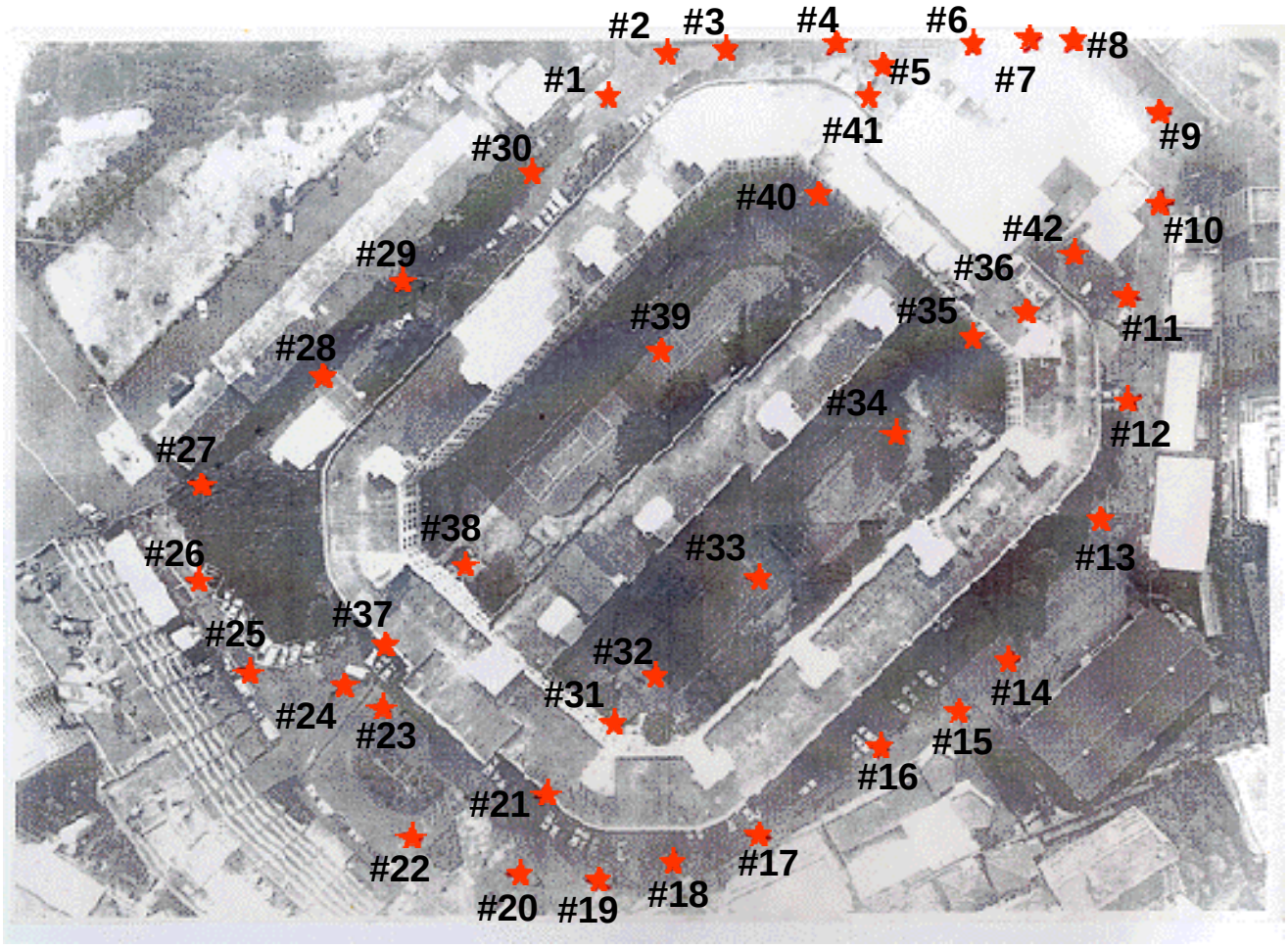



Vertical Rotation Axis
Panorama CCD Image
Range Image
Horizontal Rotation Axis



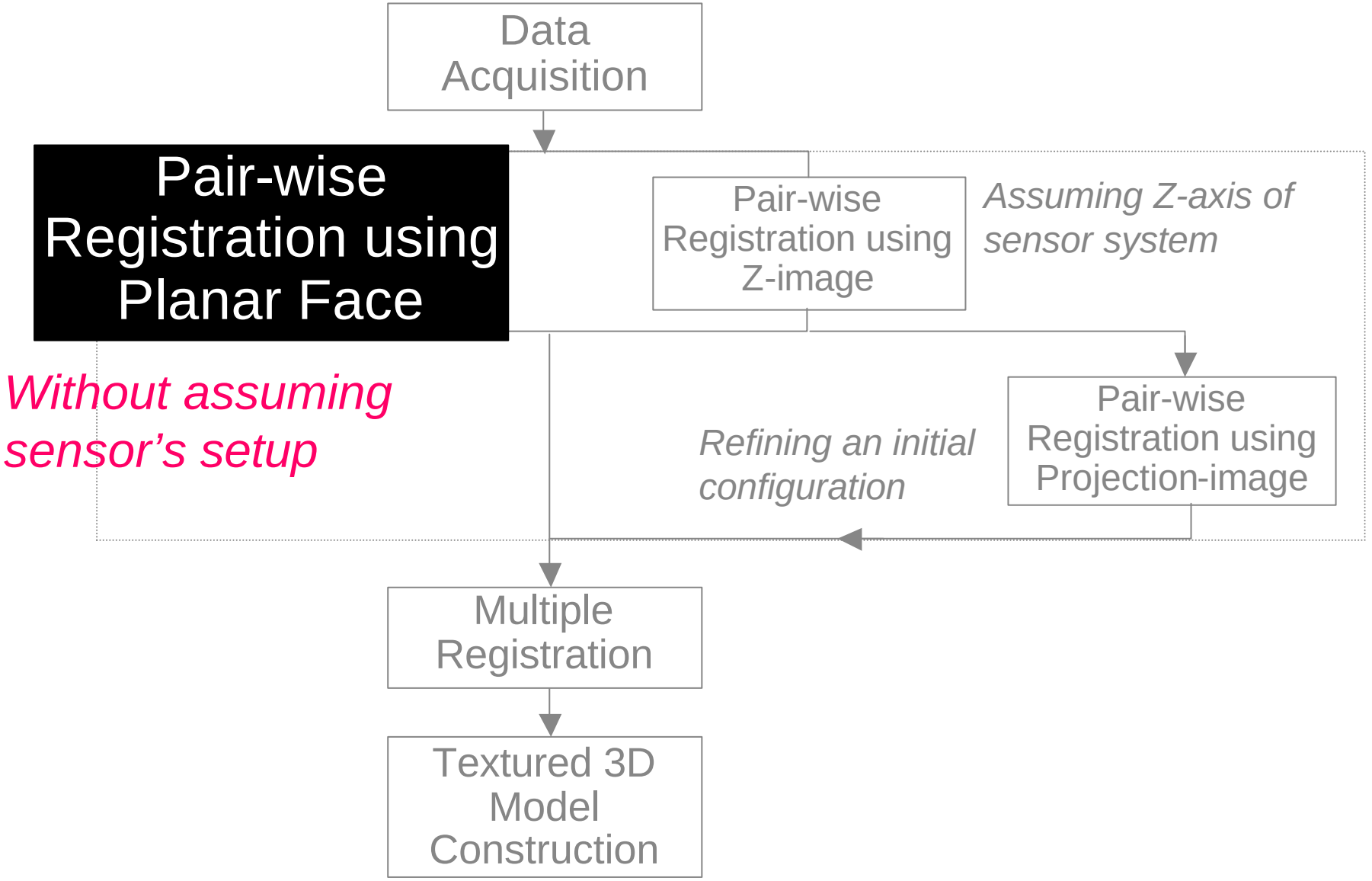

Fusion of Range and CCD image

Location of Viewpoints



42 views of range and CCD images are measured.

Flow of the Research



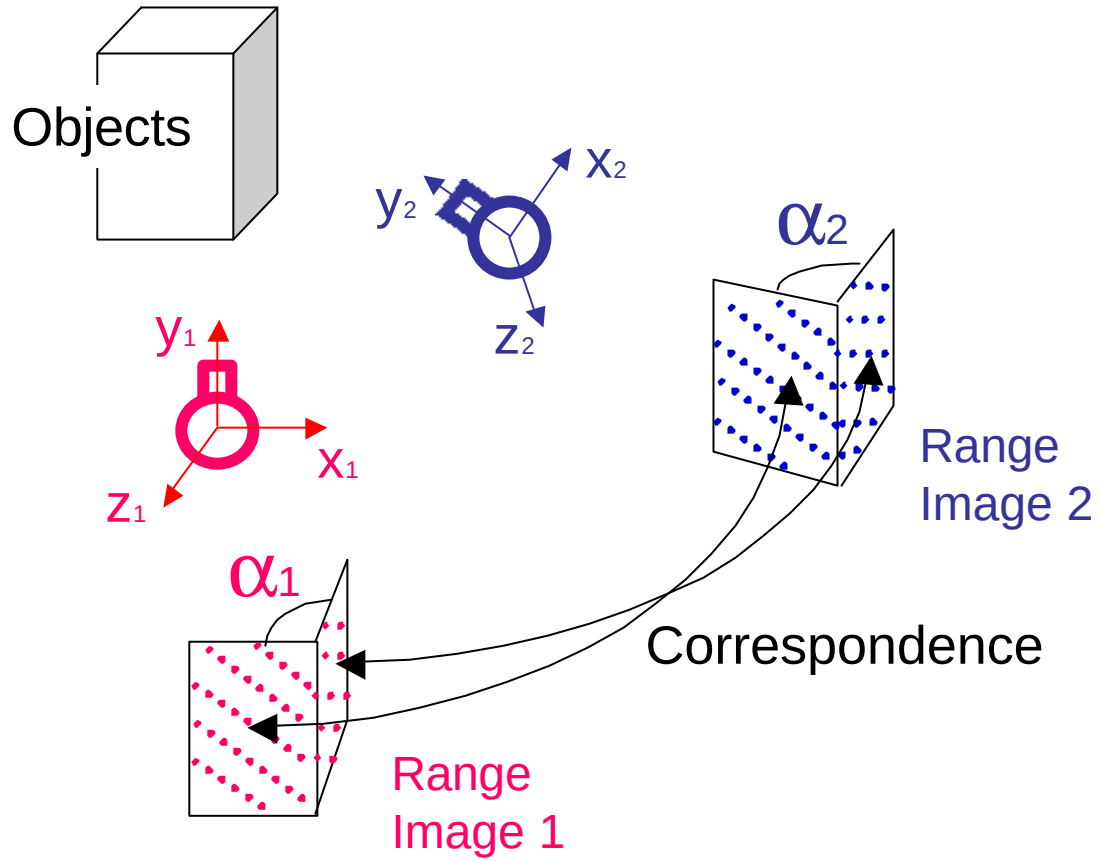
Pair-wise Registration using Planar Face

Problem

Sensor's setups are totally unknown.

Objective

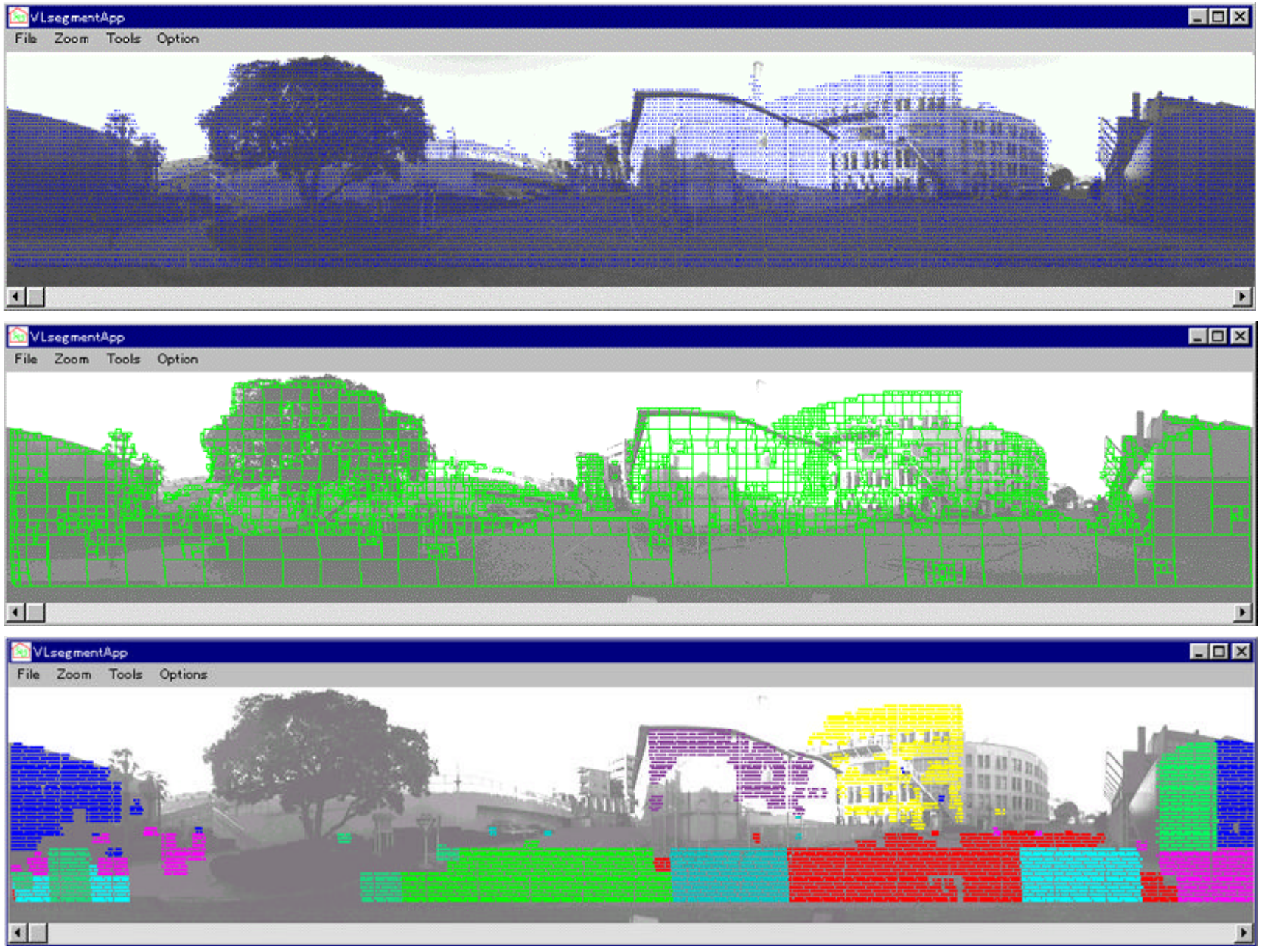
Obtaining a transformation with six degrees of freedom between two sensor's coordinate system.



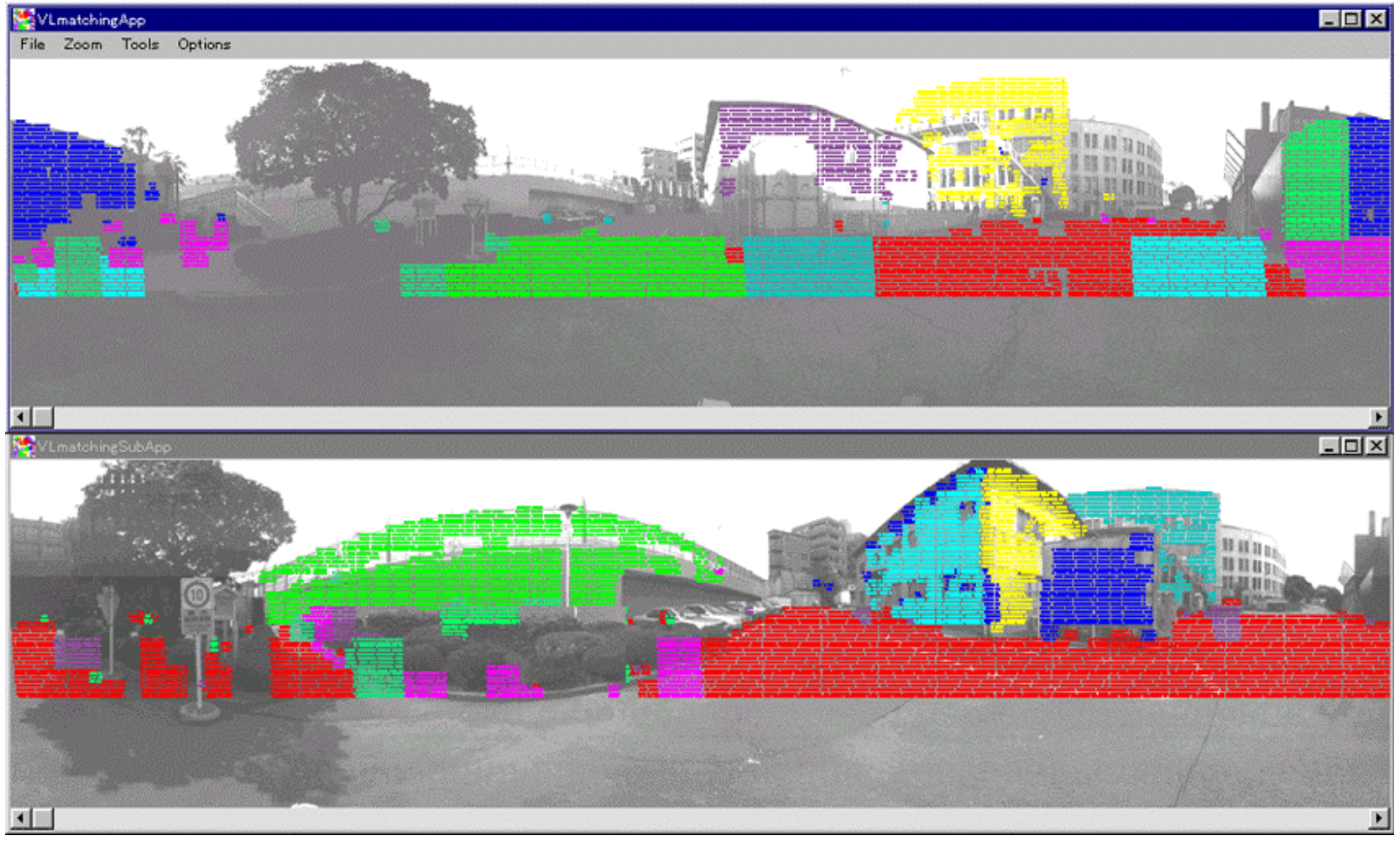
Procedures

1. Extracting planar face from range images.
2. Recovering transformation by detecting three non-parallel corresponding planar face pairs.

Planar Face Extraction



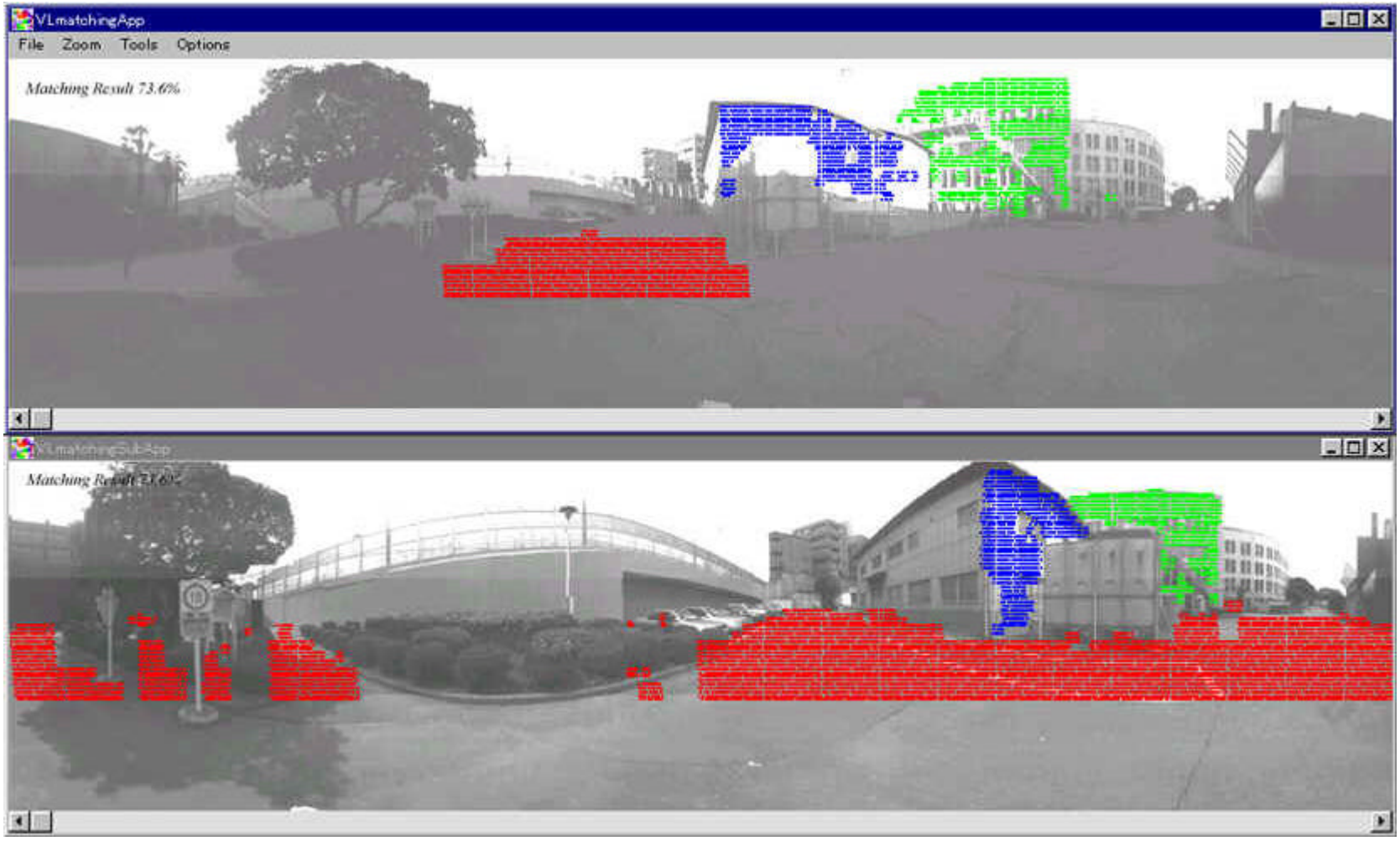
Two Unregistered Views



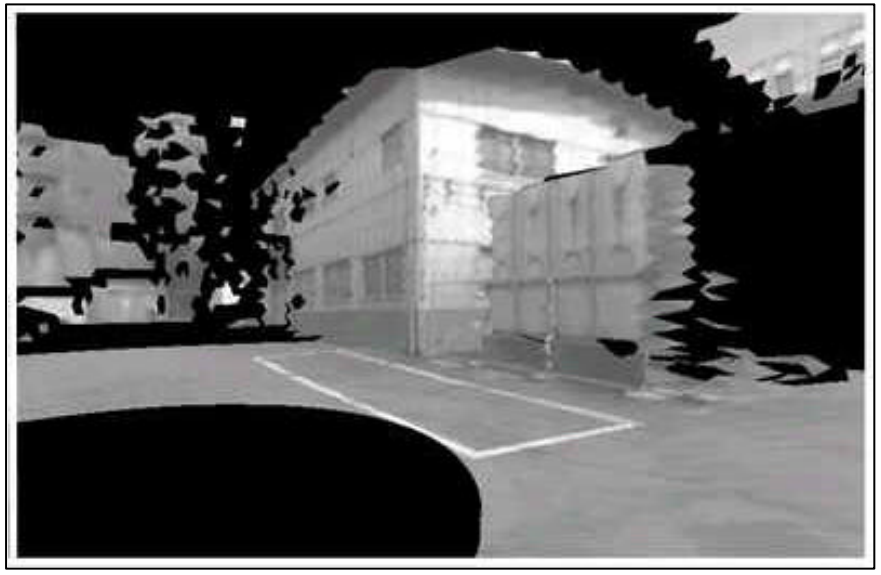
Which are the corresponding planar faces ?

How to fast and effectively detect the most reliable conjugation between the planar faces from different views?

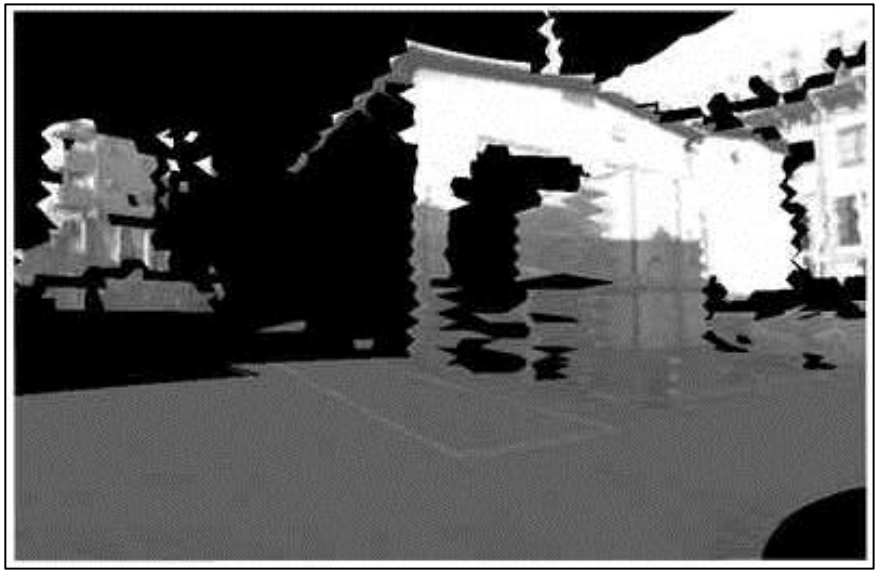
After Registration of Two Range Images



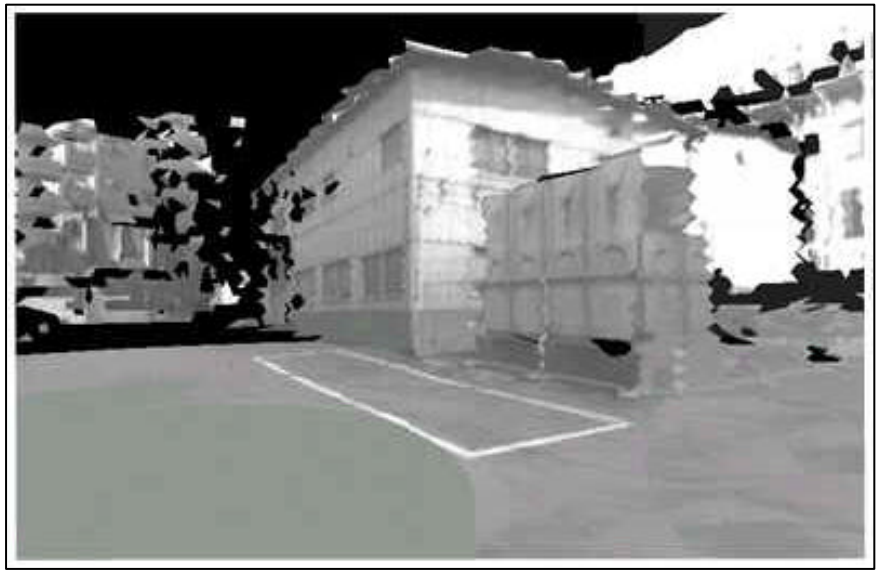
Matching Result (Overlay of Laser Range Points) : 73.6%



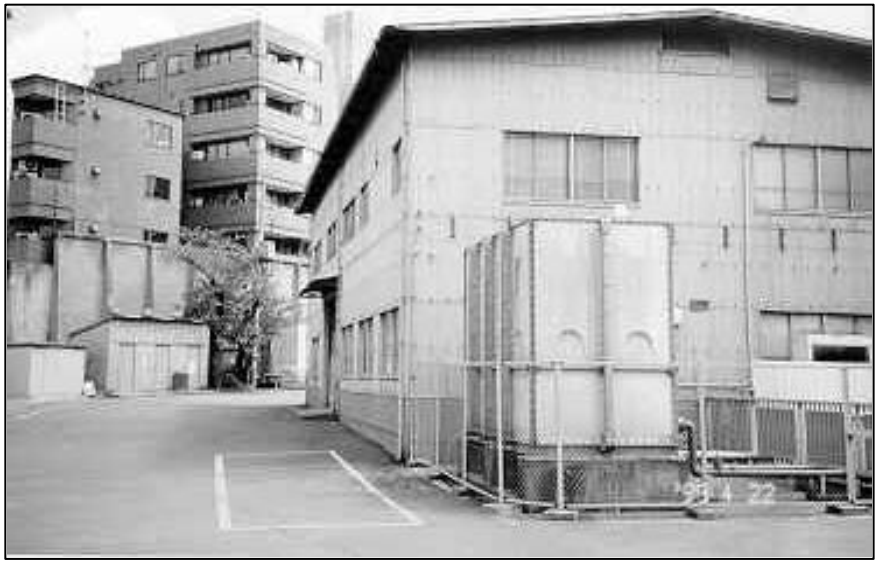
View 1



View 2



Integration of View1 and View2

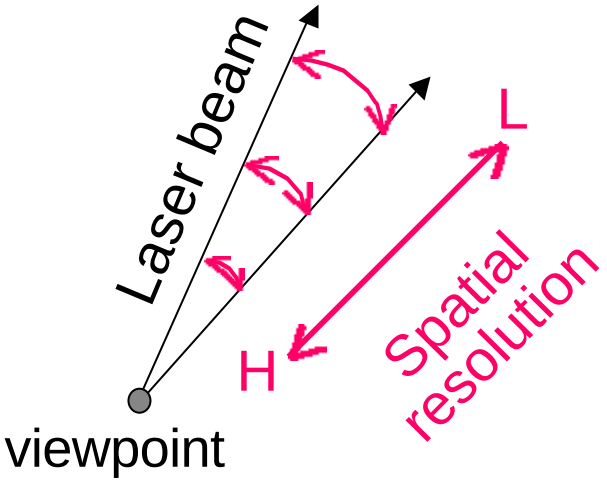


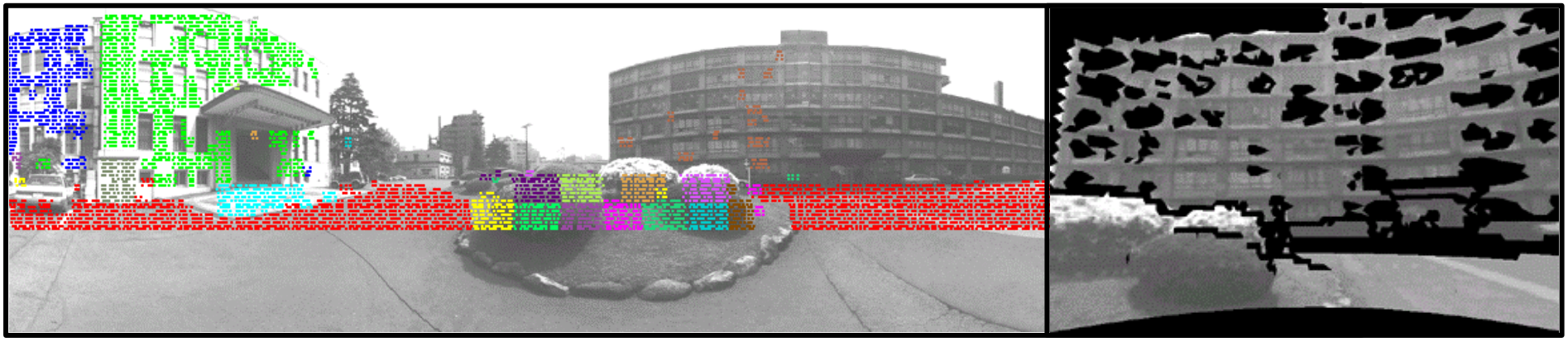
Testing Site

Limitation of pair-wise registration using planar face

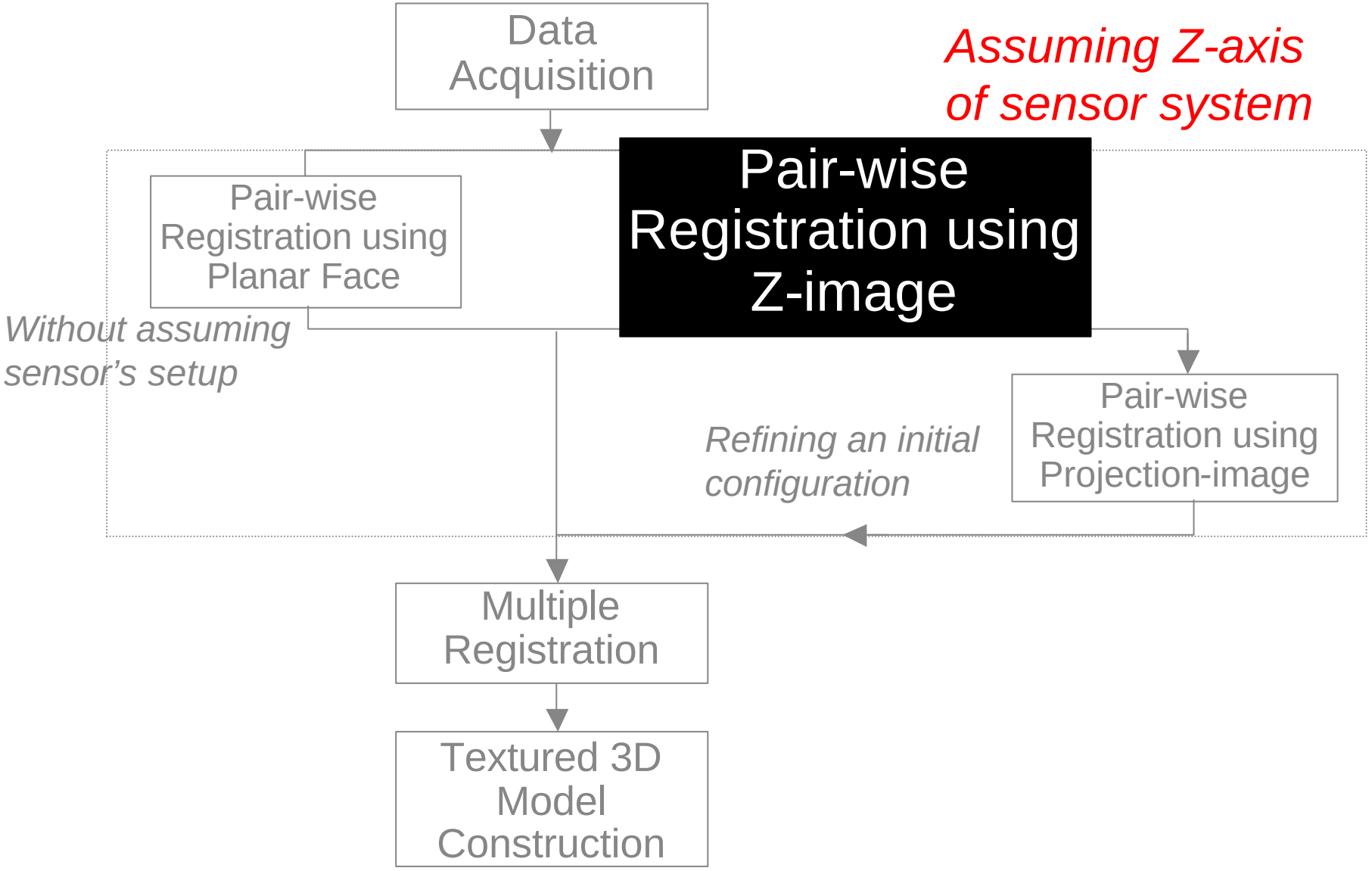
Difficult to find enough corresponding planar faces

- Occlusion
- Erroneous range measurement
- Low spatial resolution

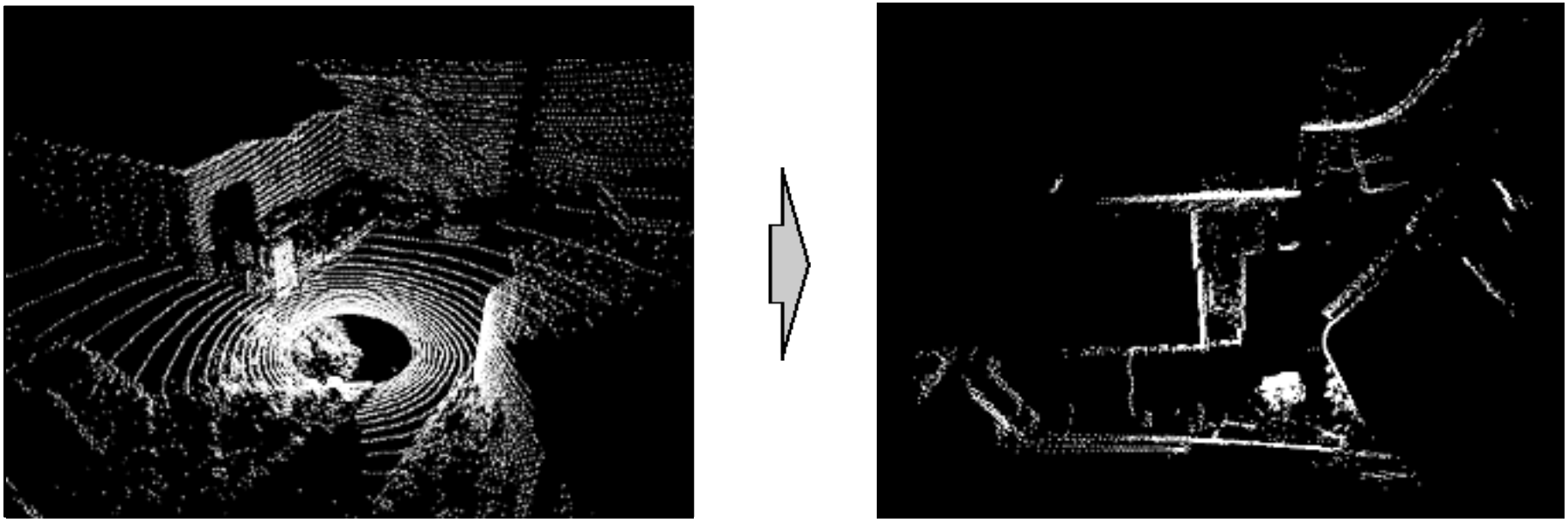




Flow of the Research



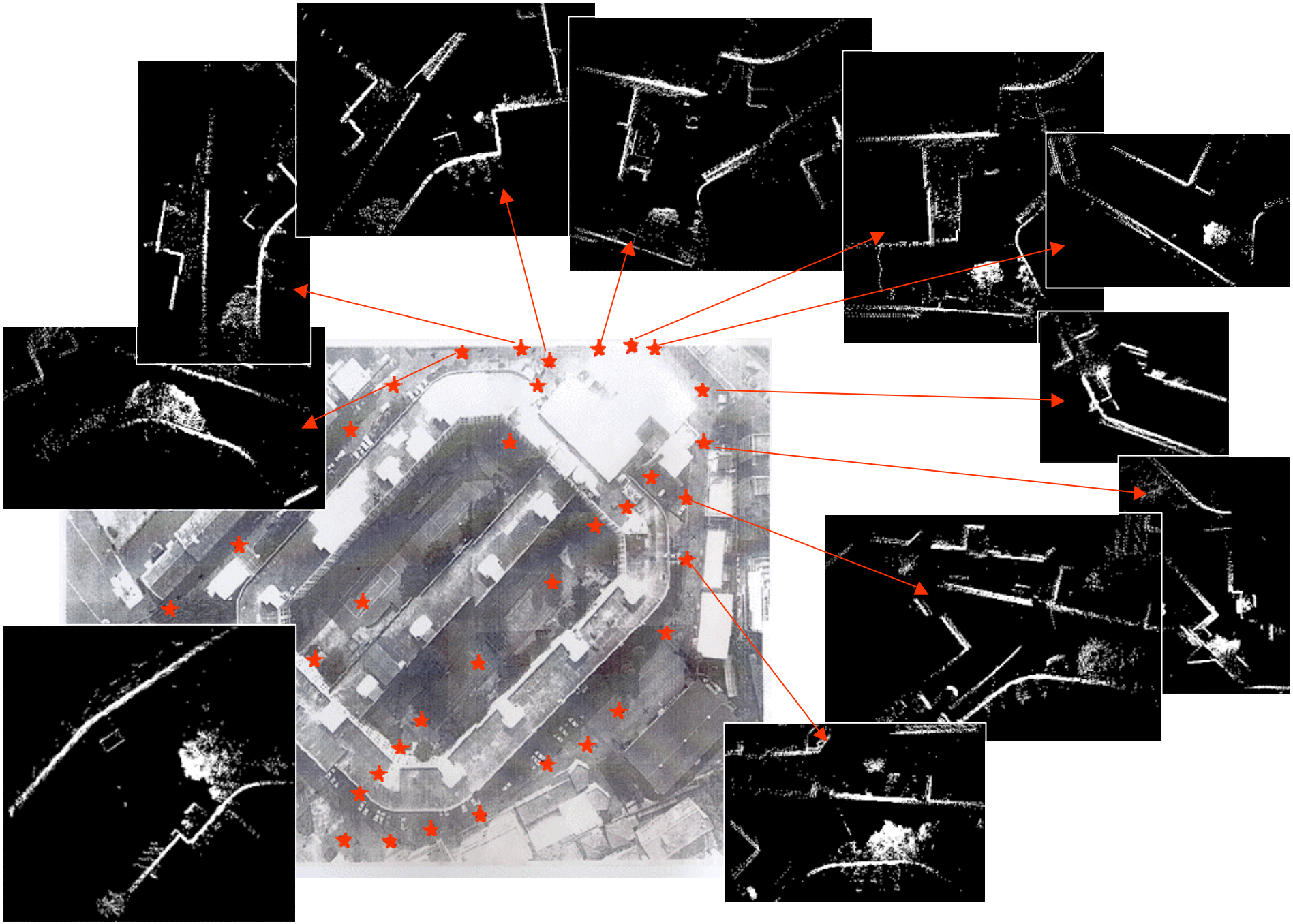
What is Z-image?



Range image

Z-image

Assuming Z-axis of sensor system is vertical to the ground surface,
a Z-image is generated by vertically projecting range points in range image to a horizontal plane.



Examples of Z-image

Pair-wise registration using Z-image

Assumption

Z-axis of sensor's coordinate system is vertical to the ground.

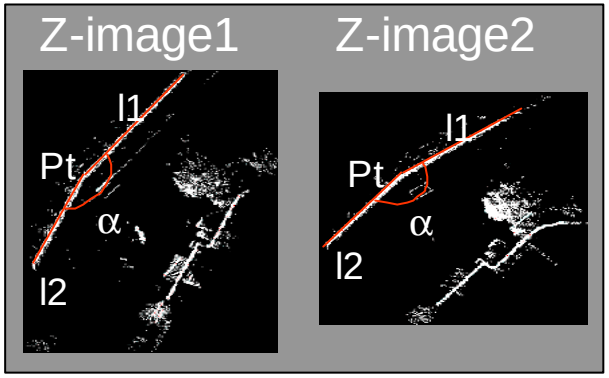
Objective

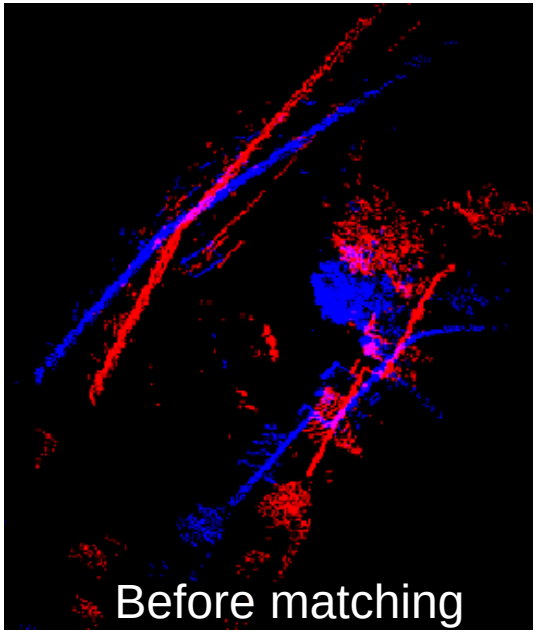
Obtaining four transformation parameters,
a horizontal rotation angle and three translation parameters.

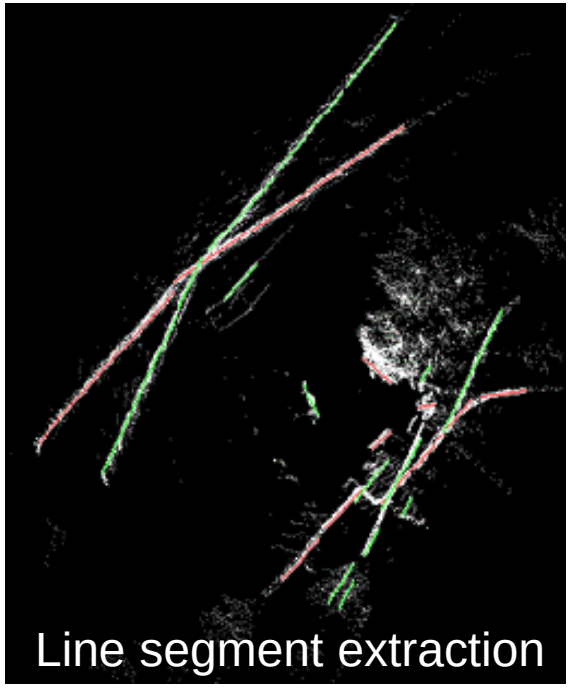
Procedure

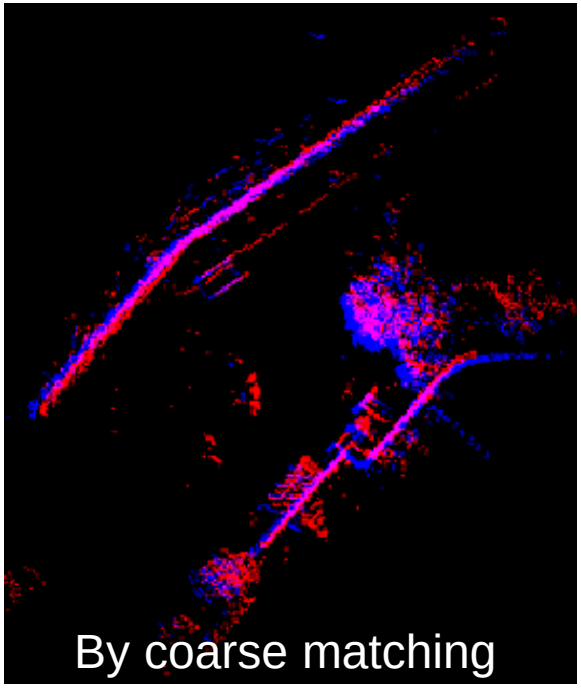
1. Matching Z-Image to find a horizontal rotation angle and two translation parameters in horizontal plane.
2. Matching ground points to calculate the translation parameter along Z-axis.

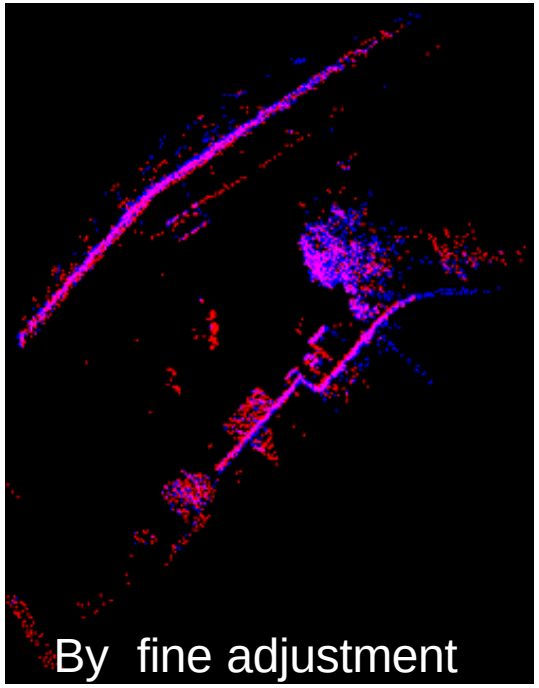
Matching Z-Images





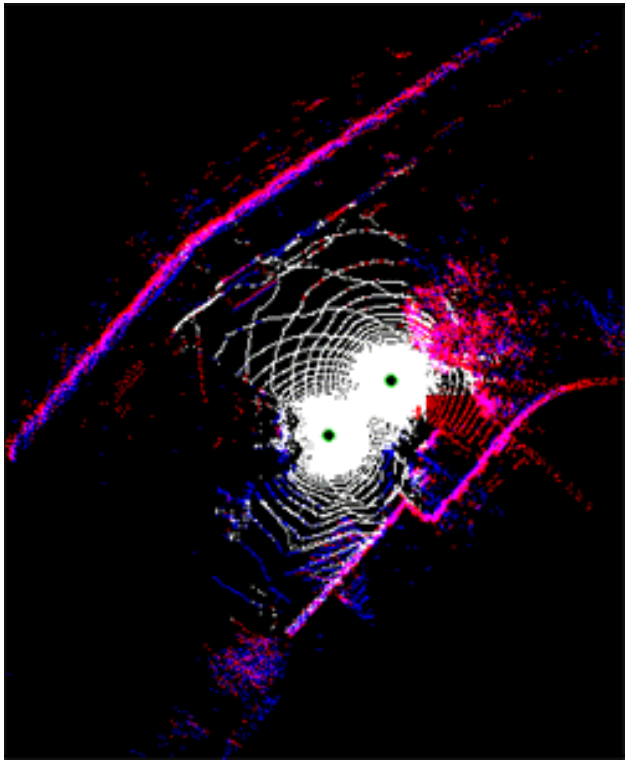






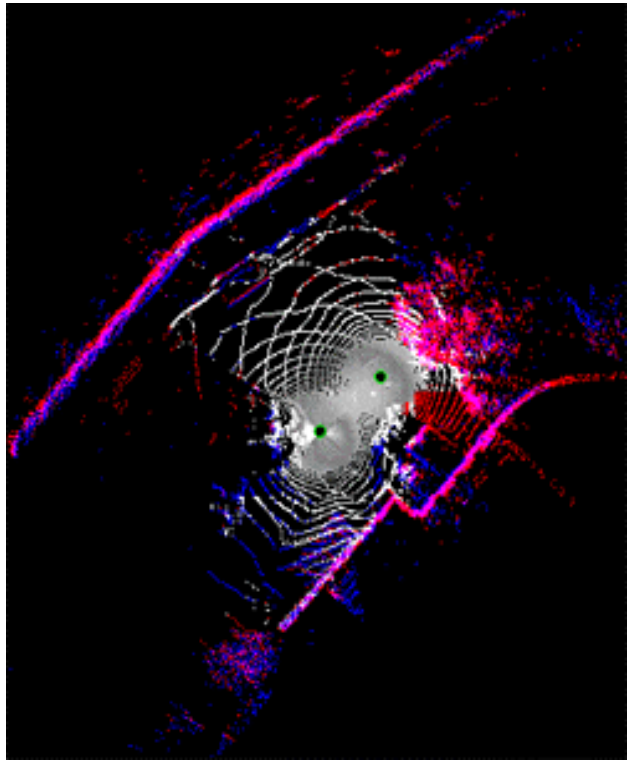
Matching Ground Points

Before Matching



Registration error 0.3622m

After Matching



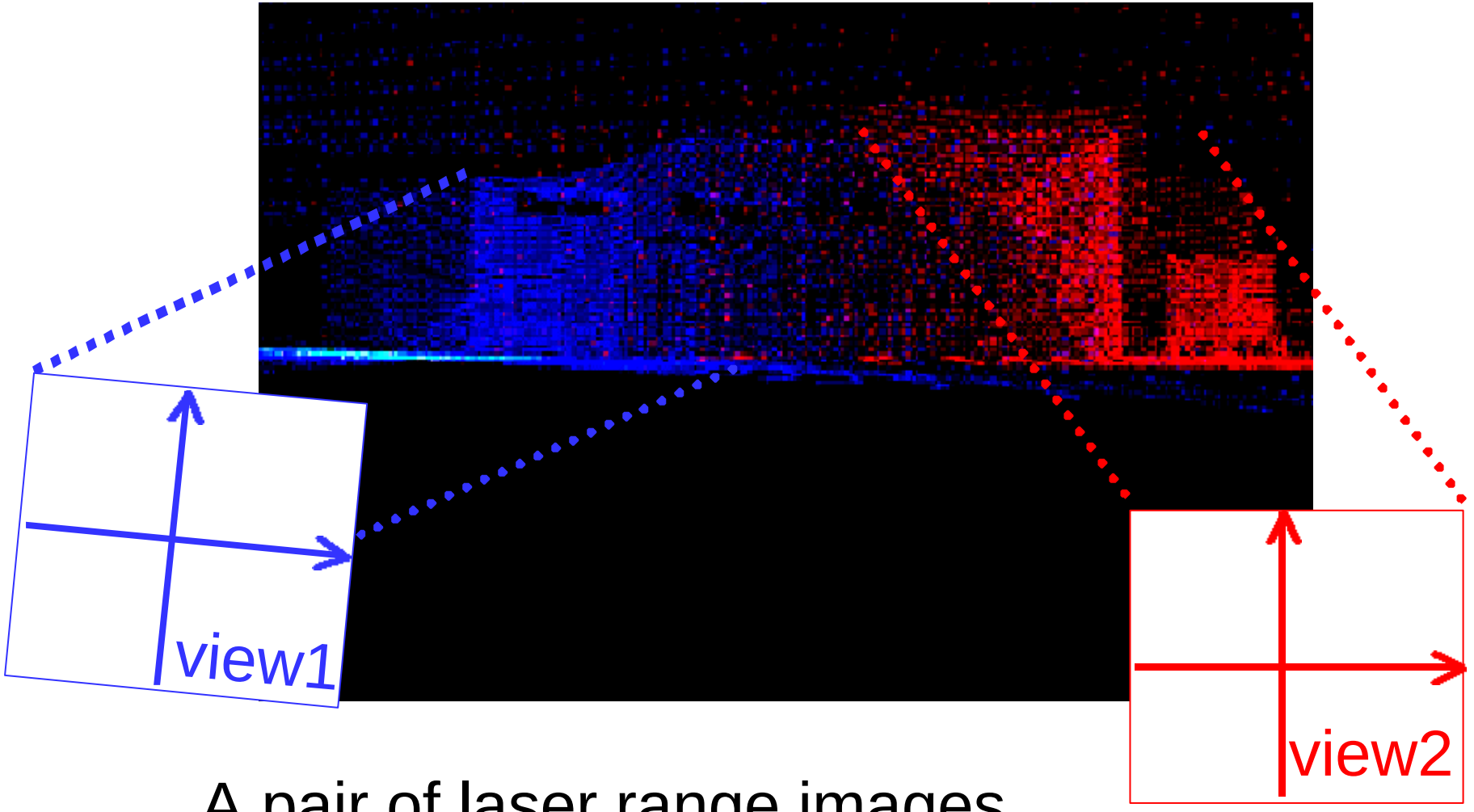
Registration error 0.03m

0.0 (m)

0.2 (m) and more

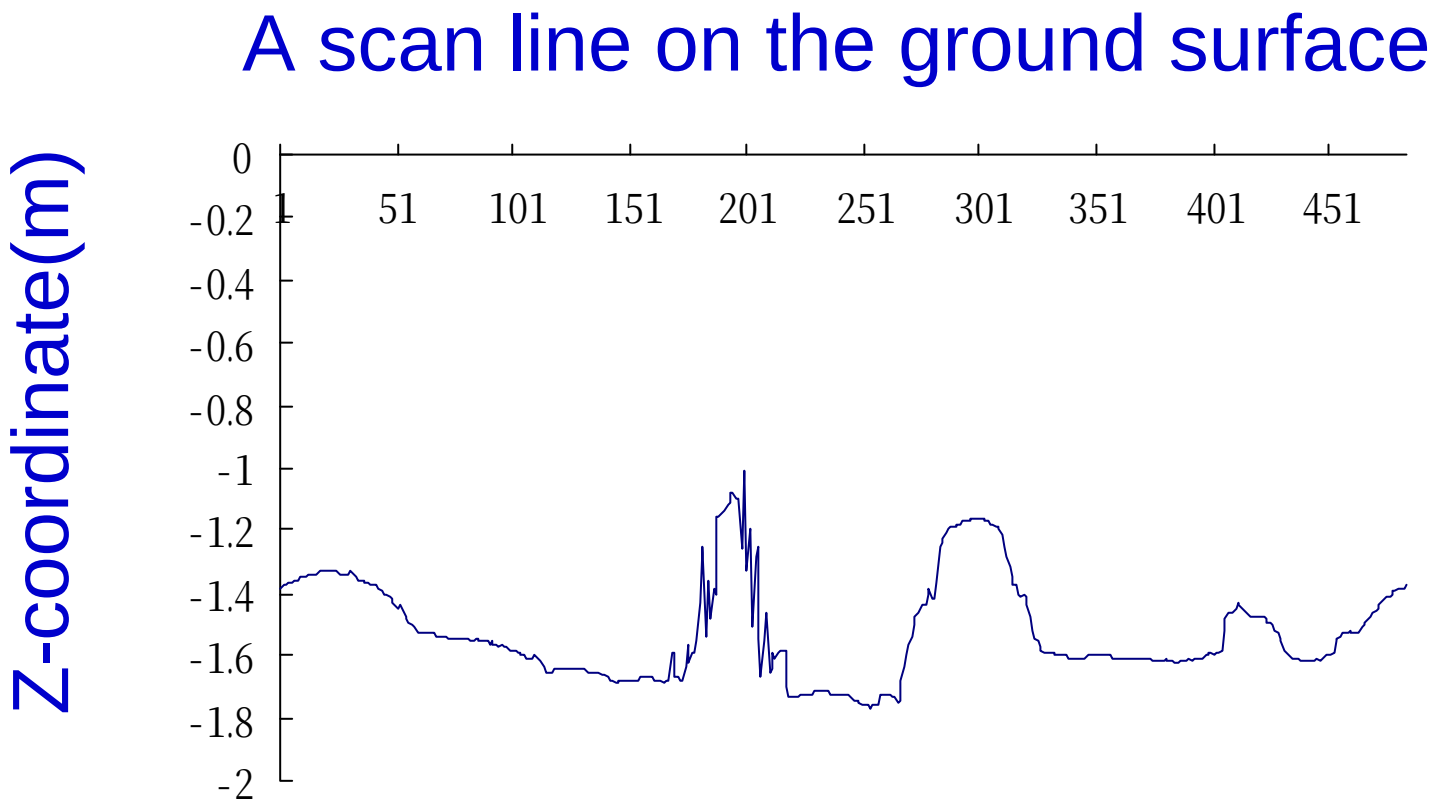
Residuals

Erroneous matching of ground surface because of the slant Z-axis in sensor's coordinate system



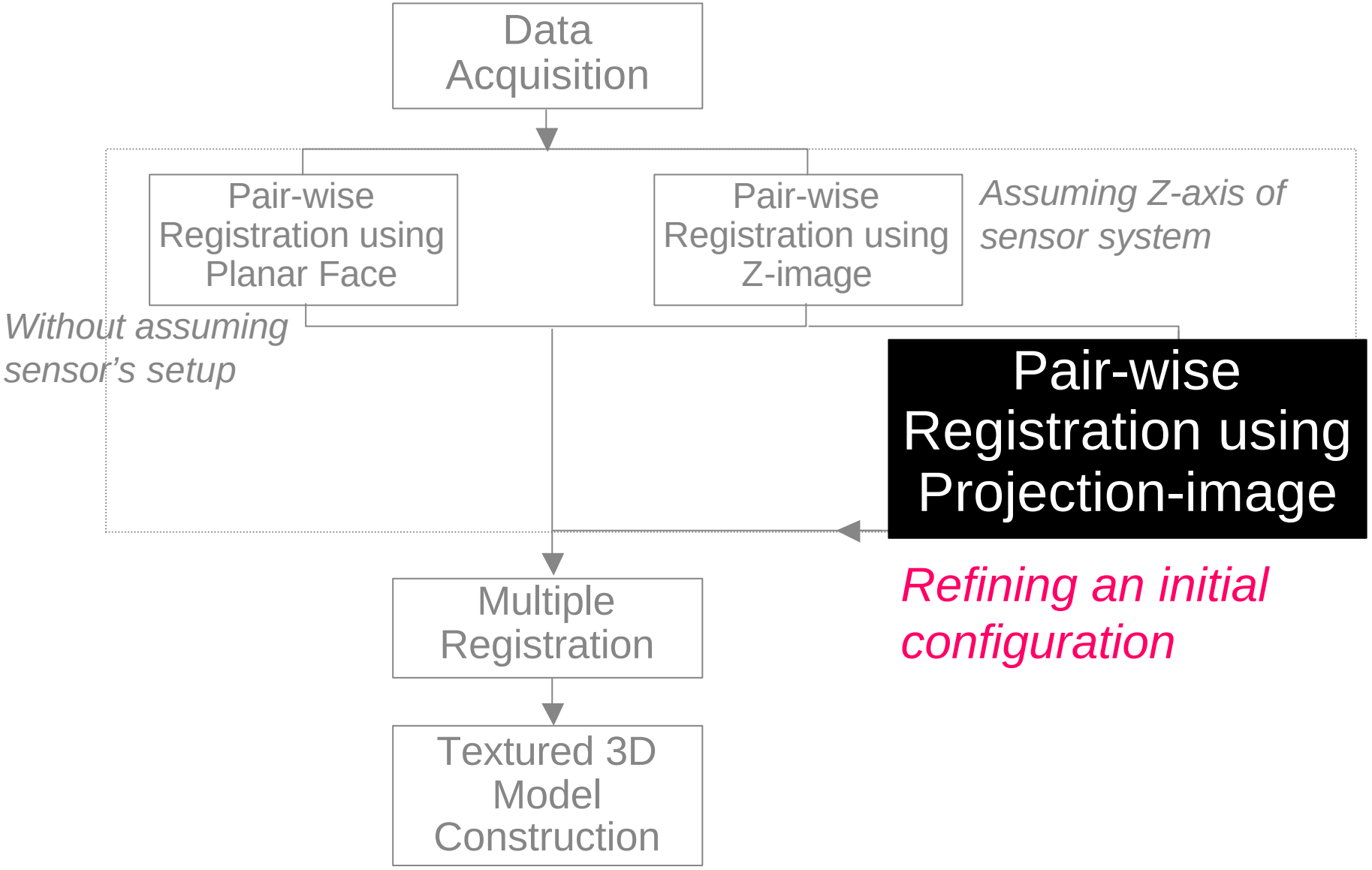
A pair of laser range images

Failed in reliable interpolation of ground surface near sensor's location

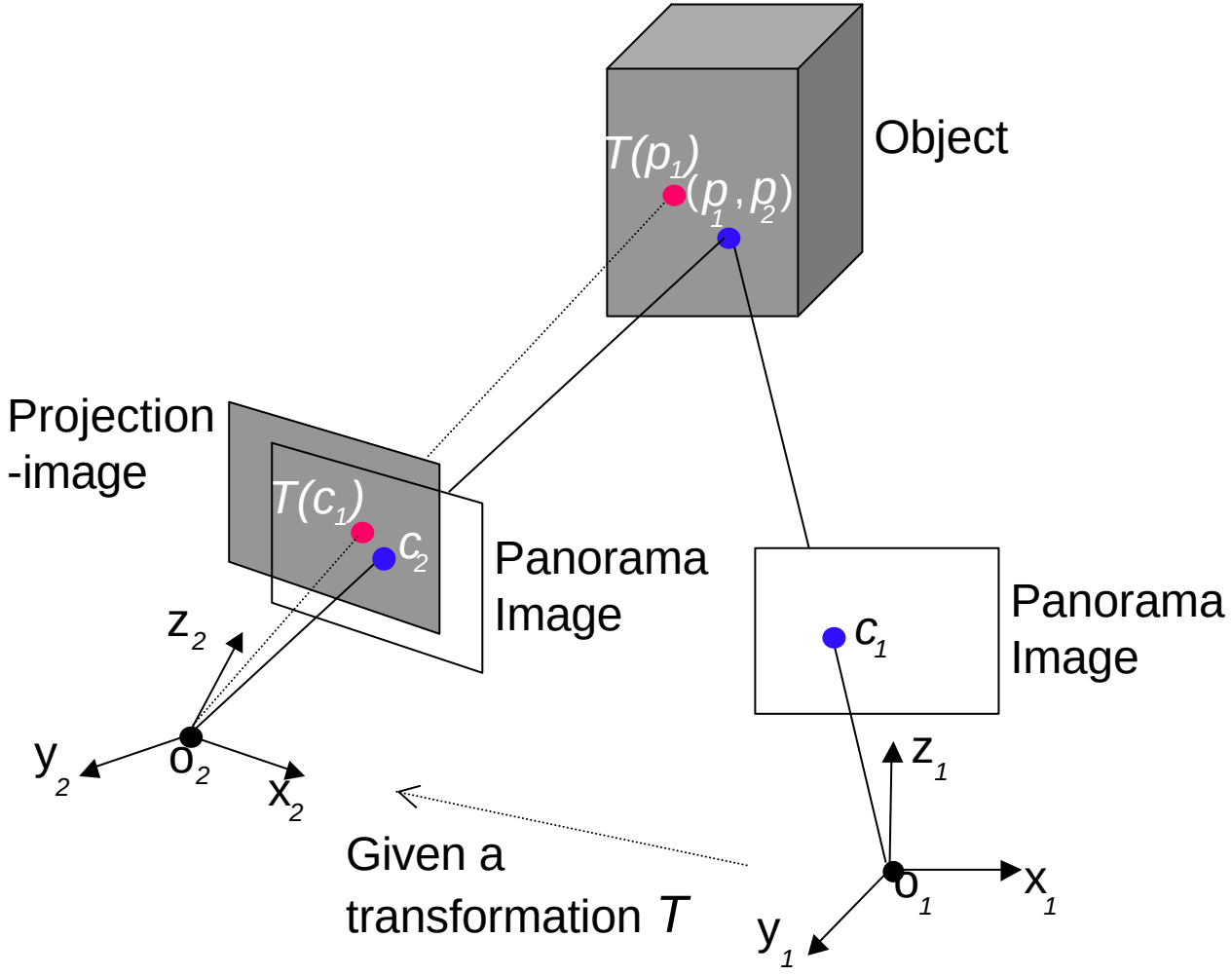


Uneven ground surface near sensor's location

Flow of the Research



What is Projection-image?




Panorama Image 1


Panorama Image 2


Projection-image

Pair-wise registration using Projection-image

Assumption

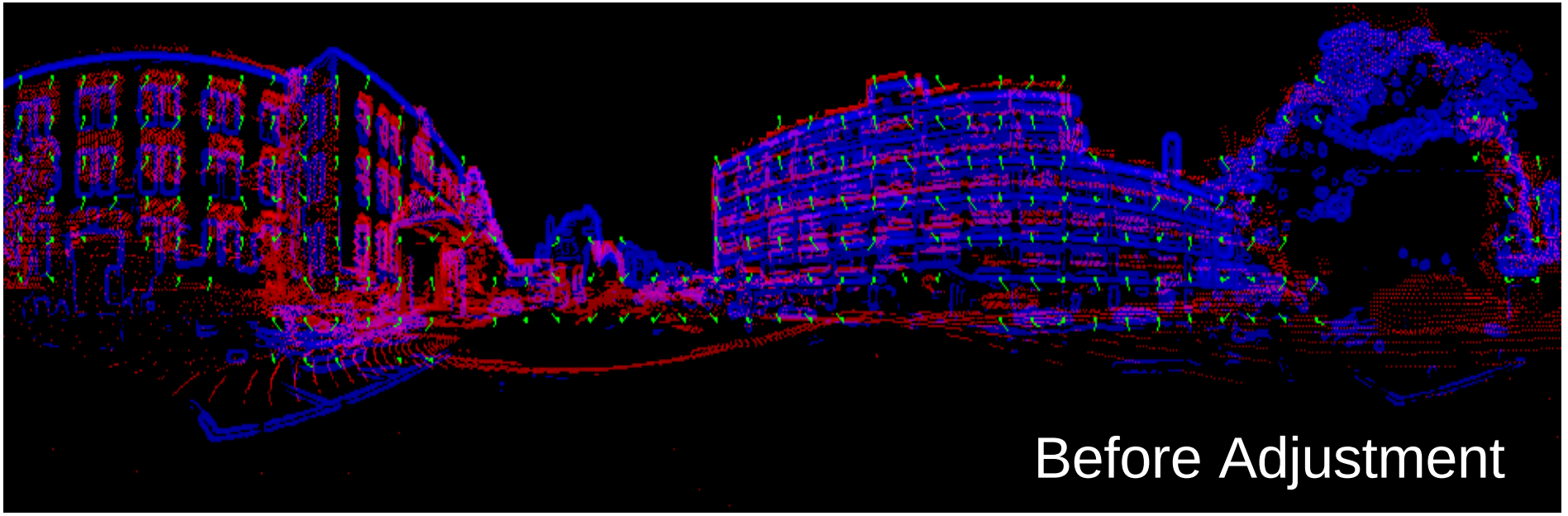
An initial configuration is given.

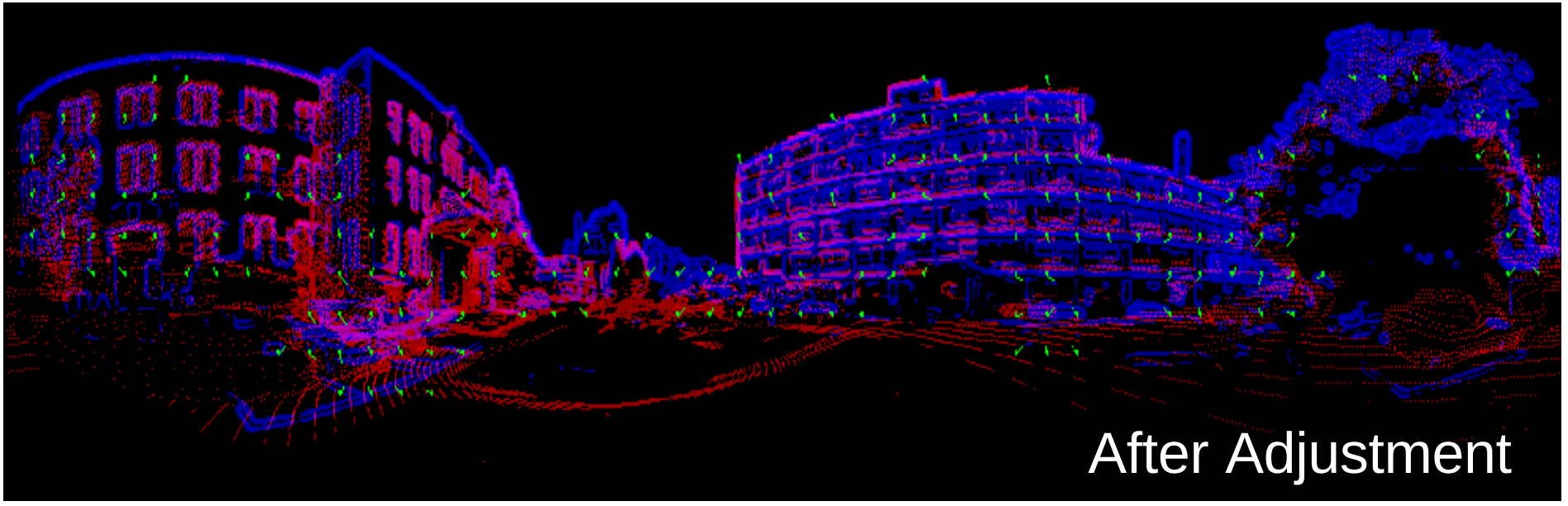
Objective

Refining the initial configuration using Projection images.

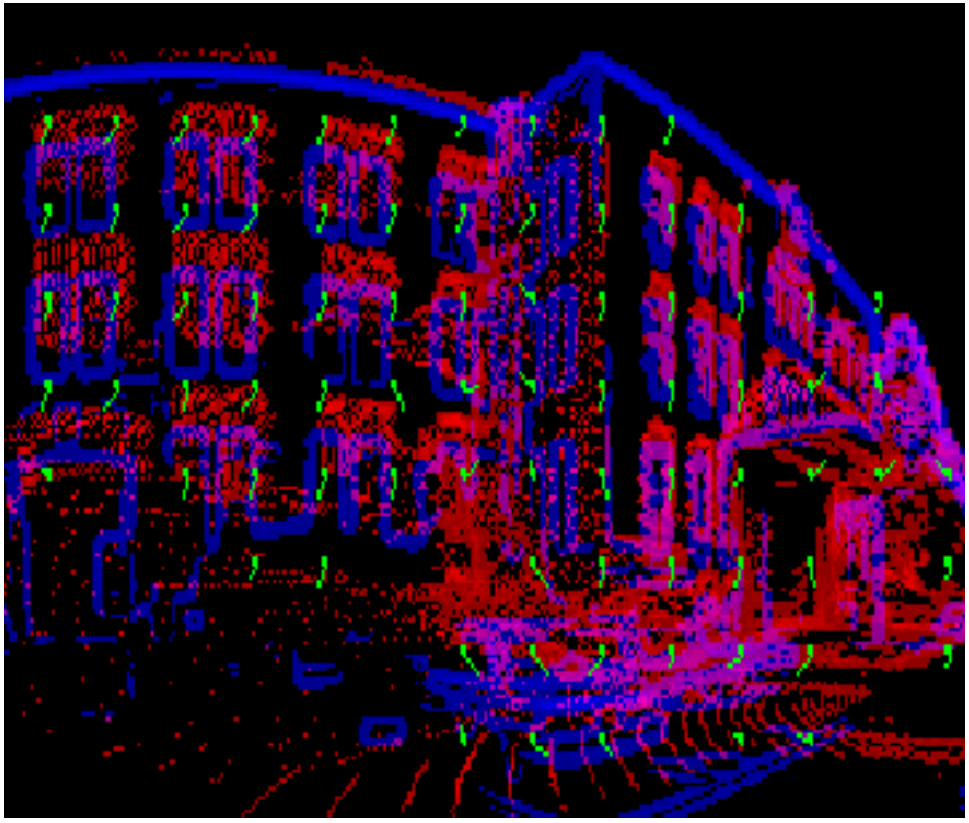
Procedure

1. Conjugated image points are found through correlation of the gradient of Projection-image and panorama image.
2. Adjustment is obtained by recovering co-planar condition on the set of conjugated image points.

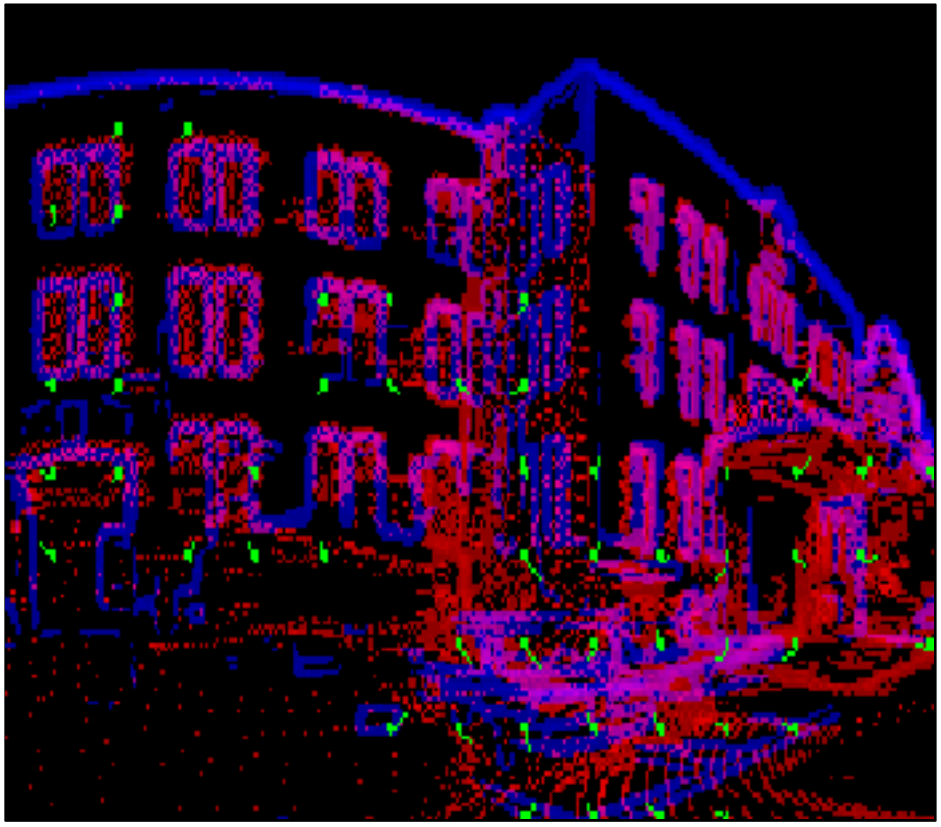

Before Adjustment


After Adjustment

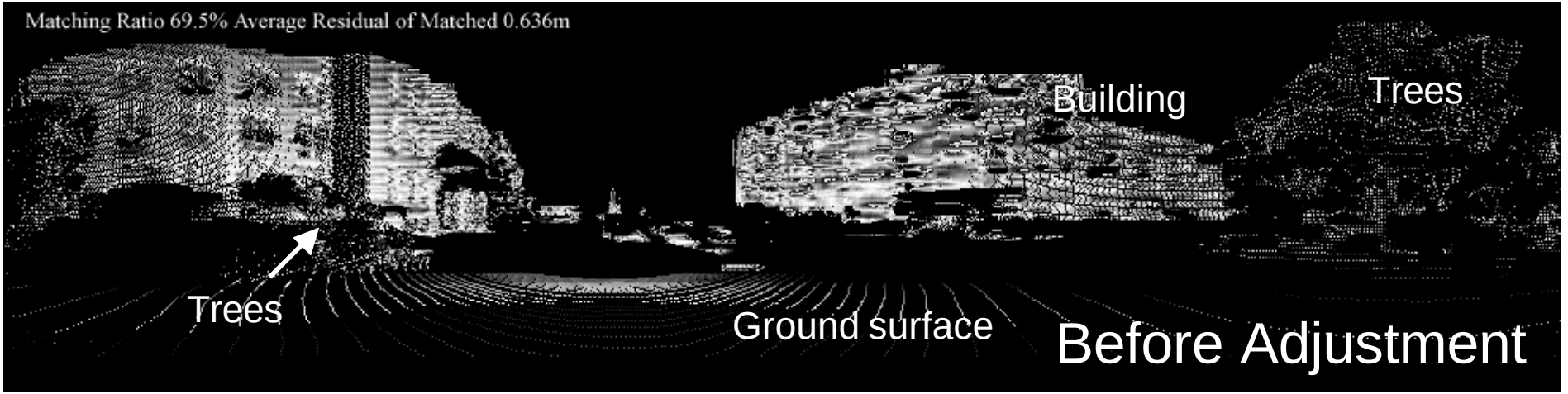
Result of Pair-wise registration using Projection-image



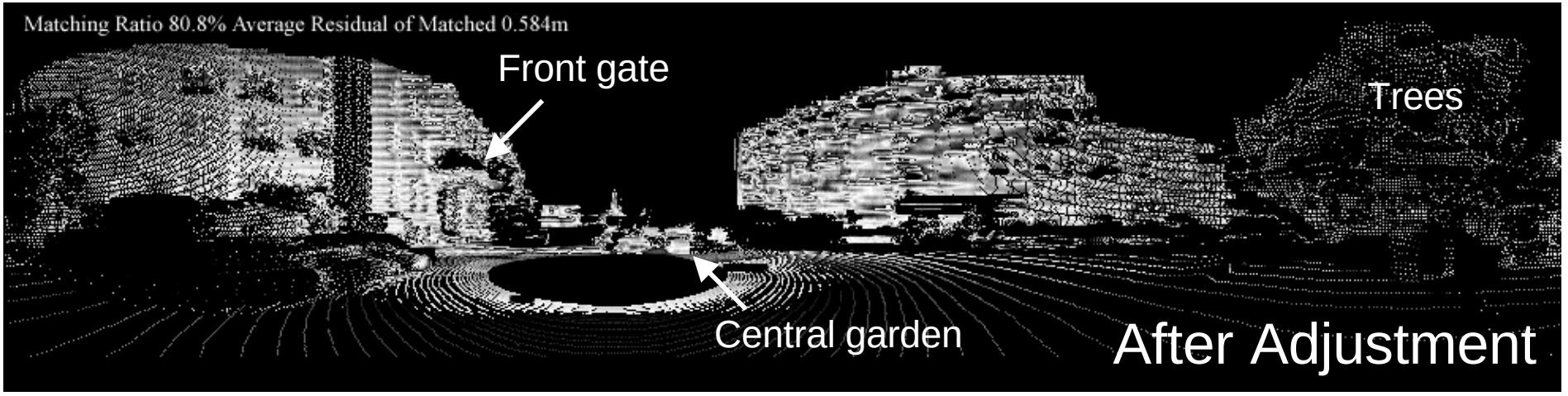
Before Adjustment



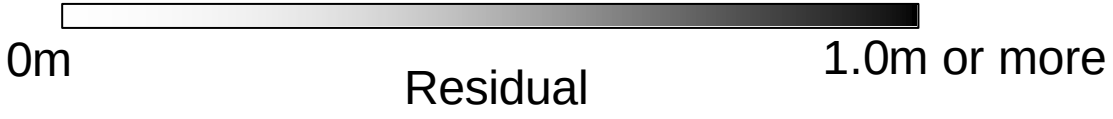
After Adjustment



Matching ratio 69.5%, Average residual of matched points 0.636m

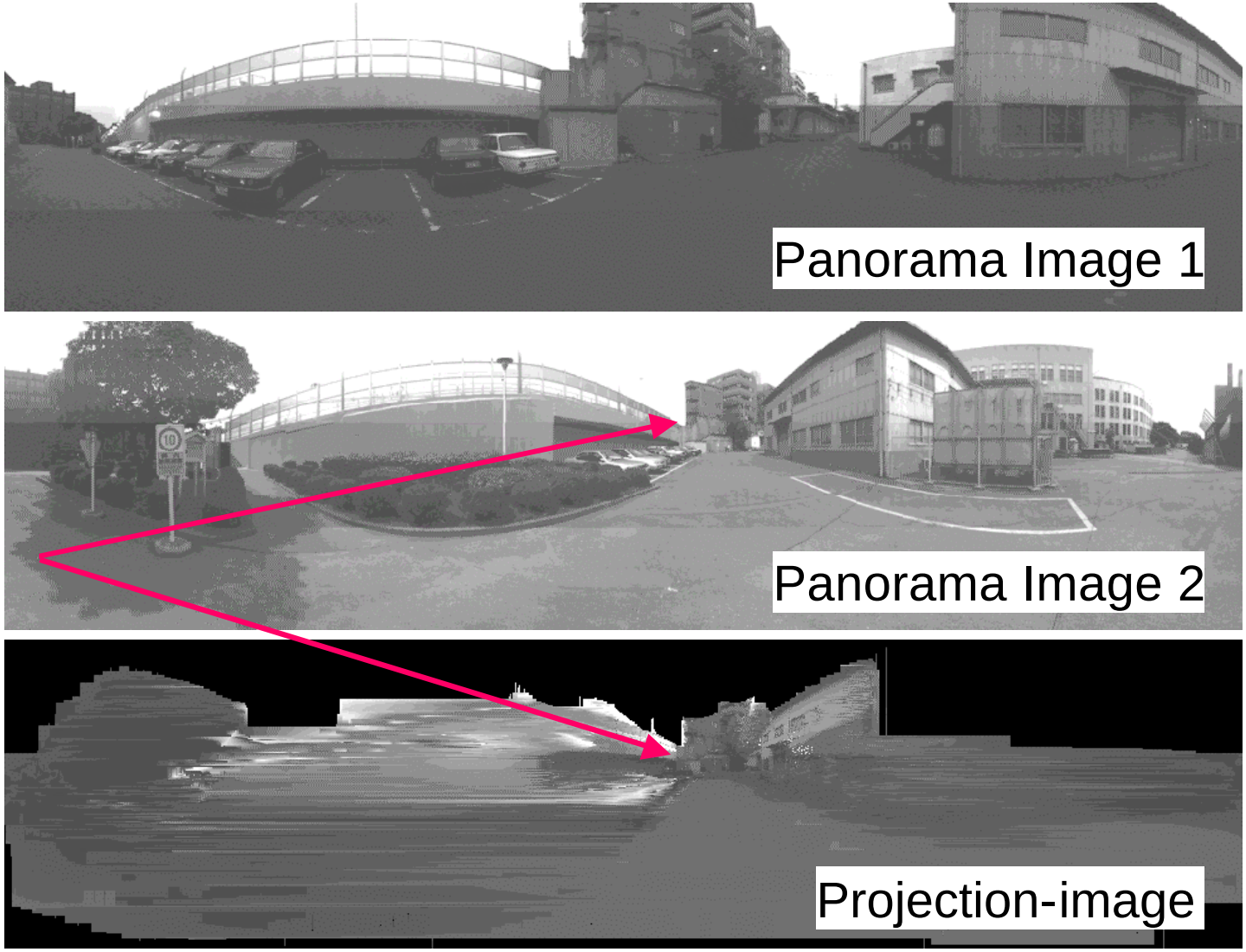


Matching ratio 80.8%, Average residual of matched points 0.584m



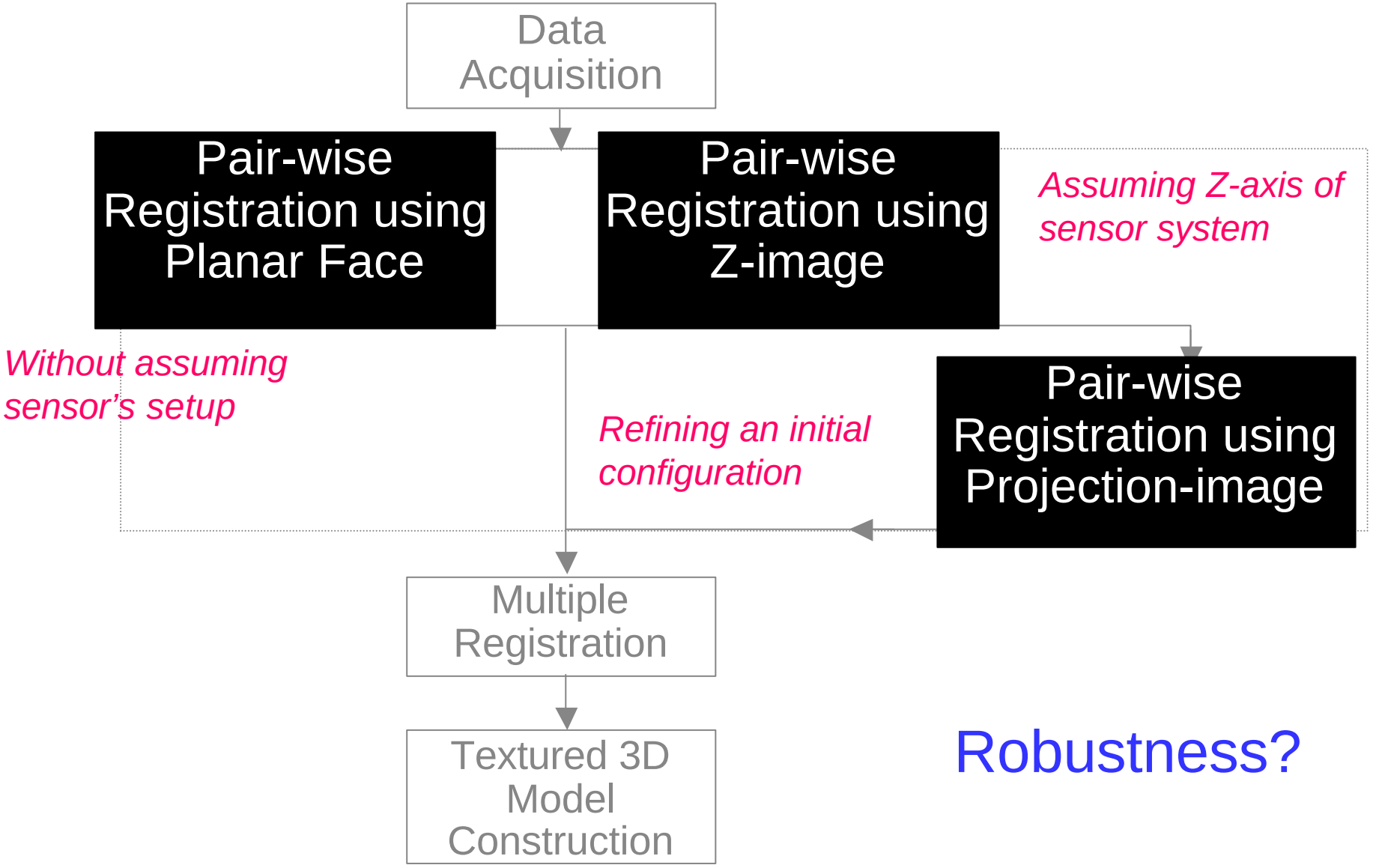
Limitation of Registration using Projection-image

Ineffective to occluded field of vision

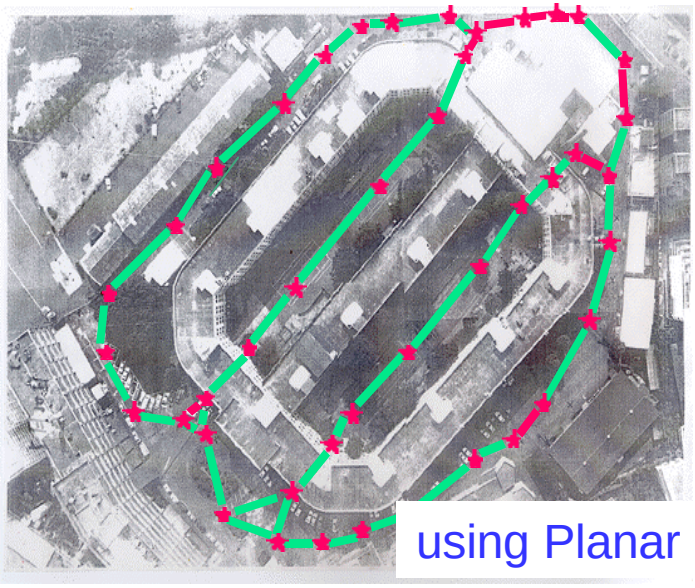


Insufficient common feature for registration

Flow of the Research



Robustness Examination of pair-wise registration methods

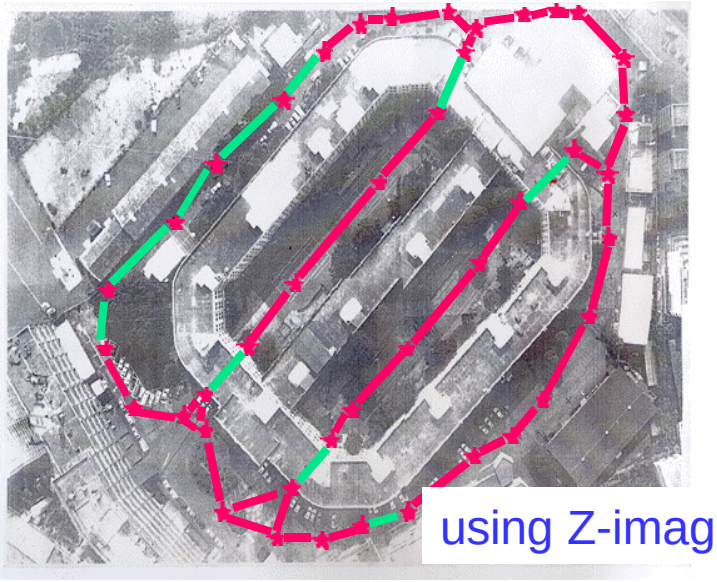


using Planar Face

Ratio of Success is 17.4%

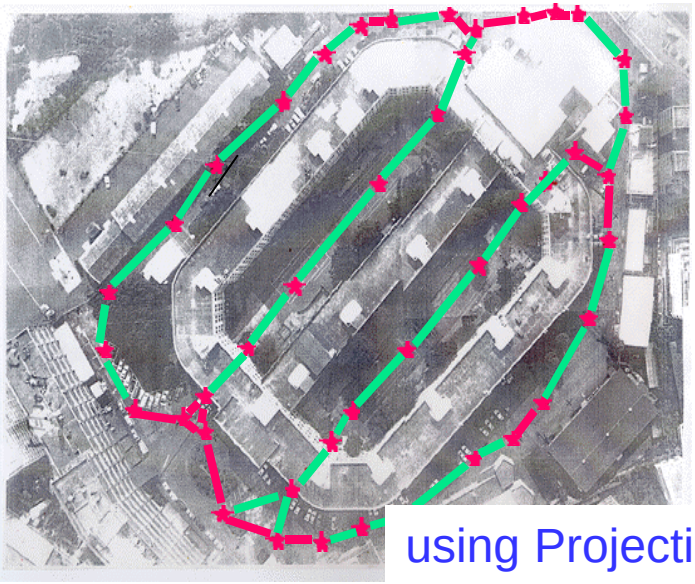
Failed case

Succeeded case



using Z-image

Ratio of Success is 78.3%



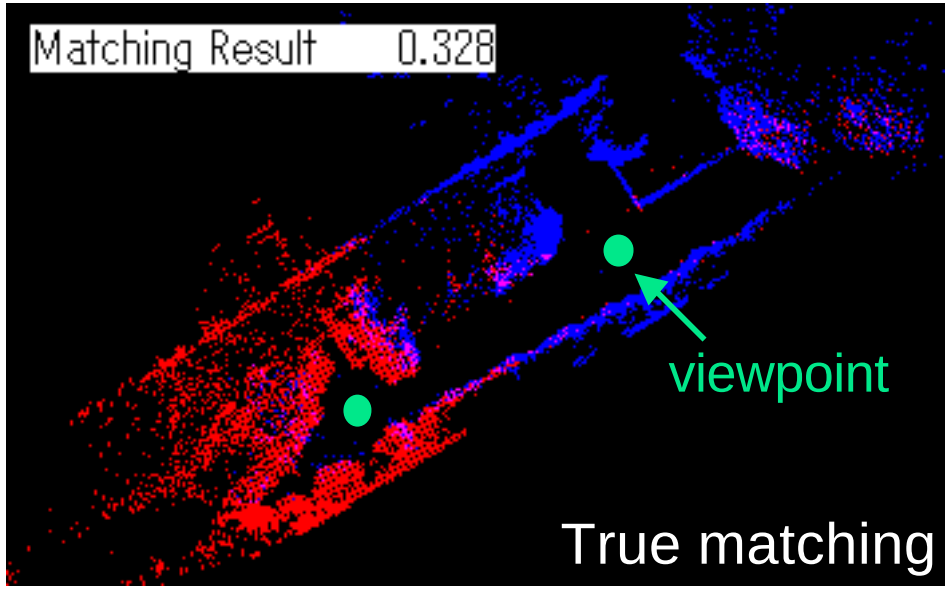
using Projection-image

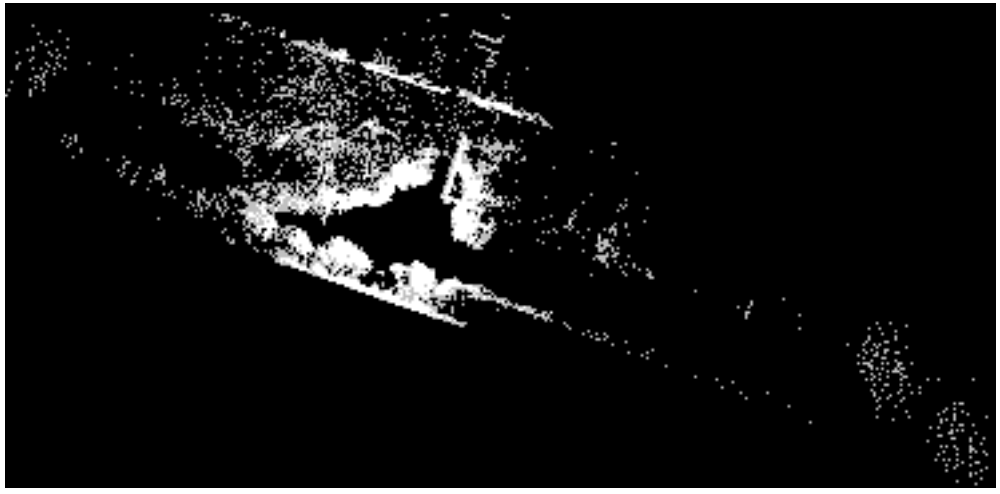
Ratio of Success is 32.6%

Failure in all pair-wise registrations

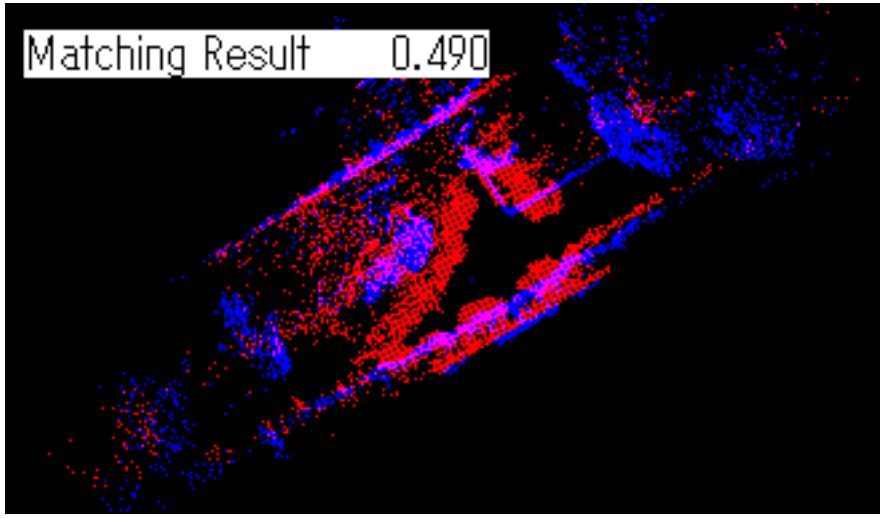
- insufficient overlay of the two images because of occlusion

Z-image 1



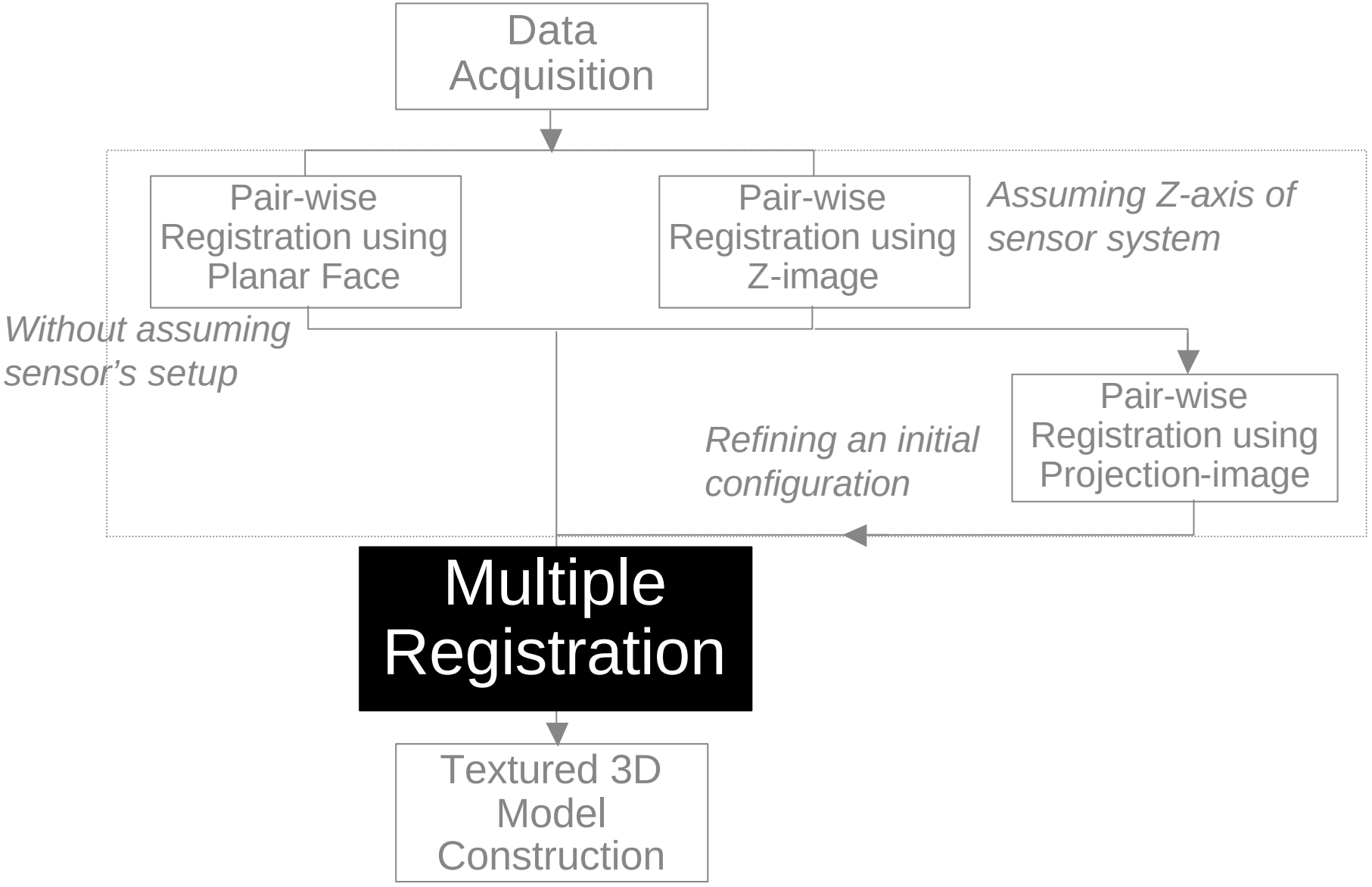


Z-image 2



Incorrect result of Z-image matching

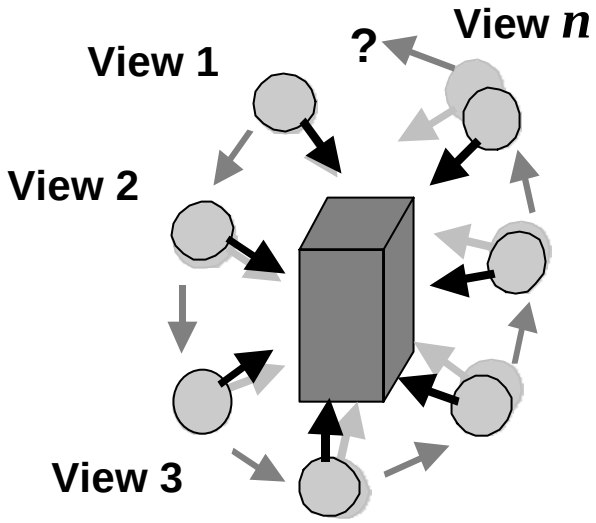
Flow of the Research



Why is Multiple Registration needed?

Problem

Error accumulation in pair-wise registration



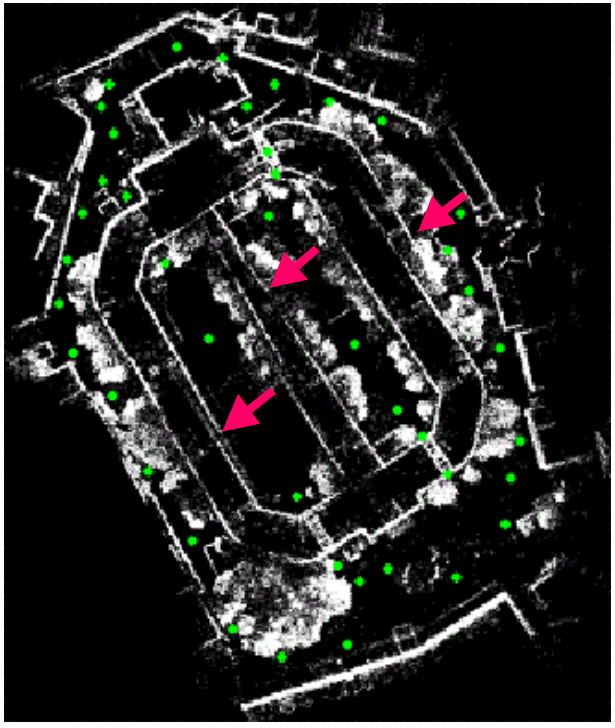
Objective

To adjust local configurations in order to achieve a closed network

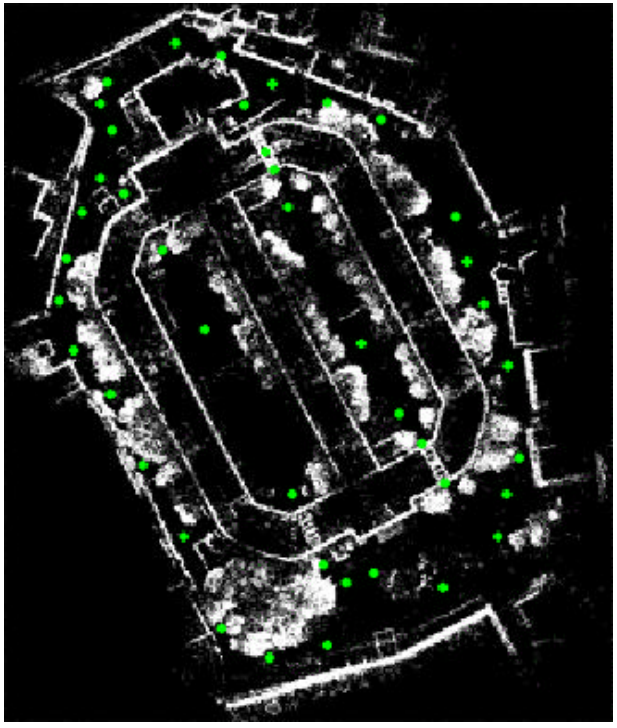
Procedure

1. Sequential registration using the shortest path
2. Adjusting local configuration to minimize the violation to the result of pair-wise registration

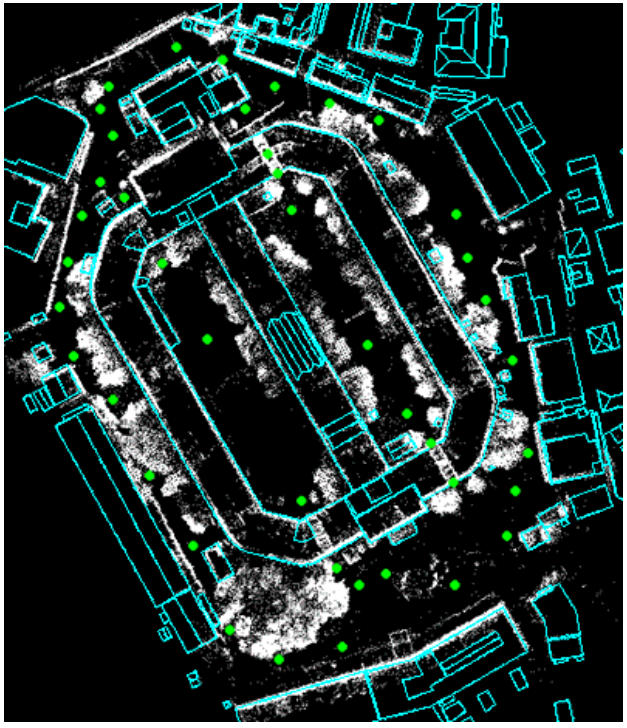
Multiple registration without using GPS points as auxiliary data



Before
multiple registration

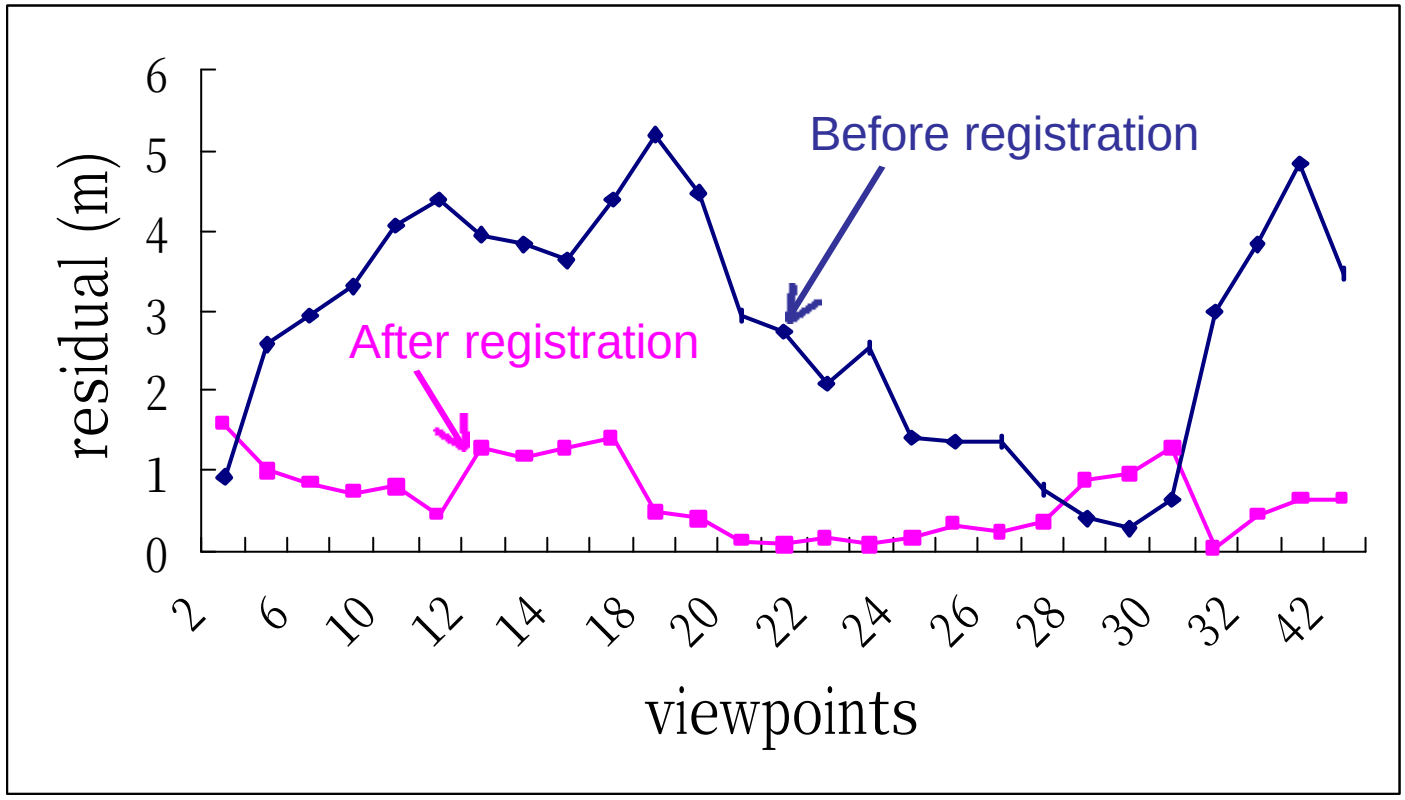


After
multiple registration



Overlapping with
a 1:500 digital map

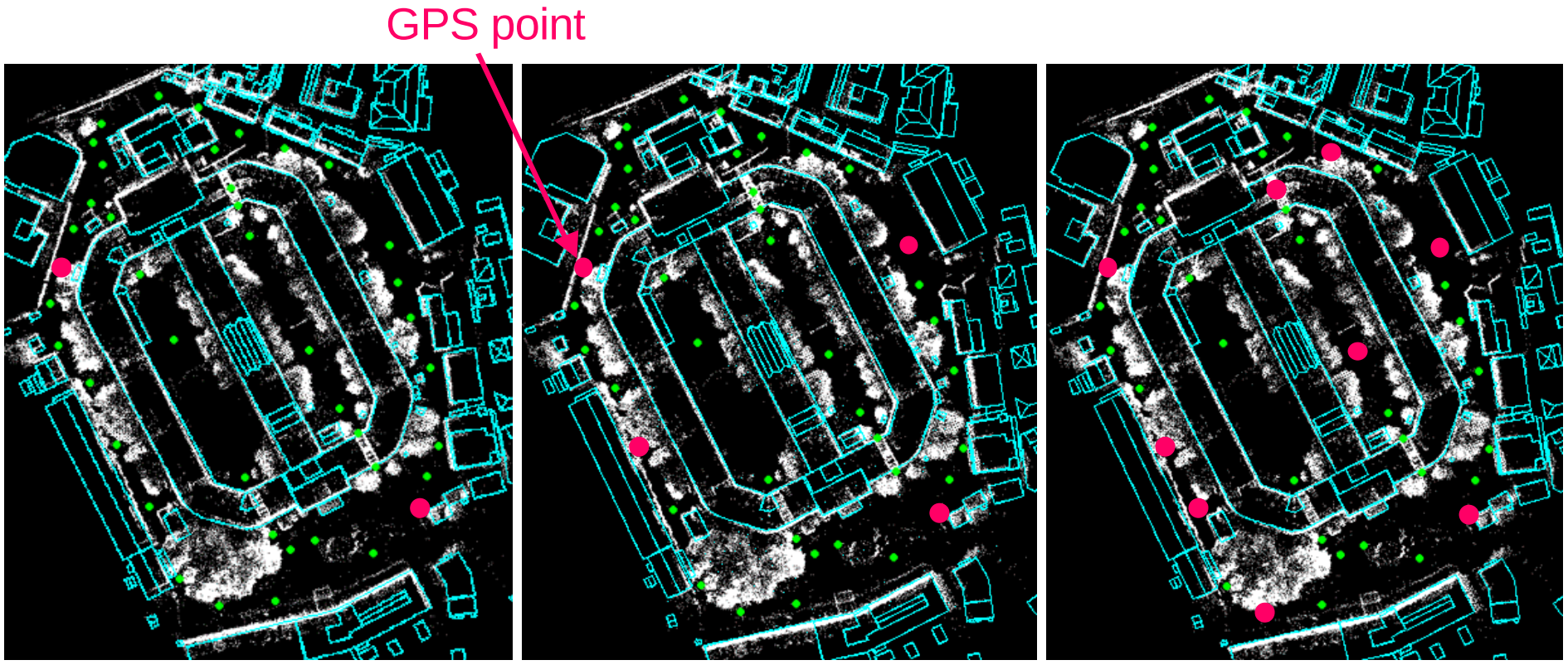
Accuracy examination of multiple registration without using GPS points as auxiliary data



Mean of residuals before registration is 3.231m

Mean of residuals after registration is 0.663m

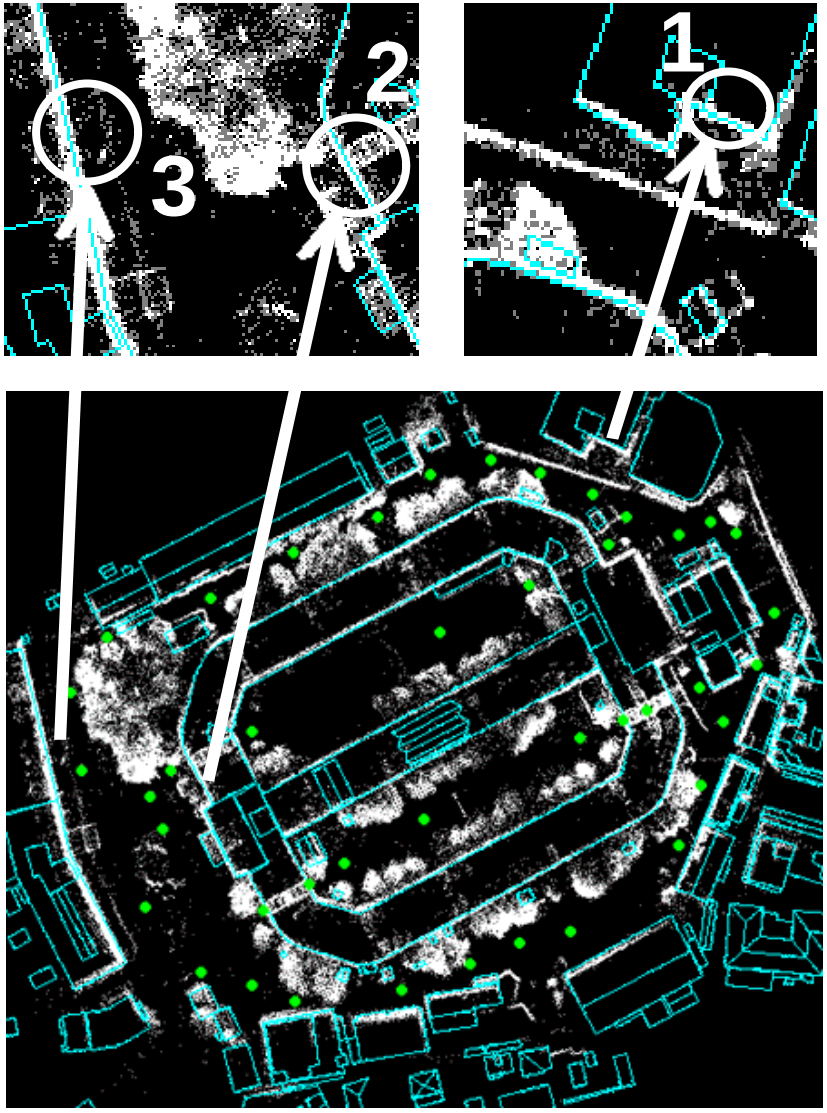
Multiple Registration using GPS measured viewpoints

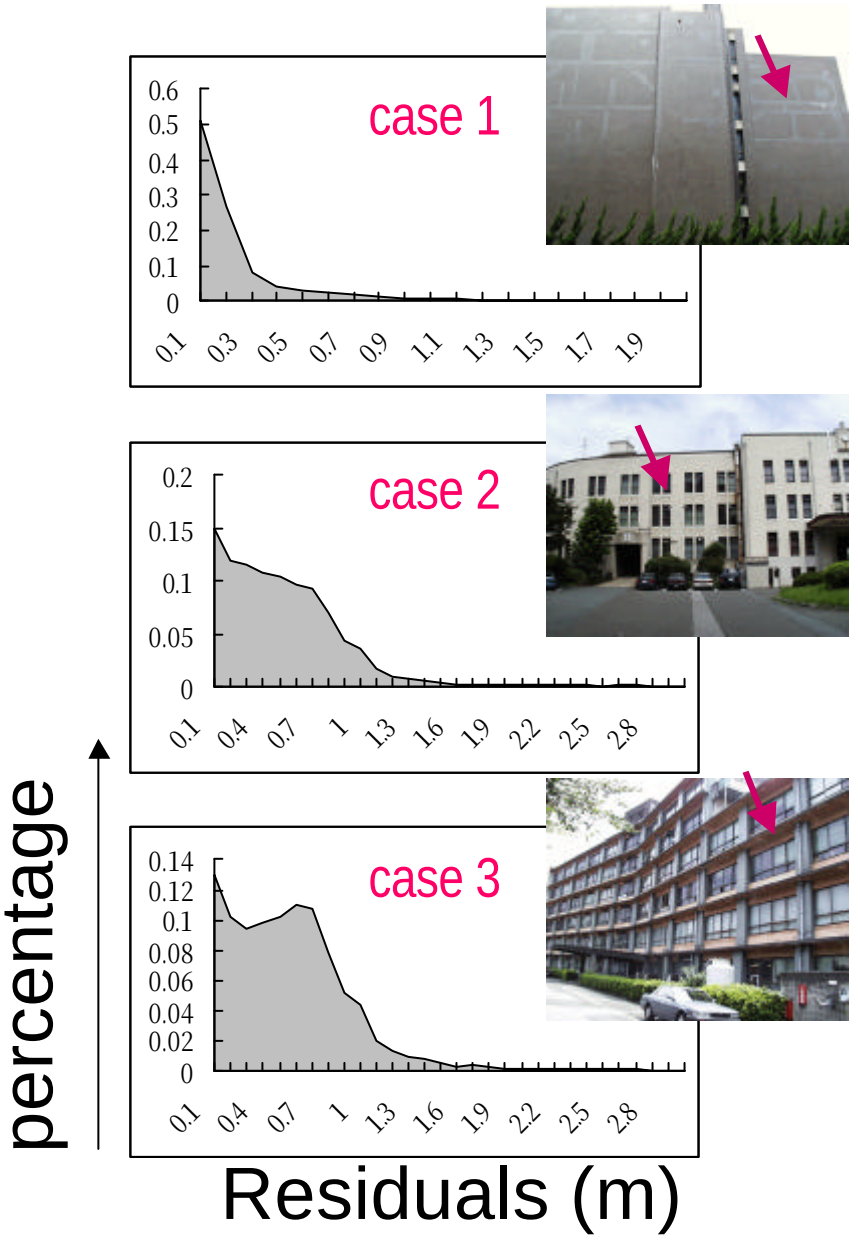


Mean of residuals from viewpoints to the ground truth

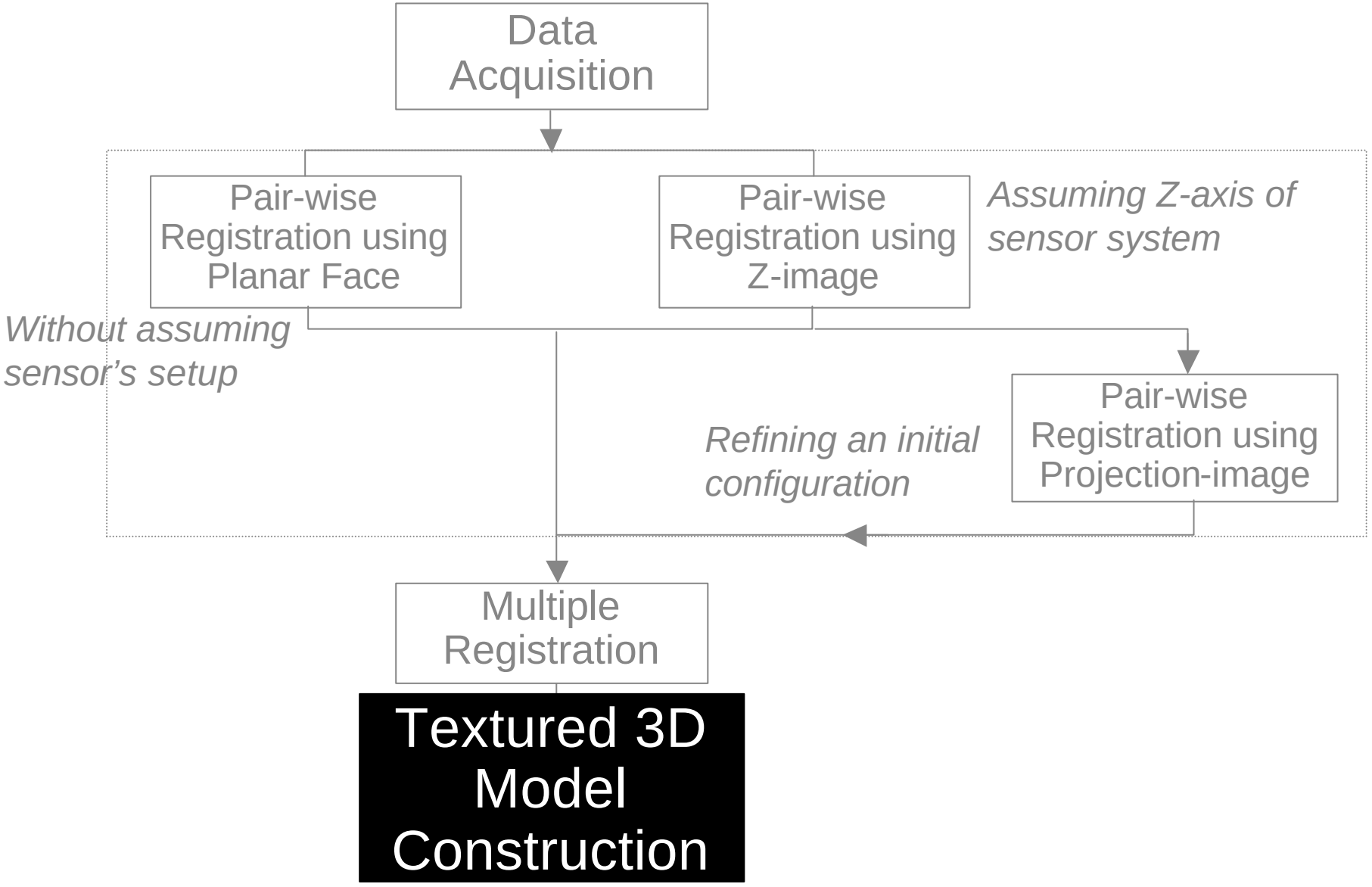
2 GPS points :0.612m 4 GPS points:0.436m 9 GPS points:0.283m

Residuals from range points to 1:500 digital map





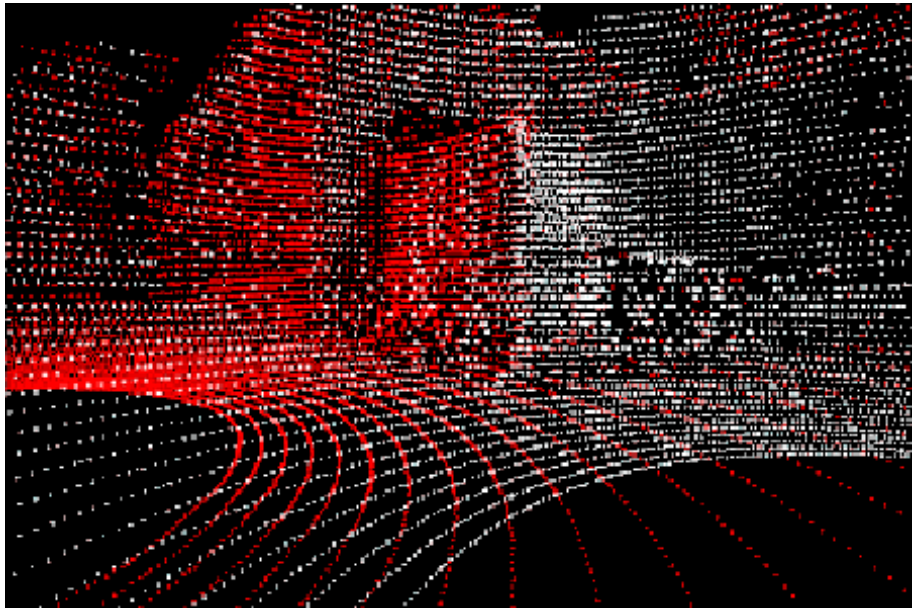
Flow of the Research

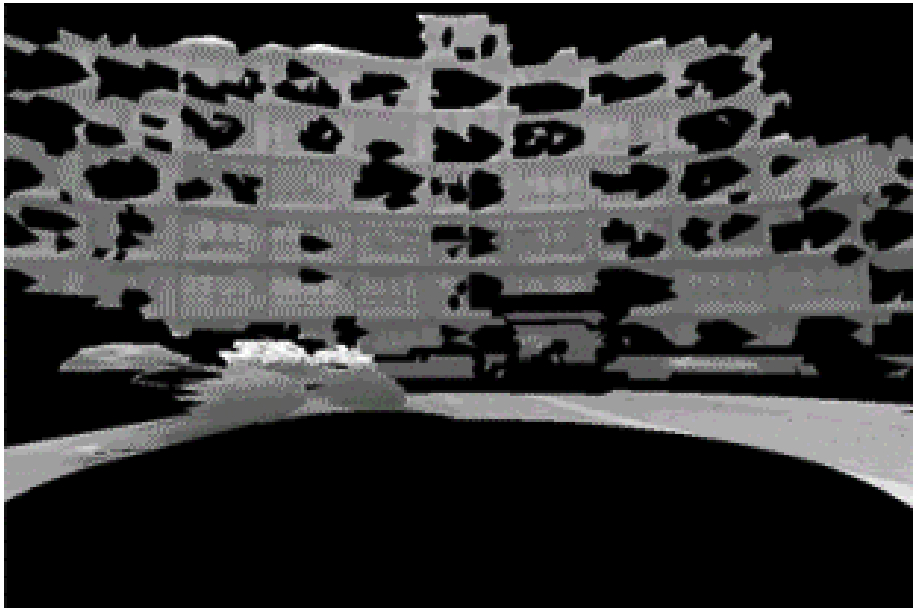


Textured 3D model construction by integrating multiple range and CCD images

Problems

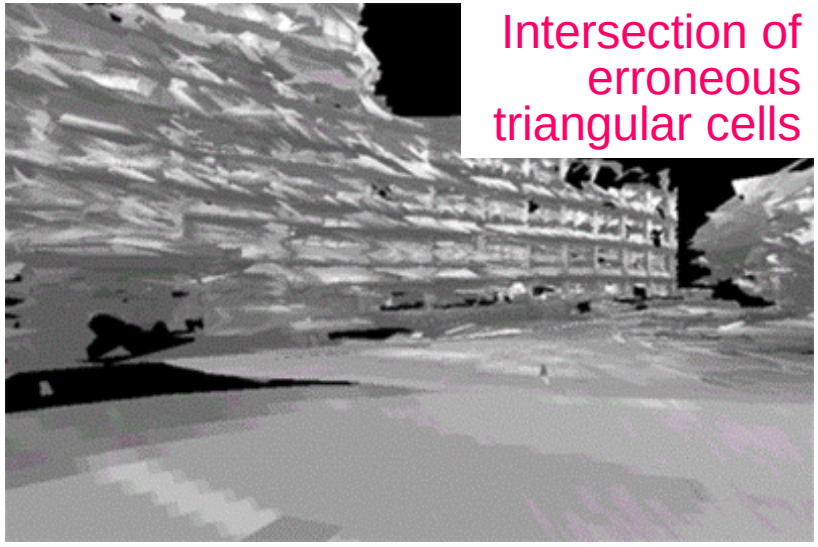
- Overwhelming redundant range data
- Error and failure of range data
- Balance of efficiency and accuracy in model representation



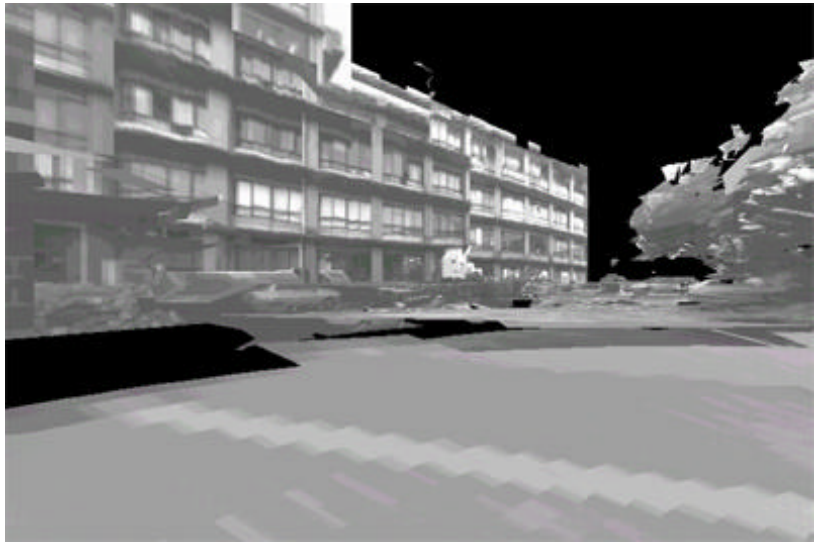


A TIN-based representation of a single view

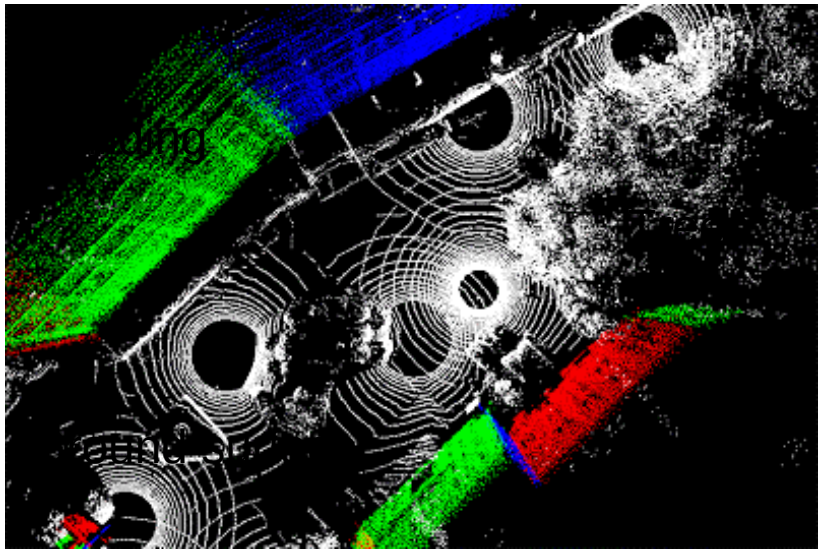
A point-based representation



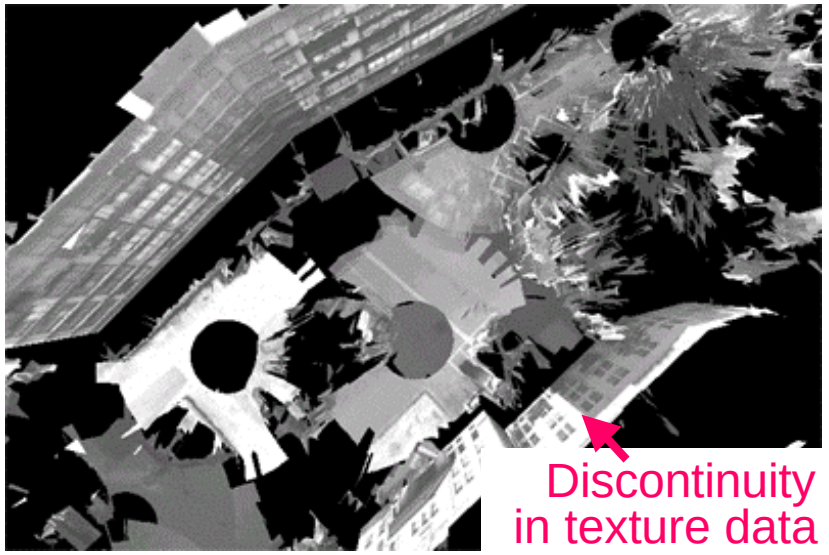
A TIN-based representation



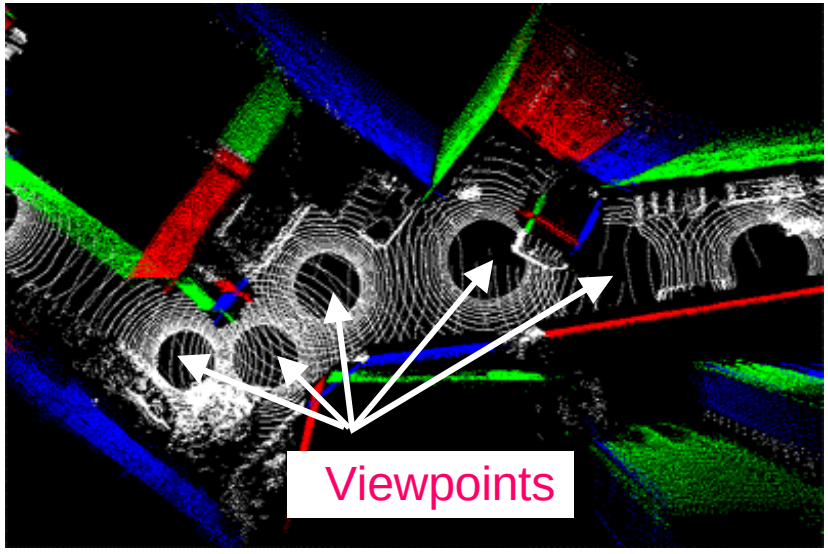
A surface-based representation



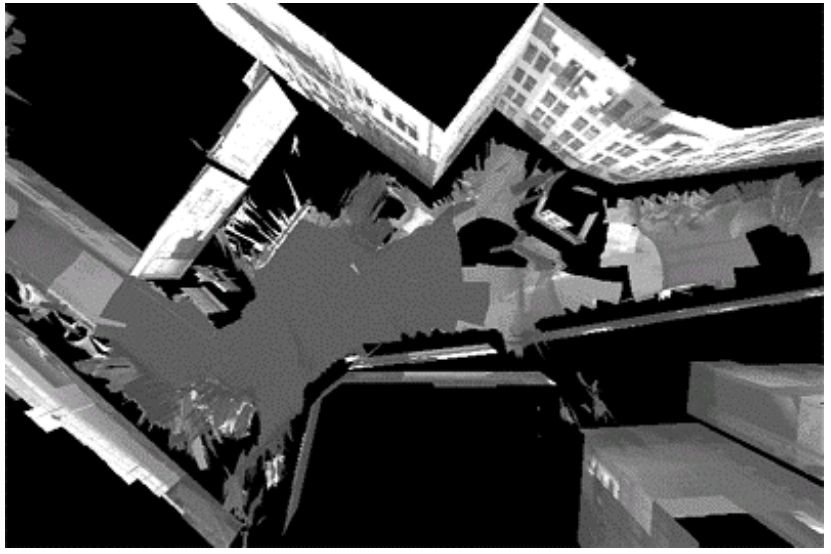
A point-based representation
Color is to discriminate different objects



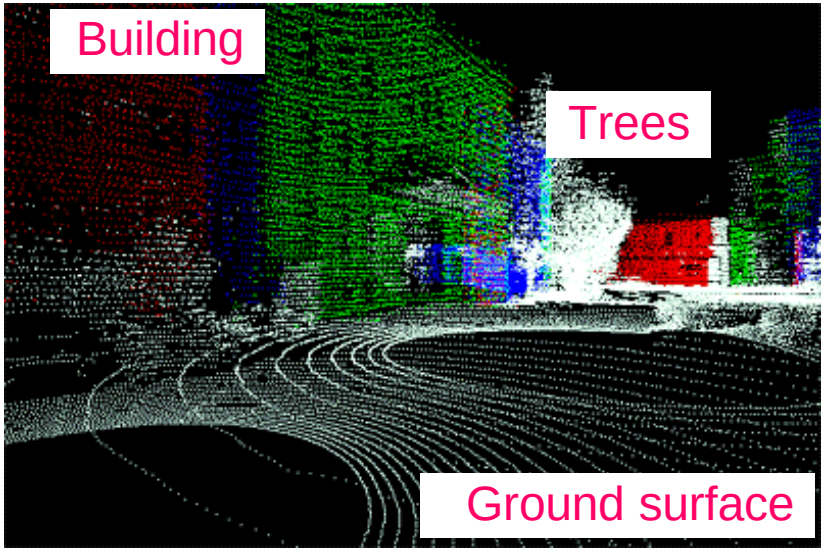
A surface-based representation



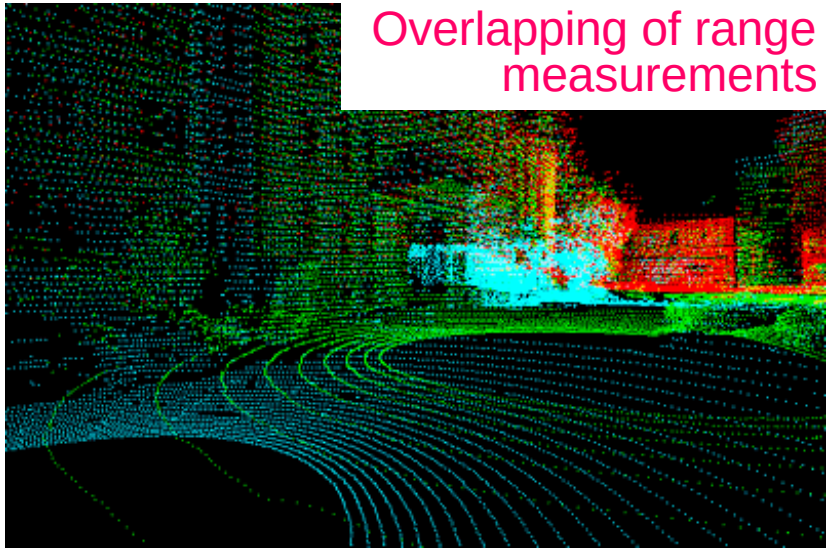
A point-based representation



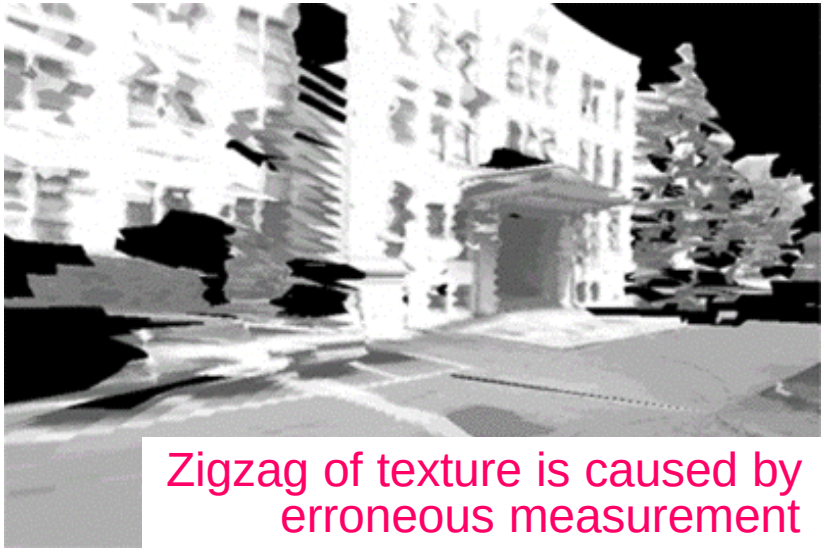
A surface-based representation



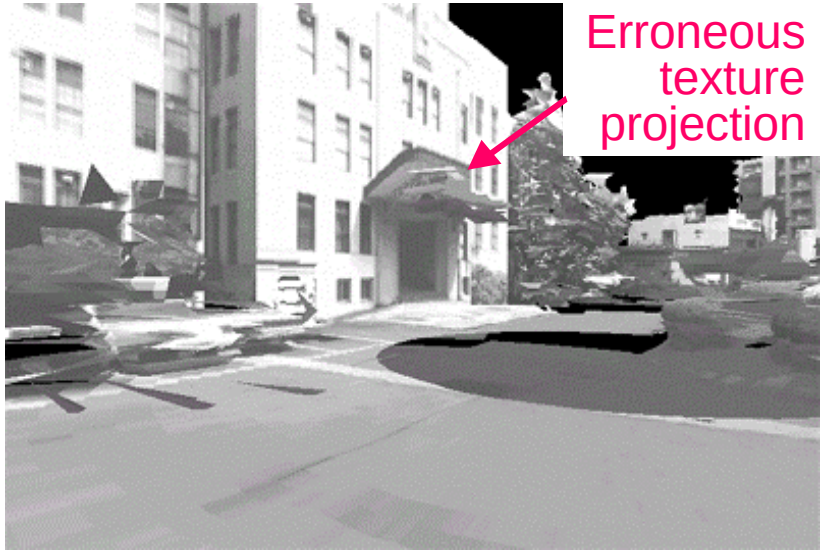
A point-based representation
Color is to discriminate different objects



A point-based representation
Color is to discriminate different views

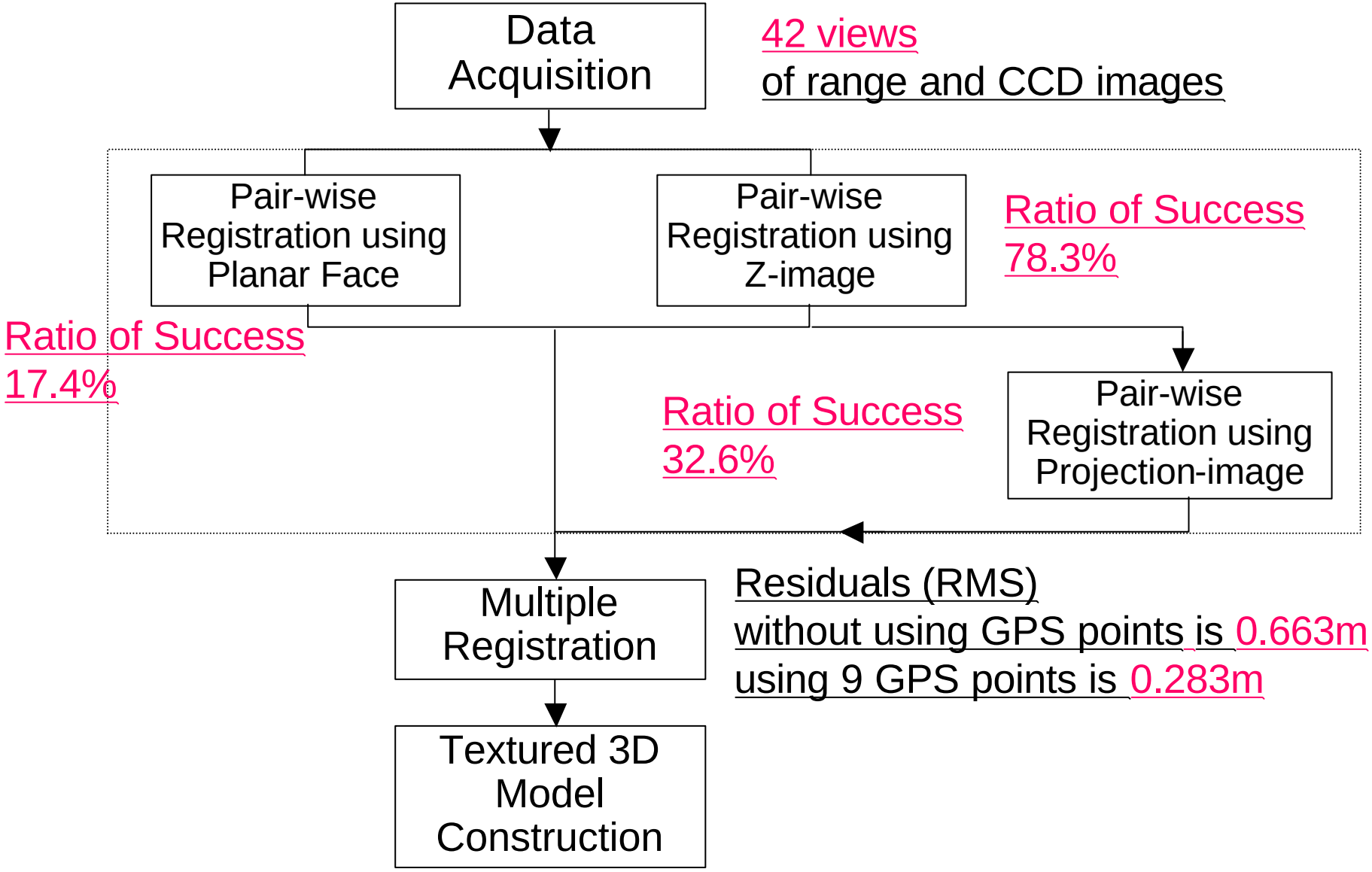


A TIN-based representation



A surface-based representation

Summary of the Results



Conclusions

Developing a framework for the reconstruction of textured 3D urban object using ground-based laser range and CCD images

- An acquisition system is developed.
- A pair-wise registration without assuming sensor's setup is developed using planar face.
- A pair-wise registration assuming Z-axis of sensor system is developed using Z-image.
- A pair-wise registration refining an initial configuration is developed using Projection-image.
- A multiple registration method is developed.
- A textured 3D model construction method is developed.

Future Studies

- Developing a method for automatic selecting and optimizing viewpoints in data acquisition.
- Constructing textured 3D model according to application requirement
- Minimizing the discontinuity of intensity value in texture data
- Developing a mobile system to improve the efficiency for the reconstruction of urban 3D objects using range and CCD images.