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Toward Autonomous Wall-Climbing Robots for Inspection of Concrete Bridges and Tunnels

Jizhong Xiao

INSPIRE

INSPECTING AND PRESERVING
INFRASTRUCTURE THROUGH
ROBOTIC EXPLORATION

Toward Autonomous Wall-climbing Robots for Inspection of Concrete Bridges and Tunnels

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Sept. 19, 2018



Outline

- Introduction
  - Opportunity and Impact
  - Project Goals
- Wall-Climbing Robot Prototypes
  - City-Climber
  - Rise-Rover
  - GPR-Rover
- Visual Inspection and Visualization
  - CNN-Based Visual Inspection
  - InspectionNet and Data Set
  - Positioning and Visualization
- Work in Progress
- Summary

Introduction

❖**Bridge Inspection[1] – 47,619 (7.7%) bridges on American roads are rated in poor conditions.**

4/10 of all 615,000 bridges are 50 years or older

❖**Dams Inspection[2] – 15,498 (17%) dams in U.S. are identified as high-hazard potential. Average age of the 90,580 dams is 56 years.**

❖**Tunnel Inspection[3] – 473 tunnels**

[1] FHWA Report: Bridge Condition by Highway System 2017

[2] American Society of Civil Engineers (ASCE): 2017 Infrastructure Report Card

[3] FHWA-HIF-15-006: **Specifications for the National Tunnel Inventory**

Bridge Inspection





Tunnel Inspection

Measure thickness of concrete layers

Opportunity/Impact

- **Inspection using wall-climbing robots**
  - **Reach difficult-to-access locations (e.g., the bottom side of bridge decks, column),**
  - **Take close-up pictures and videos,**
  - **Record and transmit NDE data to a host computer for further analysis.**

- **Impact :**
  - Vertical mobility makes data collection easier
  - Decrease costs, improve safety, and increase inspection speed & accuracy
  - Eliminate the need for scaffolding and blocking traffic

InnovBot LLC

Project Goals

1. To develop reliable and robust robots to provide vertical mobility for field deployment and data collection on concrete structures;
2. To develop NDE methods and integrate them in the rover to detect surface flaws and subsurface defects;
3. To develop image processing algorithms and innovative methods for accurate positioning of flaws;
4. To empower the rovers with rich knowledge and intelligence to automate the bridge inspection process with minimal human intervention.

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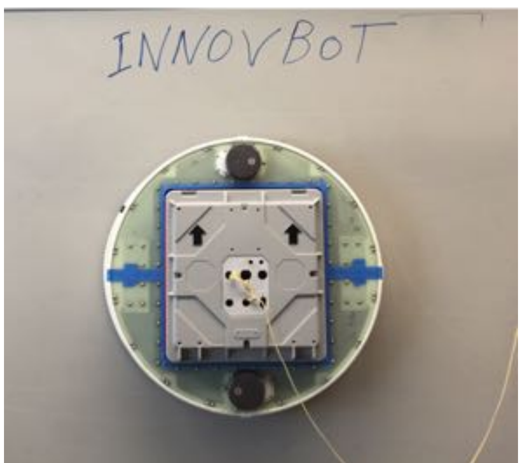
CCNY Wall-Climbing Robots

City-Climber



GPR-Rover-v1

GPR-Rover-v2

Rise-Rover

GPR-Rover-v3

City-Climber for Visual Inspection

City-Climber-V3

City-Climber-MVP

City-Climbers: compact wall-climbing robots to carry video cameras and light-weight payload (<10 lb) for visual inspection. They can operate on both smooth and rough surfaces.

City-Climber Robots are versatile tools that can provide

- Real-time video feed
- Follow cracks beyond reach of scaffold
- Cheaper and safer way to take close-up pictures for thorough inspection
- Photographic documentation

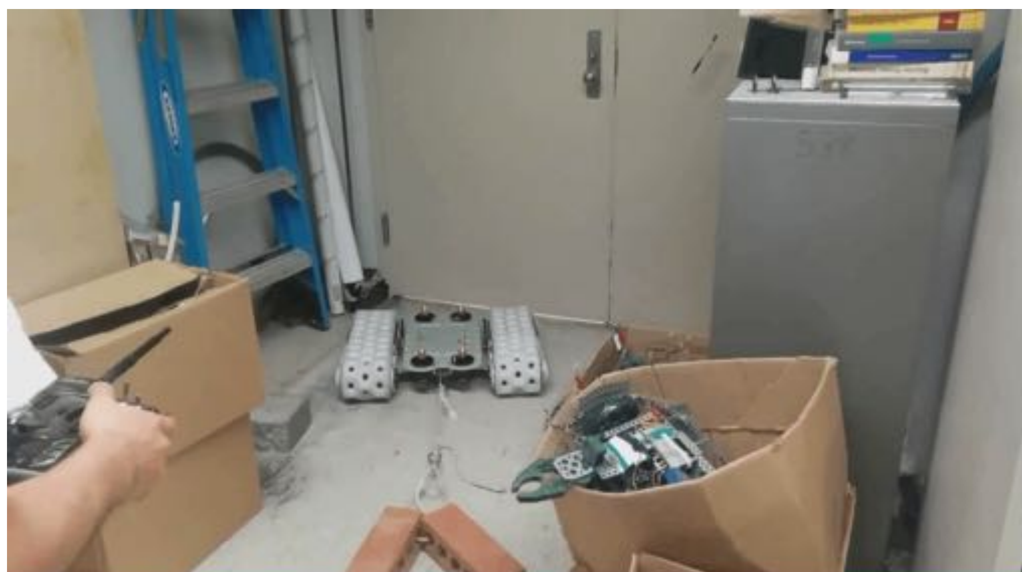
ICRA2006 Best Video finalist

Rise-Rover for NDT Inspection

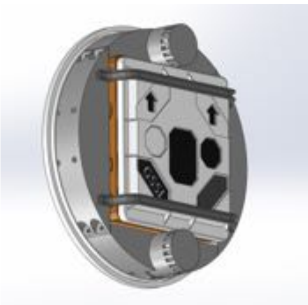
Rise-Rover: a wall-climbing robot to carry heavy NDT instruments (>50lb) for visual and contact-based inspection.

- Each drive module can operate independently.
- Two drive modules can carry large payload.
- Provide vertical mobility for heavy NDT instruments
- Easily performs inspection on inclined/vertical surfaces, both rough and smooth

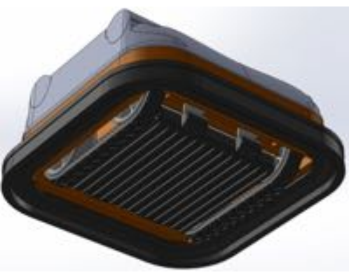
CLAWAR'2015
Industrial Robot
Innovation Award



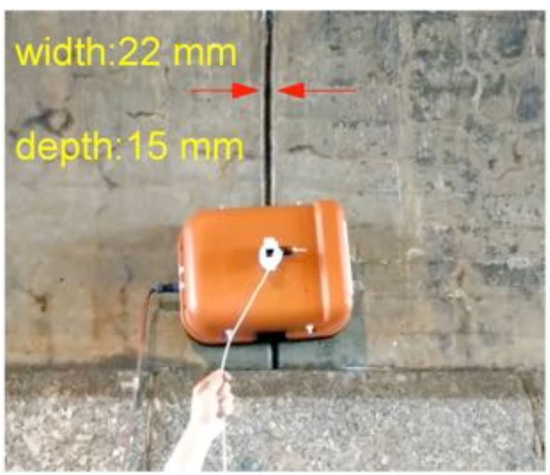
GPR-Rovers for NDT Inspection



GPR-Rovers: custom designed wall-climbing robots to carry GSSI's ground penetrating radar (GPR) for detecting subsurface defects, locating rebar and pipes.



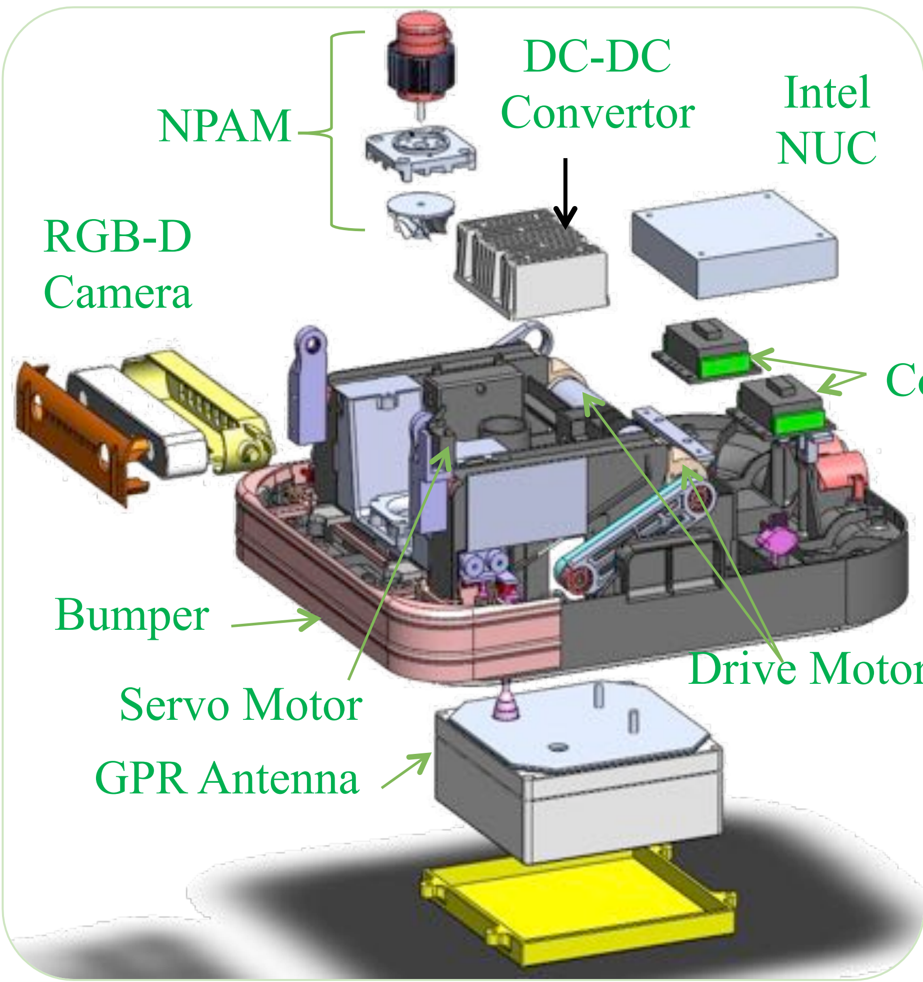
- **Empower GPR with vertical mobility**
- **Use RGB-D sensor to detect surface flaws**
- **Use GPR sensor to detect sub-surface defects**



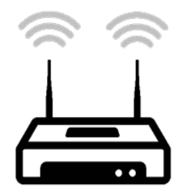
(*a*)Under - bridge area test

(*b*)Test at CCNY

Architecture of GPR-Rover-V3



Remote Controller



Communication Module

RGB-D Camera

GPR-Rover Videos

GPR-Rover-V2

GPR-Rover-V1

GPR-Rover-V3

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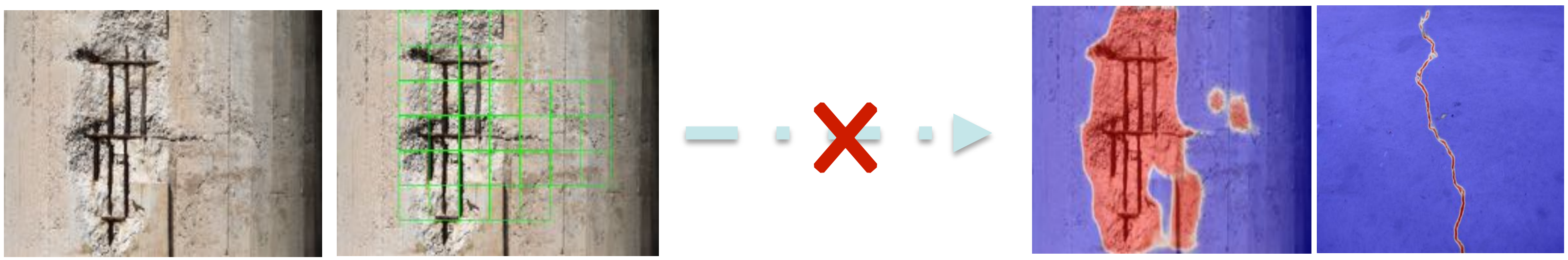
the City College of New York

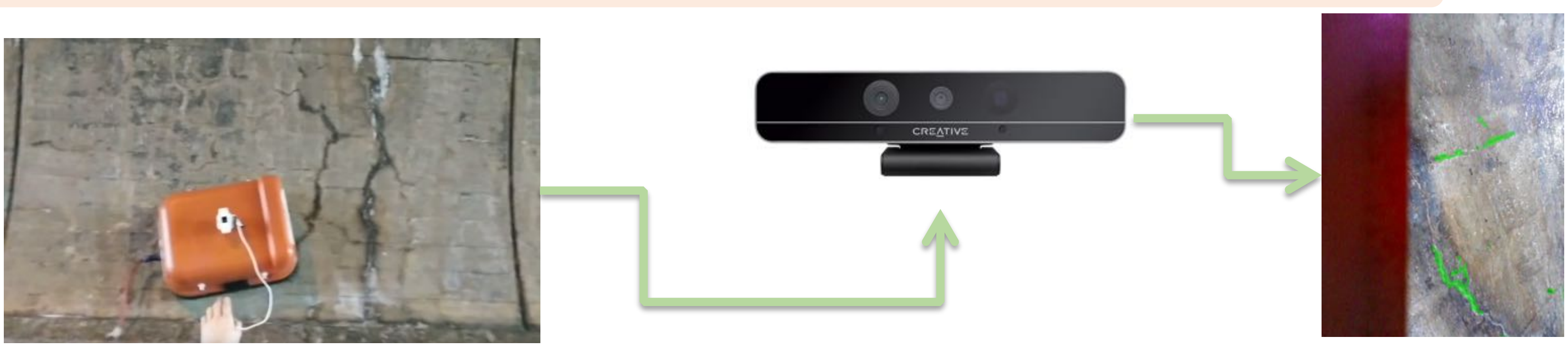
Visual Inspection Problems

Problem 1: Lack of Accurate detection and pixel-level measurement



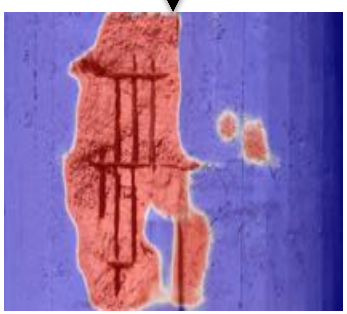
Problem 2: No Dataset available for machine learning purpose

Problem 3: Lack of a robotic approach for automatic data-collection and positioning



Visual Inspection and Visualization

region level accuracy



pixel level accuracy

❖ Desired Features:

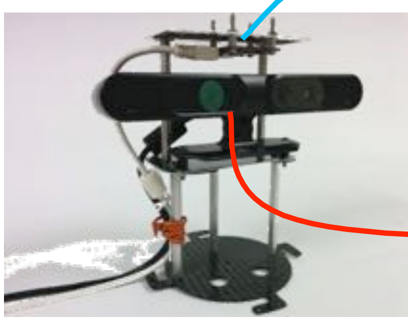
- Perform pixel-level segmenation
- Register to 3D Map for visualiztion

❖ Issues:

- Accurate Positioning
- 3D Reconstruction

Visual Odomotry for Positioning

Indirect Kalman:



Feature with covariance

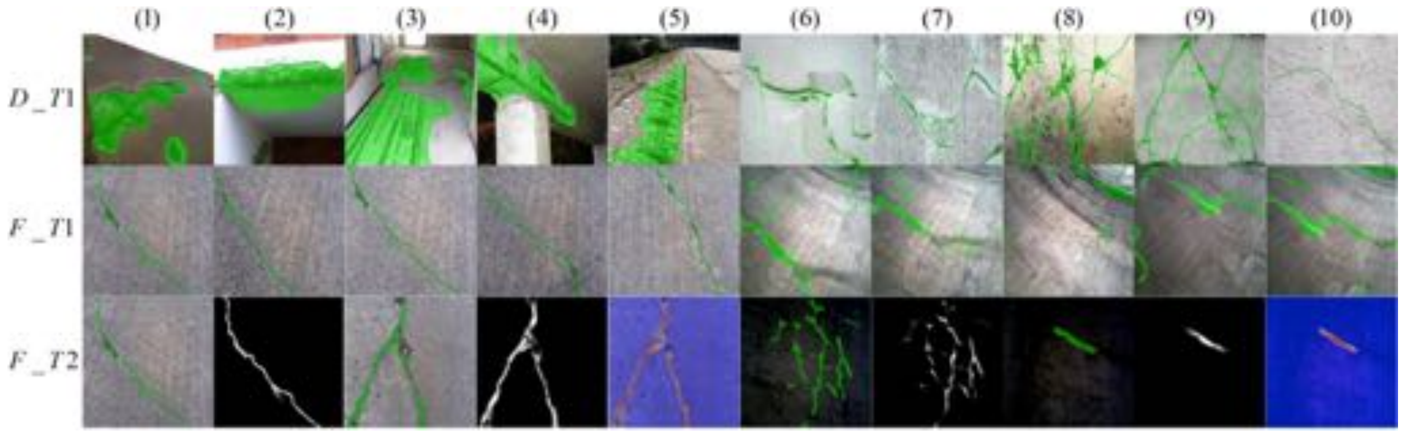
Trifocal tensor for feature estimation

IMU to propagate

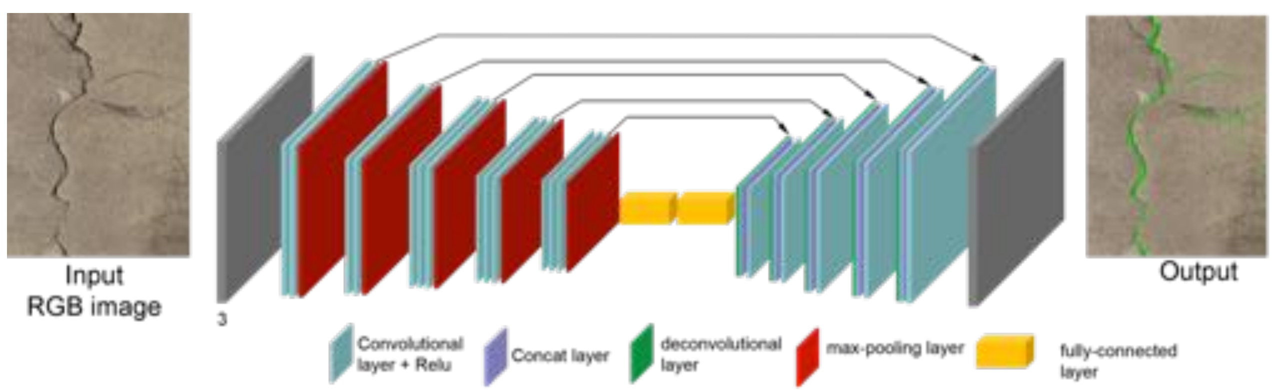
Update error to correct the nomial state

InspectionNet and Dataset

- Create a Concrete Structure Spalling and Cracks (CSSC) database with 820 labeled images

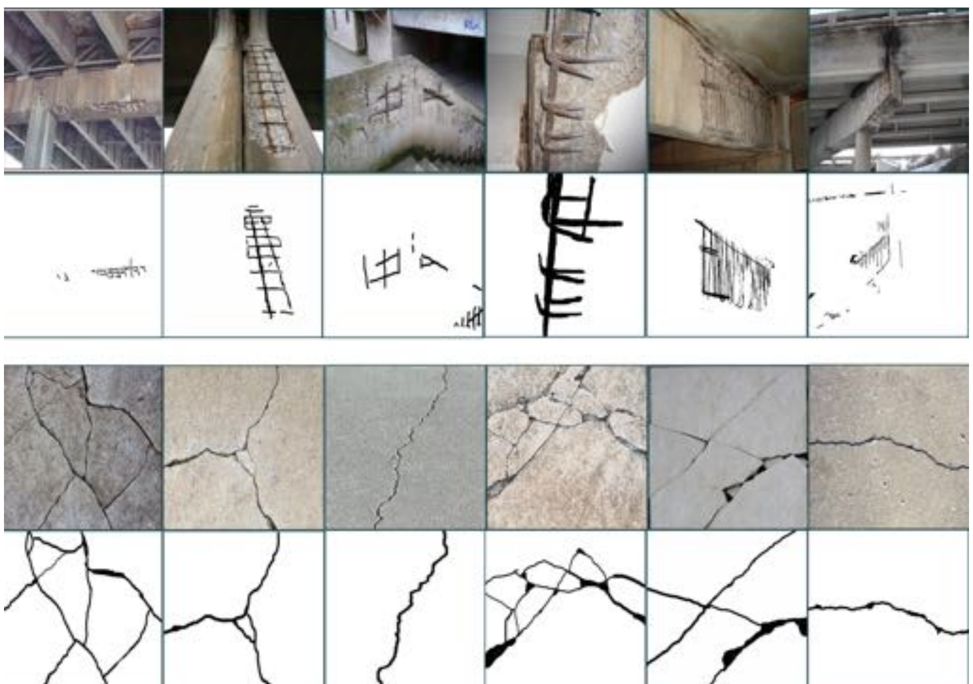


- Develop InspectionNET for surface flaw detection and measurement.



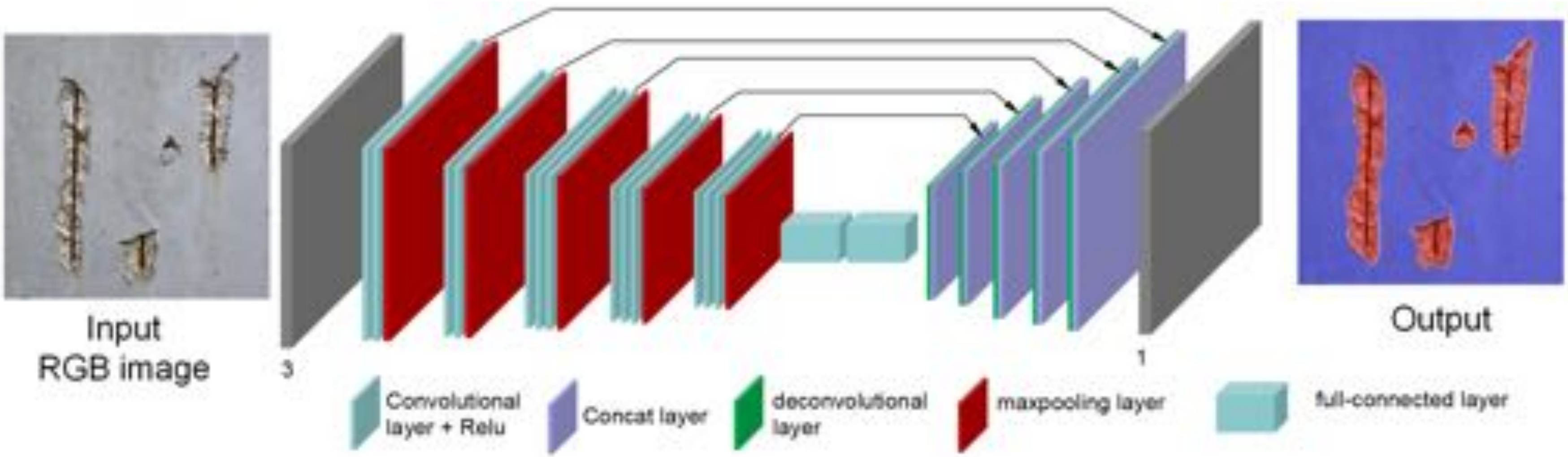
Data Set Preparation

- Data Collection:
  - Real pictures; Web search (Google, Yahoo, Bing, flicker)
- Labeling:
  - Most manually; Pay attention to information you want



For Training

InspectionNet for Segmentation

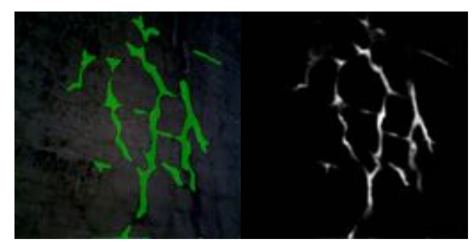


	Concrete Crack				Concrete Spalling			
Item	max F1	Ave Prec.	min Entropy	min Loss	max F1	Ave Prec.	min Entropy	min Loss
(CN) Training	79.59	91.66	0.048	0.3152	96.63	93.77	0.0128	0.388
(CN)Test	74.98	76.41	-	-	95.80	93.88	-	-
(FCN-8s) Training	7.33	3.81	-	-	96.37	94.039	0.09	0.43

CNN for detection

Crack and Spalling segmentation based on test dataset

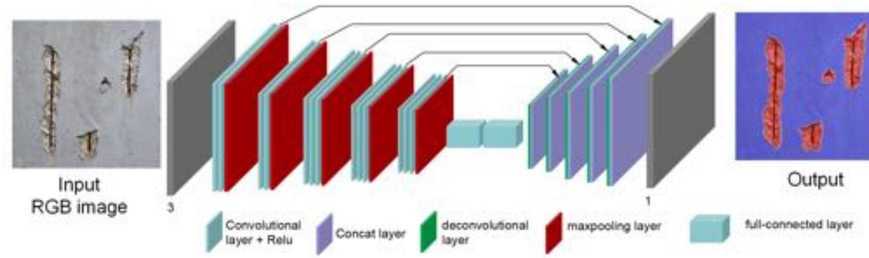
The white and black probability distribution & Dark illuminance case



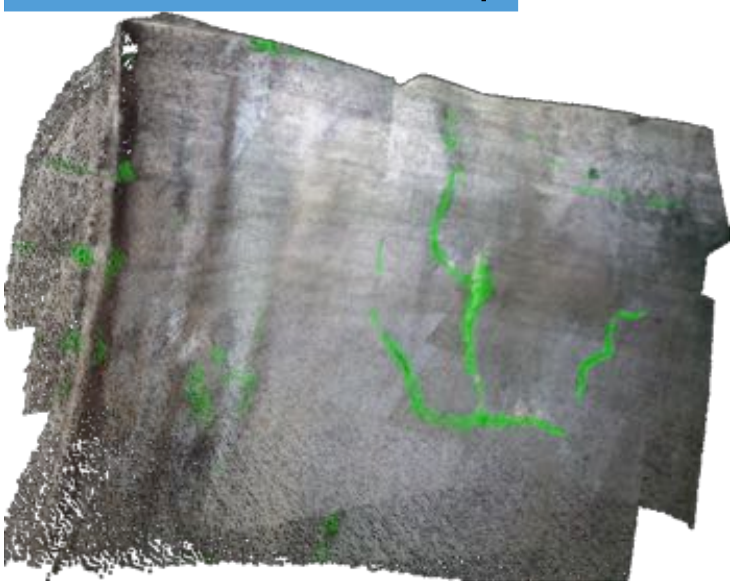
Detection and 3D Registration

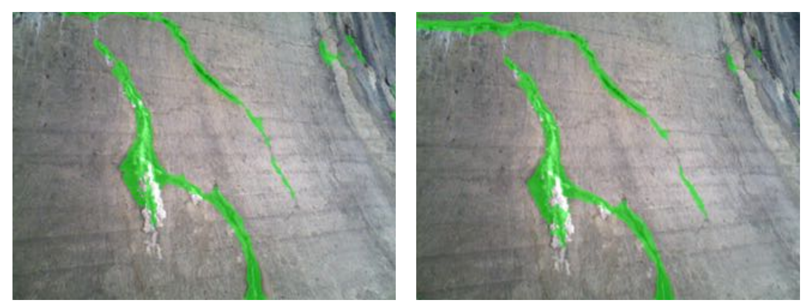
3D Registeration:

InspectionNet for Pixel-level Detection



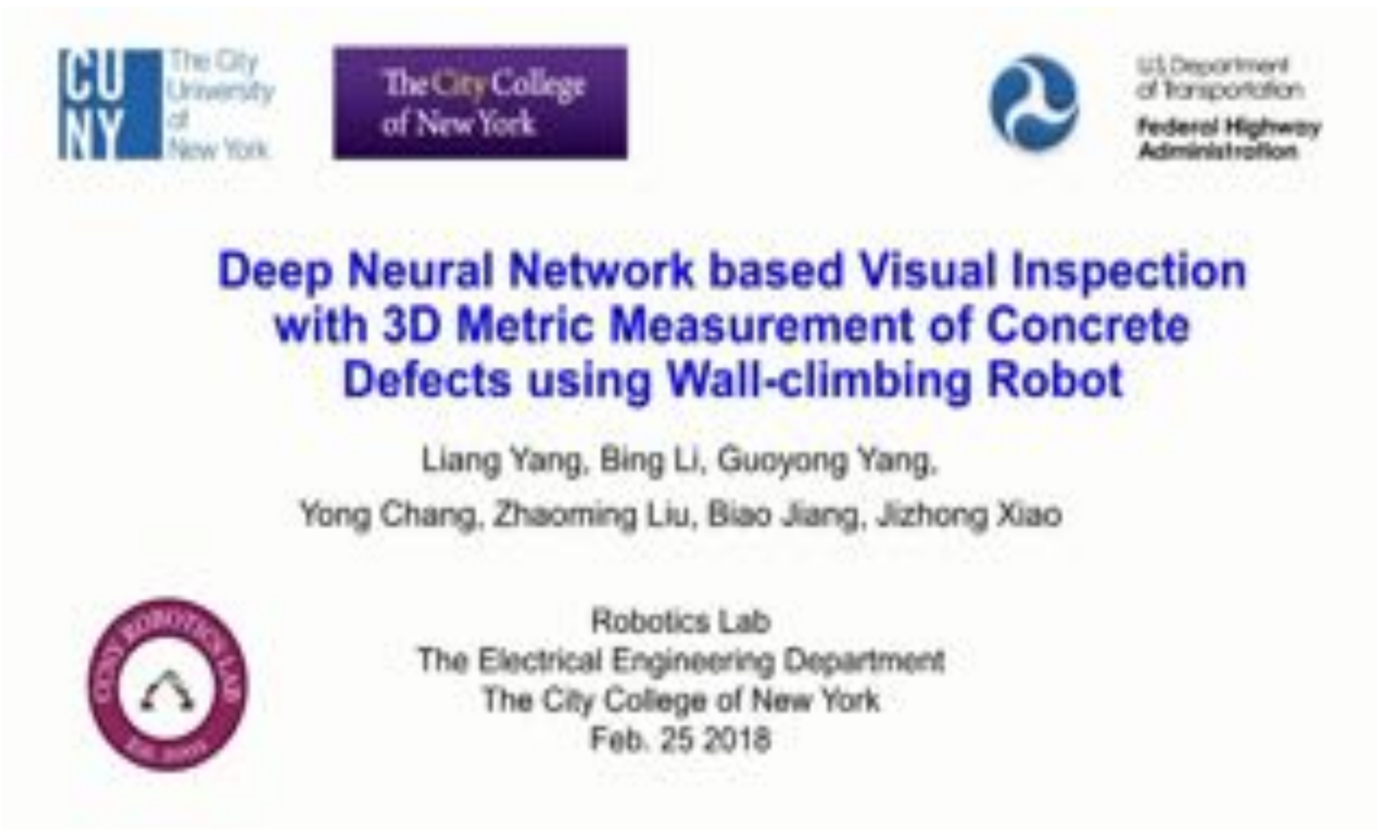
3D Reconstructed Map





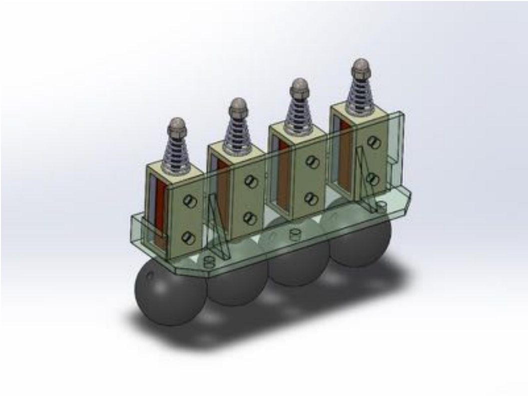
Segmentation Mask over defects

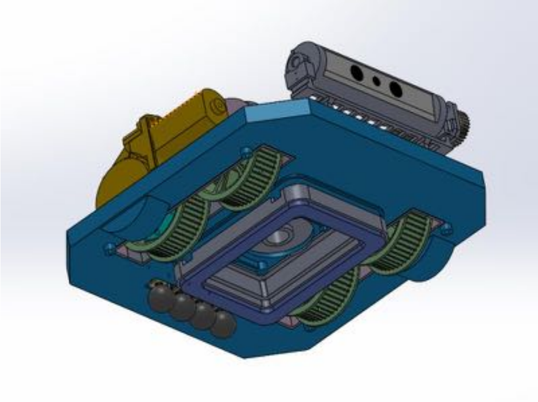
CNN for detection -- Experiment

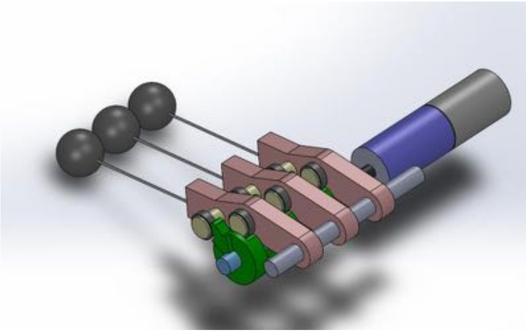


Work in Progress

- **Develop a Impact sounding mechanism and data analysis methods.**







Summary

- GPR-Rovers provide vertical mobility to ease the data collection process in difficult-to-access locations;
- Use RGB-D camera to detect surface flaws, GPR to detect subsurface defects, impact sounding to detect delamination;
- Develop image processing and visual odometry algorithms for accurate positioning of flaws;
- Propose CNN-based machine learning algorithms and dataset for surface flaw detection and measurement.

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