INSPIRE

INSPECTING AND PRESERVING INFRASTRUCTURE THROUGH ROBOTIC EXPLORATION

Climbing Robots with Automated Deployment of Sensors and NDE Devices for Steel Bridge Inspection

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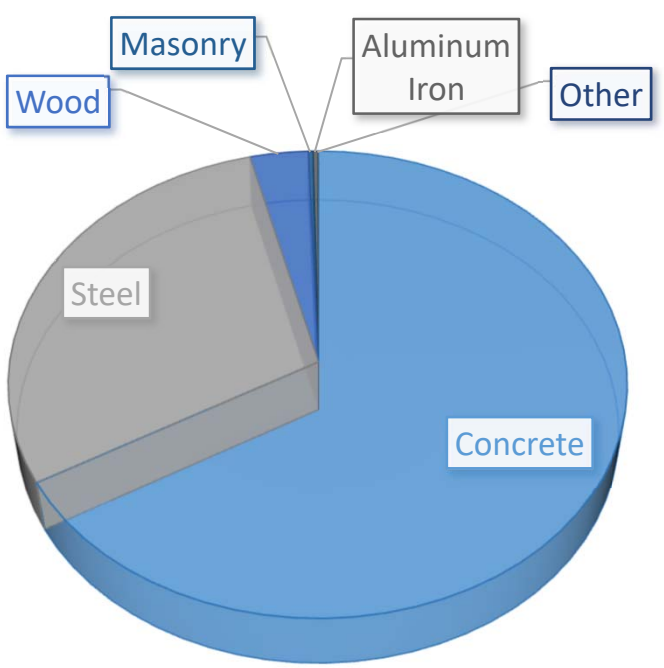
August 14, 2018

Agenda

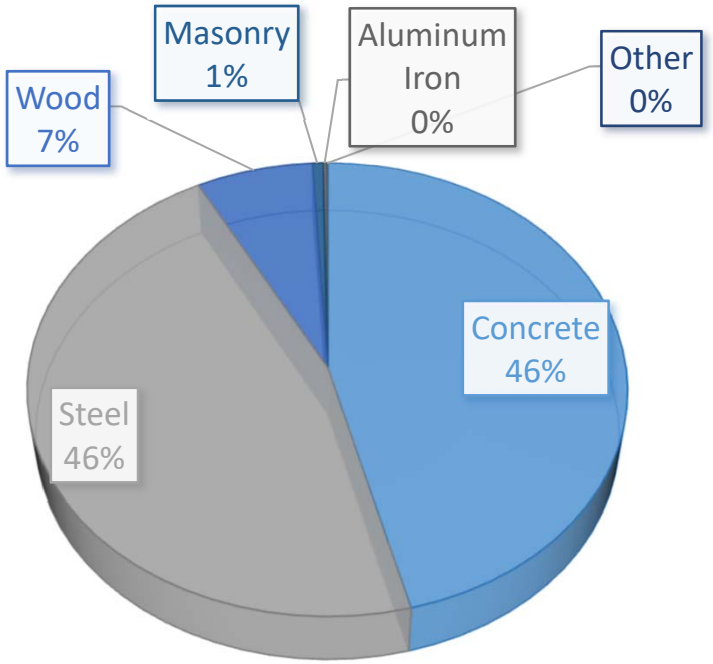
1. Introduction
2. Magnetic Wheel Designs
3. Failure Investigation
4. Climbing Robots
5. Demonstrations

1. Introduction

- **There are 611,845 highway bridges in the US, and 30% (179,565) are steel bridges.**
- **Nearly 1/3 (66,079) are structurally deficient or functionally obsolete.**



Bridge Count



Deficient Bridges

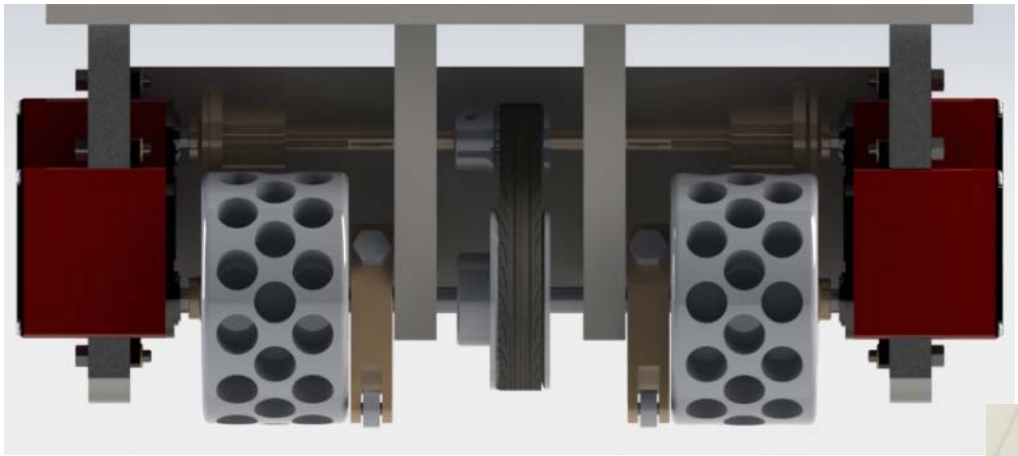
Note: all data recorded in 2015 by FHWA at https://www.fhwa.dot.gov/bridge/nbi

Bridge Inspection Activities

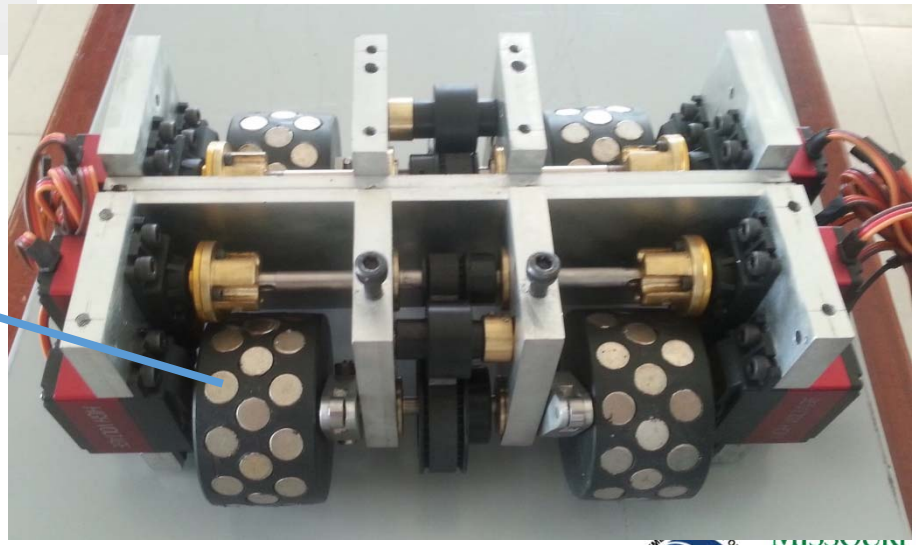
Golden Gate Bridge Inspection: April 2018

Source: http://sanfrancisco.cbslocal.com/2018/04/30/engineers-stage-high-wire-inspection-of-golden-gate-bridge/

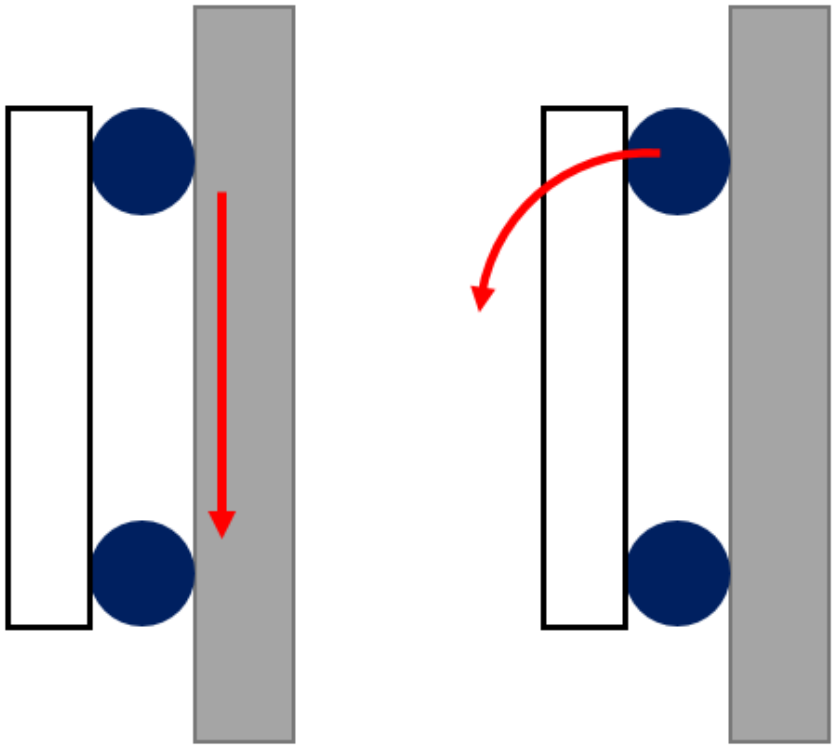
2. Magnetic Wheel Designs



(Up to 5kg pull force)



3. Failure Investigation

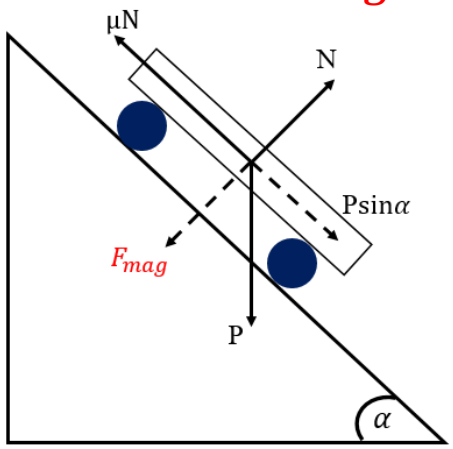


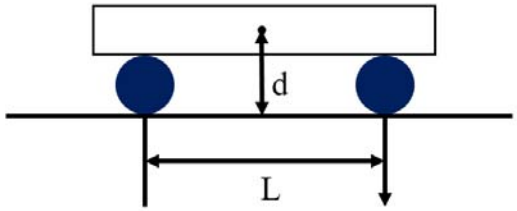
Sliding failure

Turn-over failure

Failure Investigation (cont.)

$$F_{mag} > \max\left\{\frac{P\sin\alpha}{\mu} + P\cos\alpha\,;\, 2\frac{Pd}{L}\right\}$$

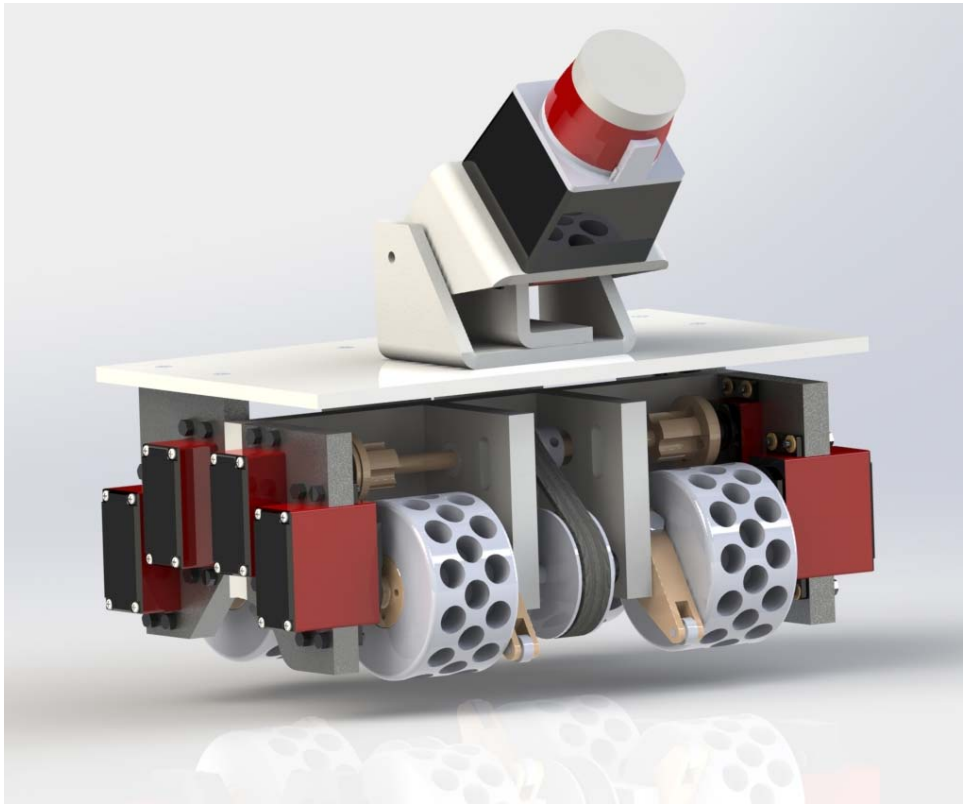


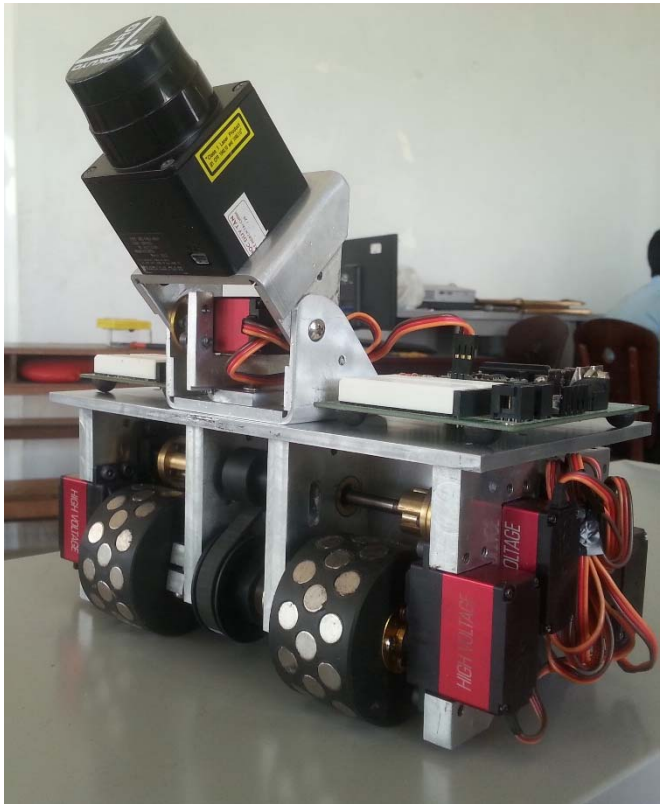


where F_{mag} is the total magnetic force created by all wheels, α is the degree of inclination of the steel surface ($0 \leq \alpha \leq 90°$), μ is the frictional coefficient between the wheel cover and steel surface, P is the robot's weight, d is the distance between the center of mass to the surface, and L is the distance between the front and rear wheels. Condition (1)

H. M. La, T. Dinh, N. Pham, Q. Ha, and A. Pham. Automated robotic monitoring and inspection of steel structures and bridges. ***Robotica***, *Cambridge University Press,* 1-21. 2018, doi:10.1017/S0263574717000601

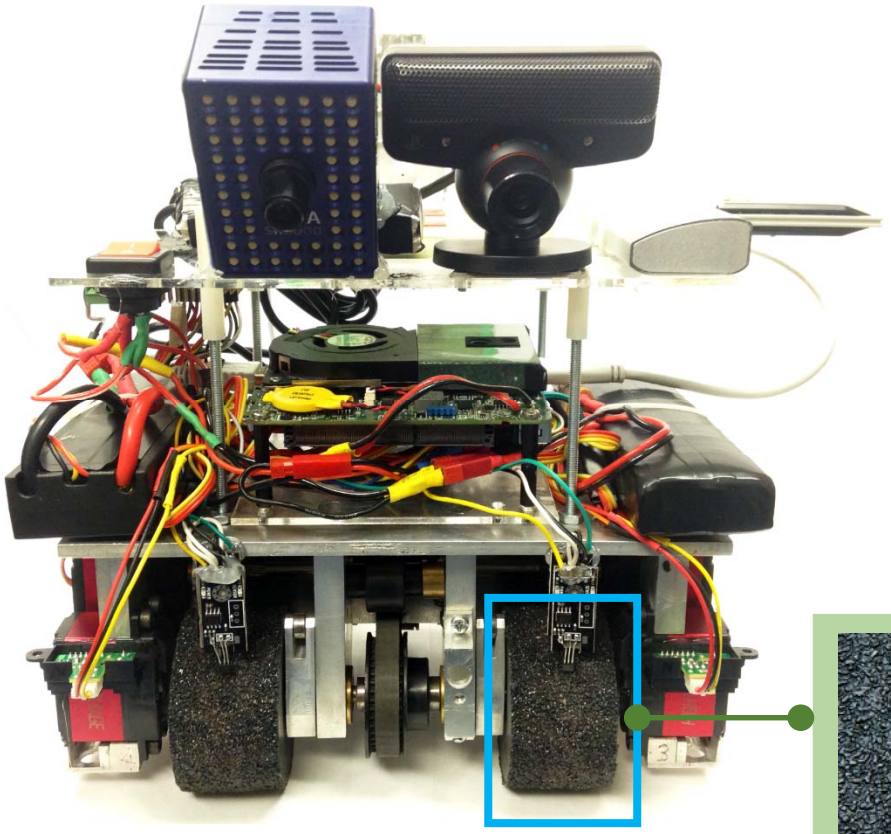
4. Climbing Robots



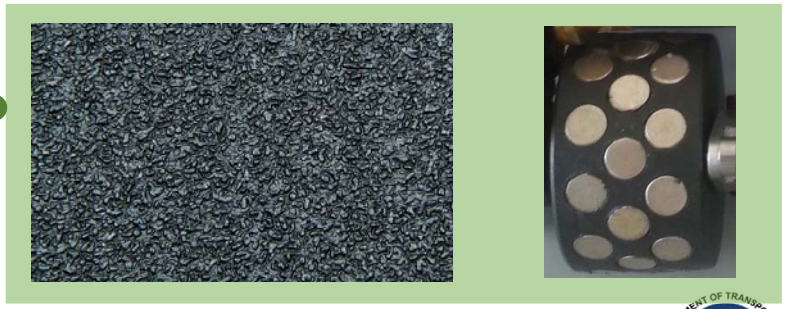


Initial prototype

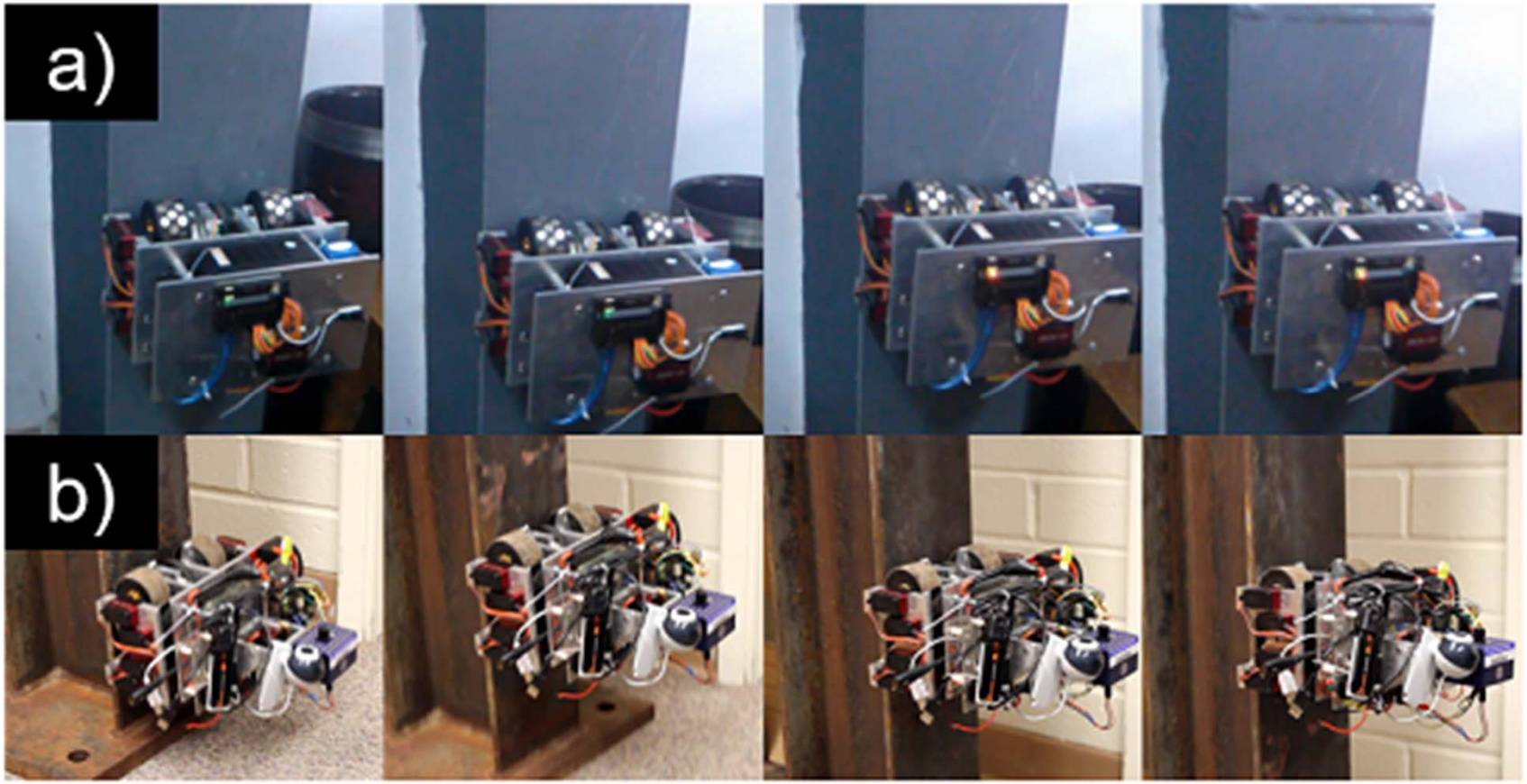
Climbing Robot (cont.)



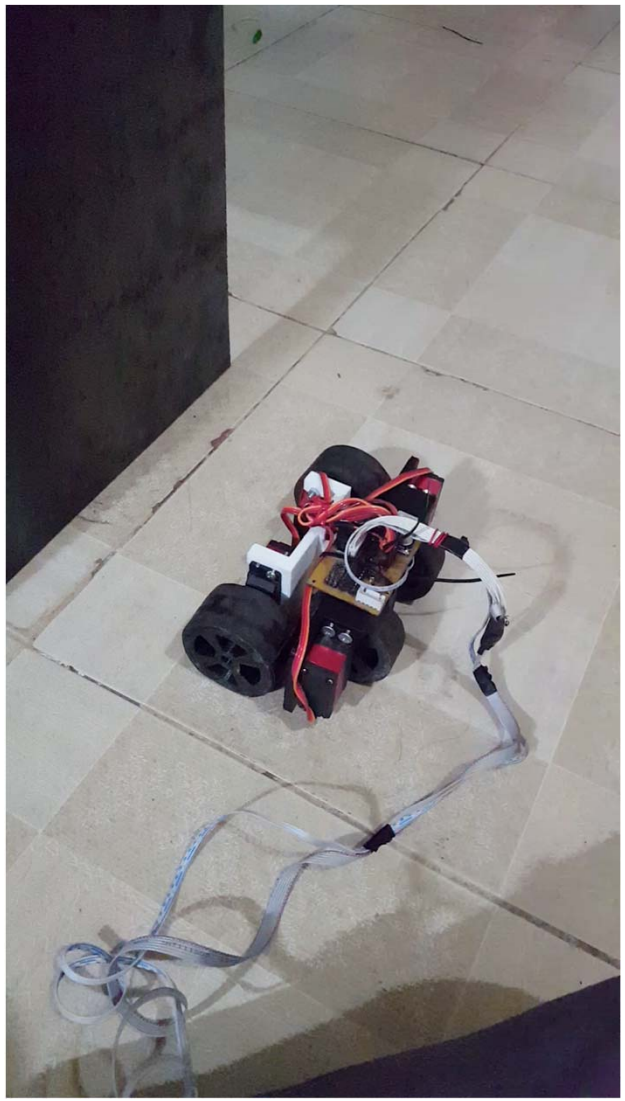
Length	221 mm
Width	130 mm
Height	241 mm
Weight	6 kg

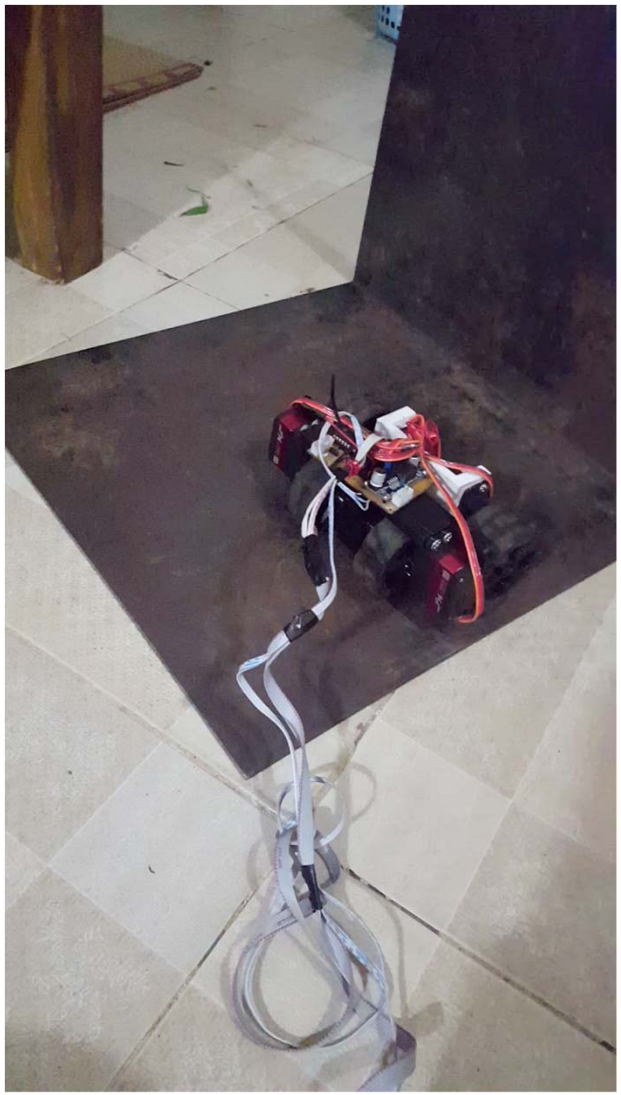


Climbing test w/o load

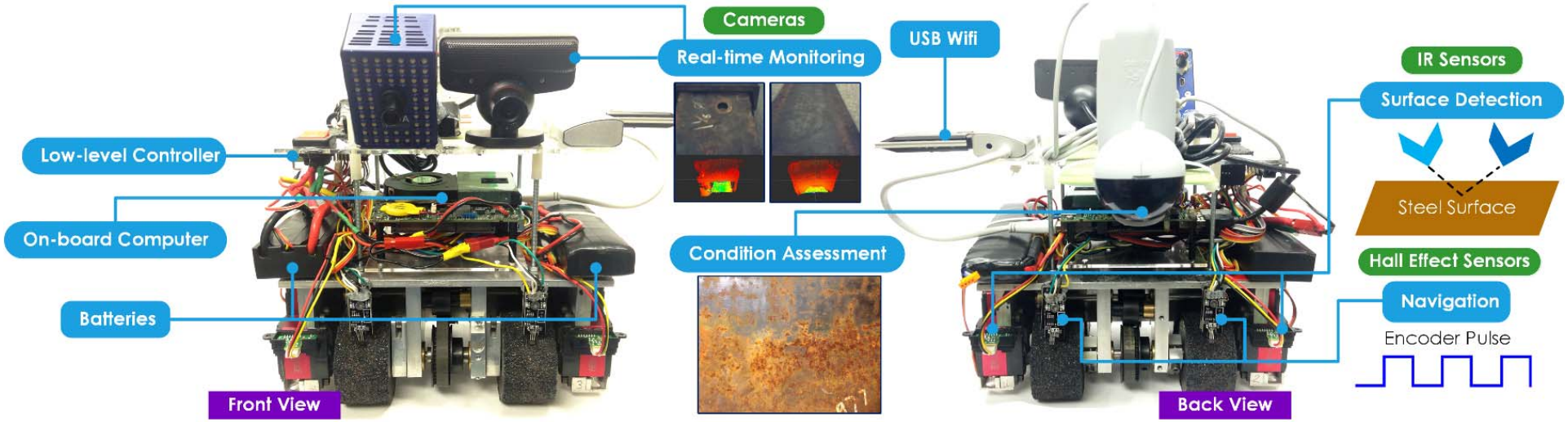


Design Test

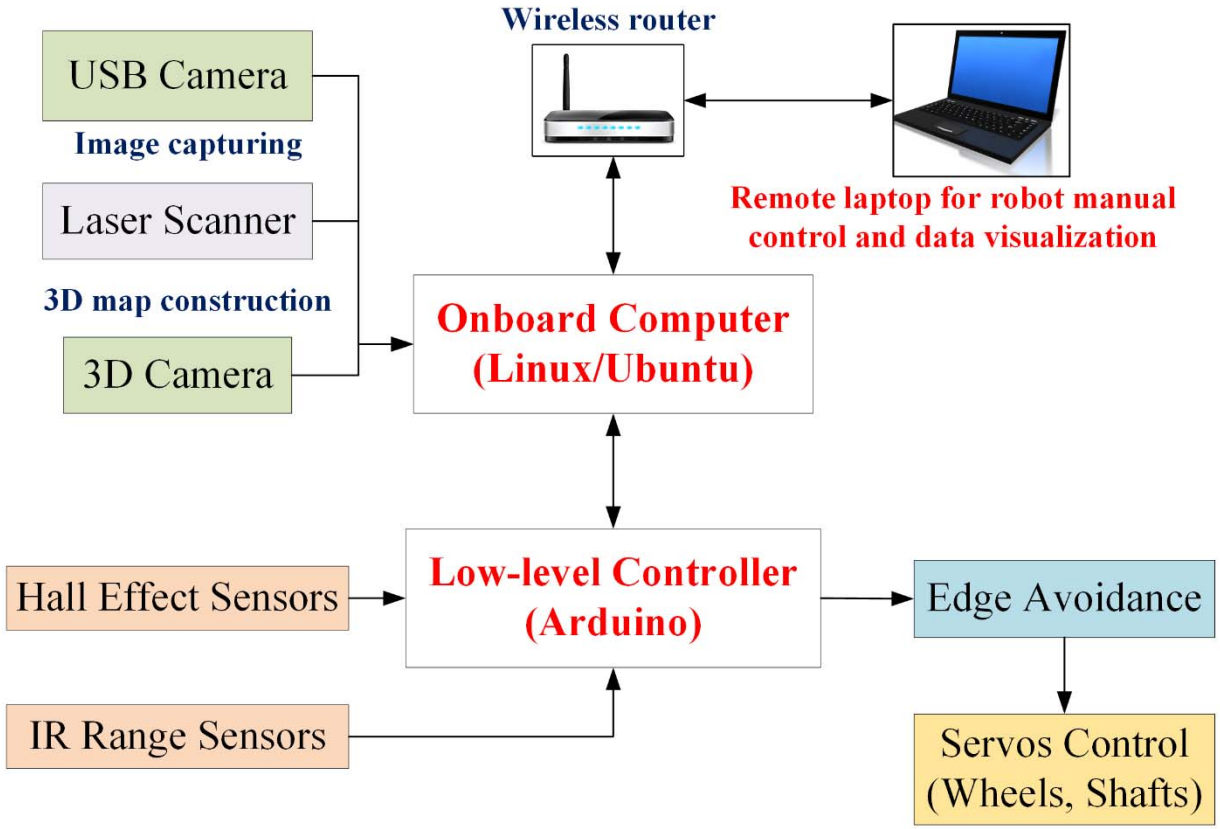




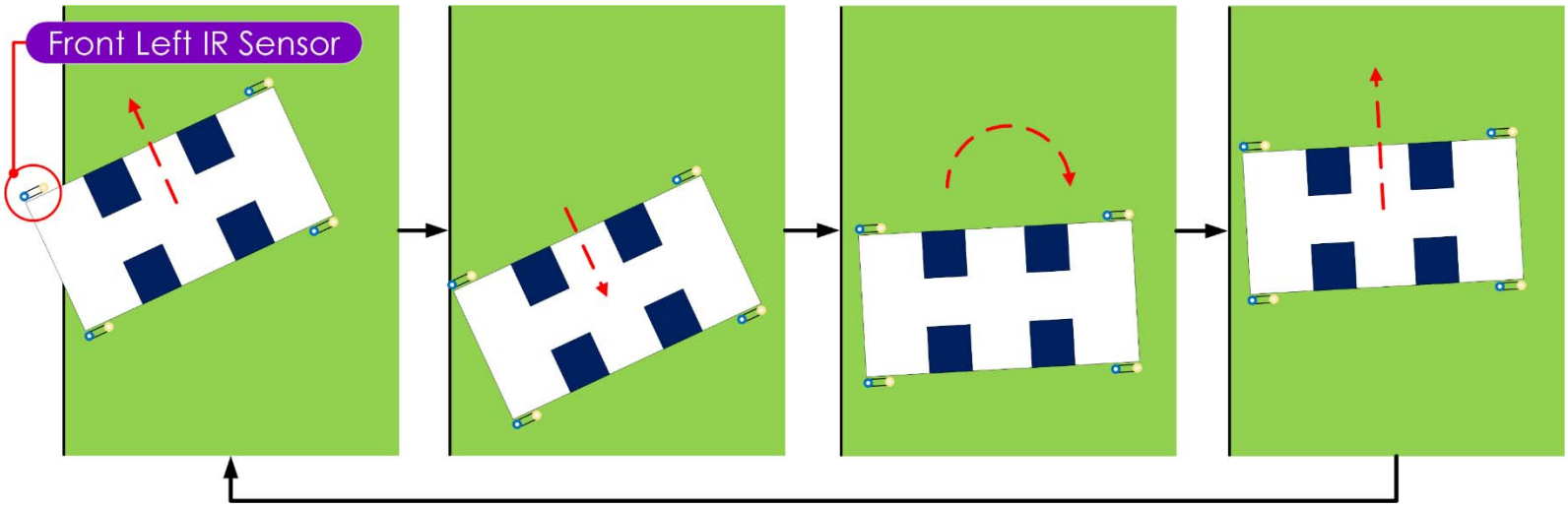
Climbing Robot (cont.)



Robot Architecture



Edge Avoidance with IR sensors



Edge Avoidance Algorithm

Algorithm 1: EDGE AVOIDANCE.

Input: $(r\_cal_1, r\_cal_2, r\_cal_3, r\_cal_4)$, (r_1, r_2, r_3, r_4), ϵ, (d_1, d_2, d_3, d_4)

```
for i=1:4 do
    if only one (r_i) ∉ [r_cal_i − ε; r_cal_i + ε] then
        if i== front right IR sensor then
            Stop
            Go backward with a distance of 5cm (Δd_i ≈ 3)
            Rotate left when travel distance of either right wheel reach 3cm
            (Δd_i ≈ 2)
            Keep moving
        Check other sensors and take similar actions
    else
        stop and wait for commands
```

Edge Avoidance Test

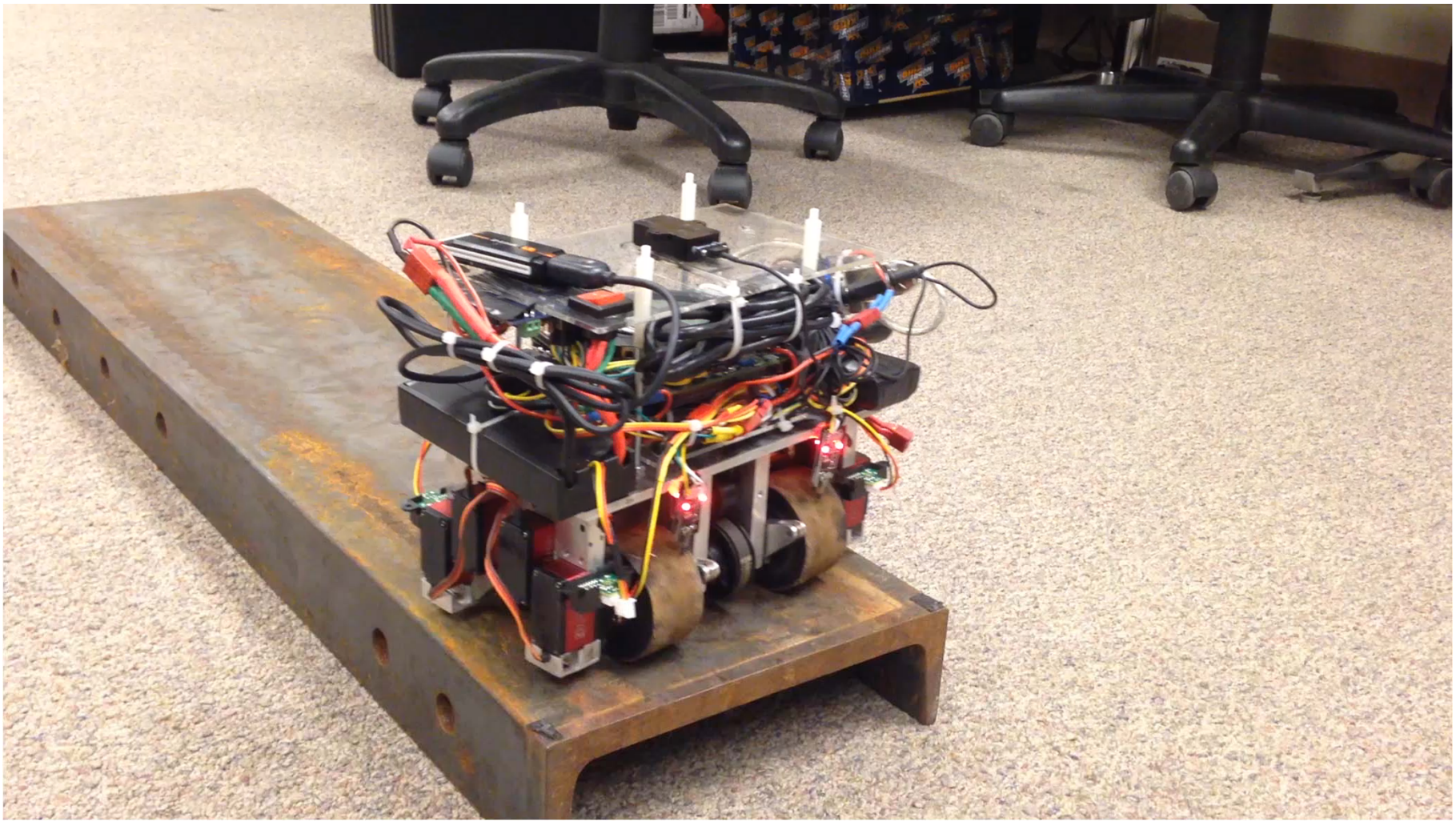
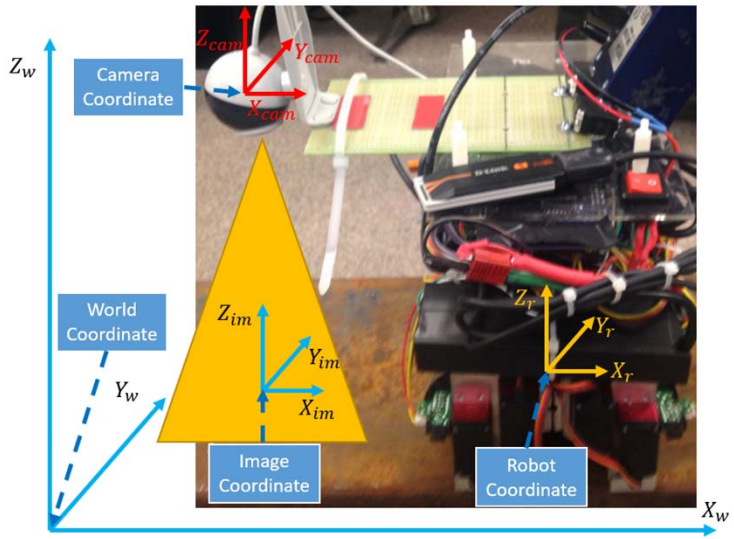
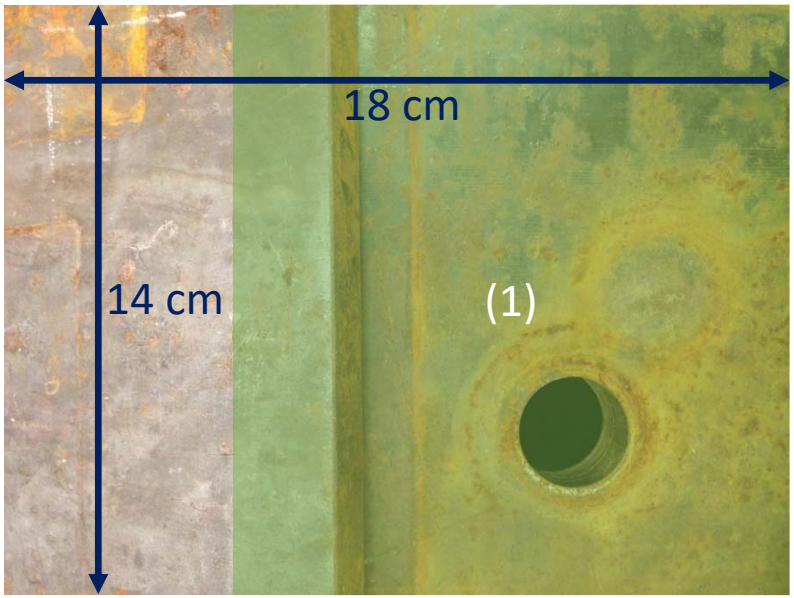
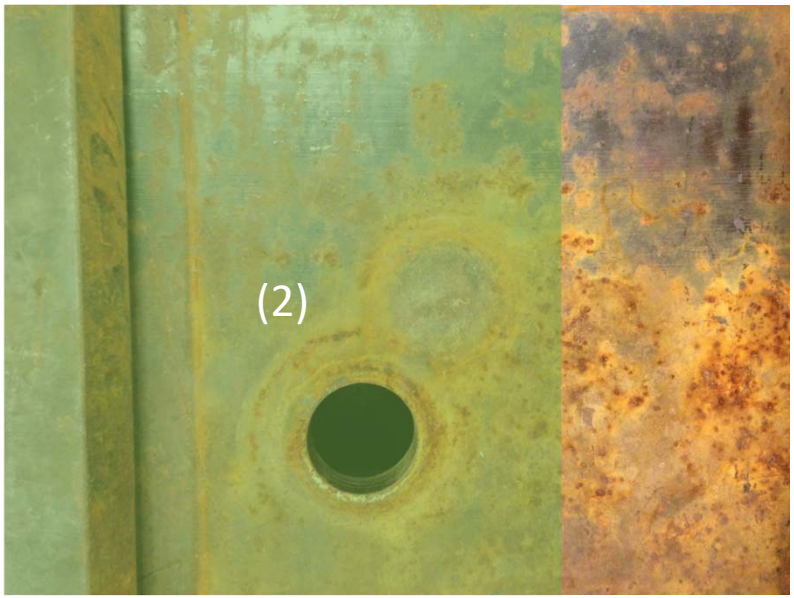


Image Stitching (1)







Overlapped areas ≥ 30%

Image Stitching (2)

Sparse feature-matching → Image-to-image matching

Image Stitching (3)

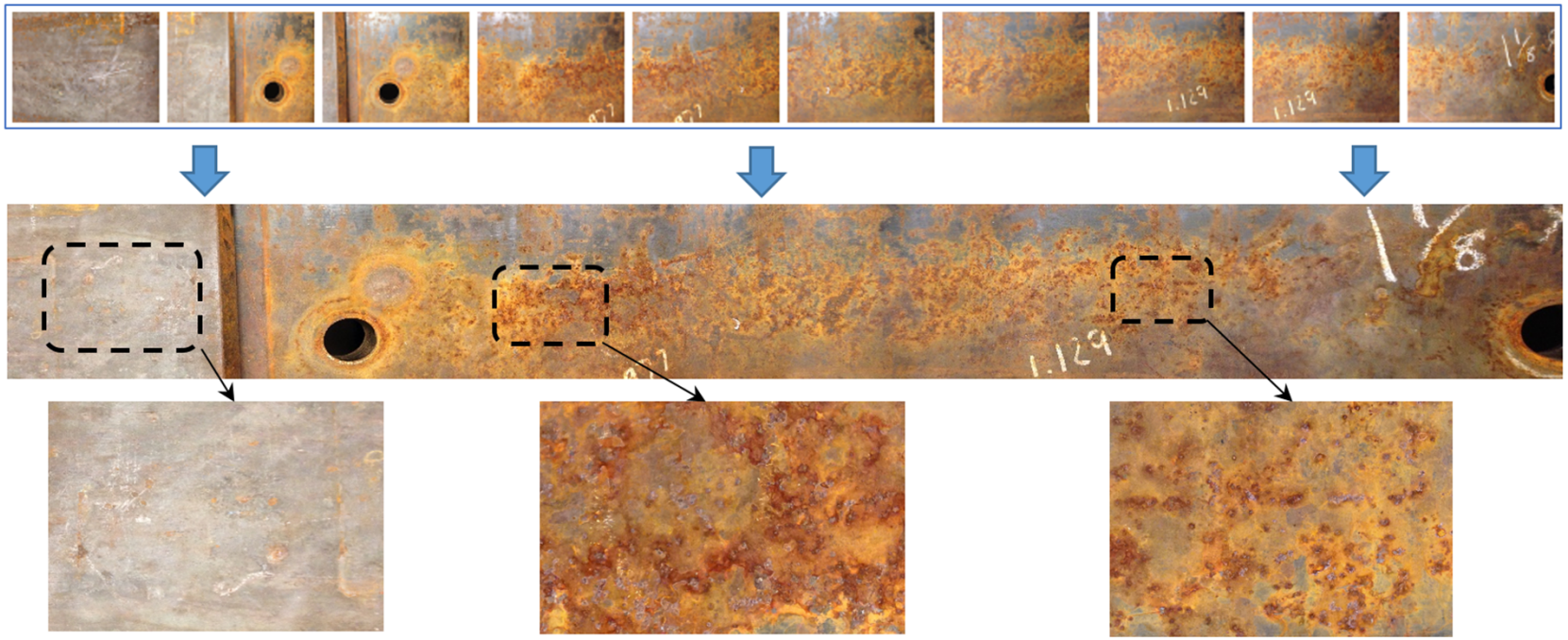
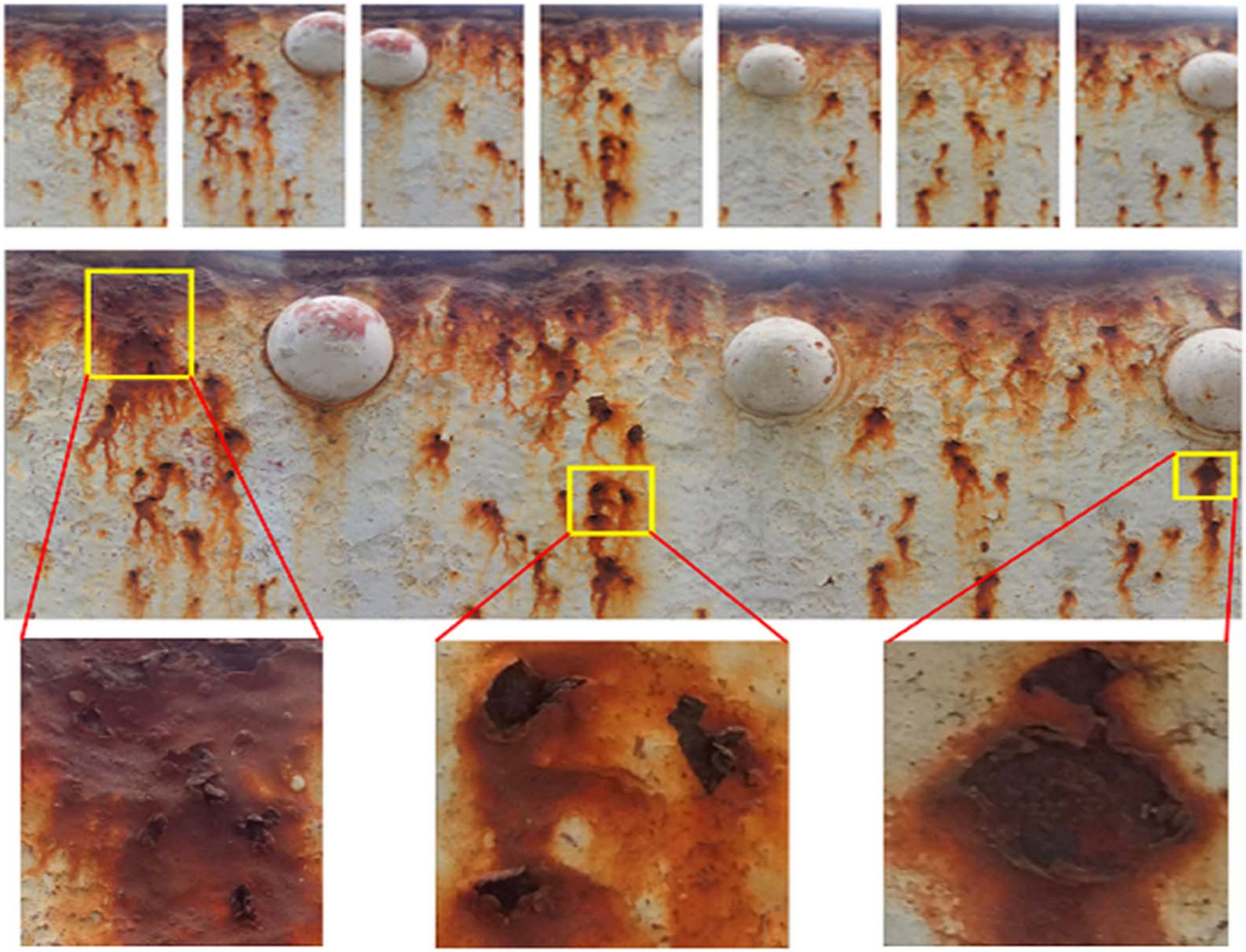
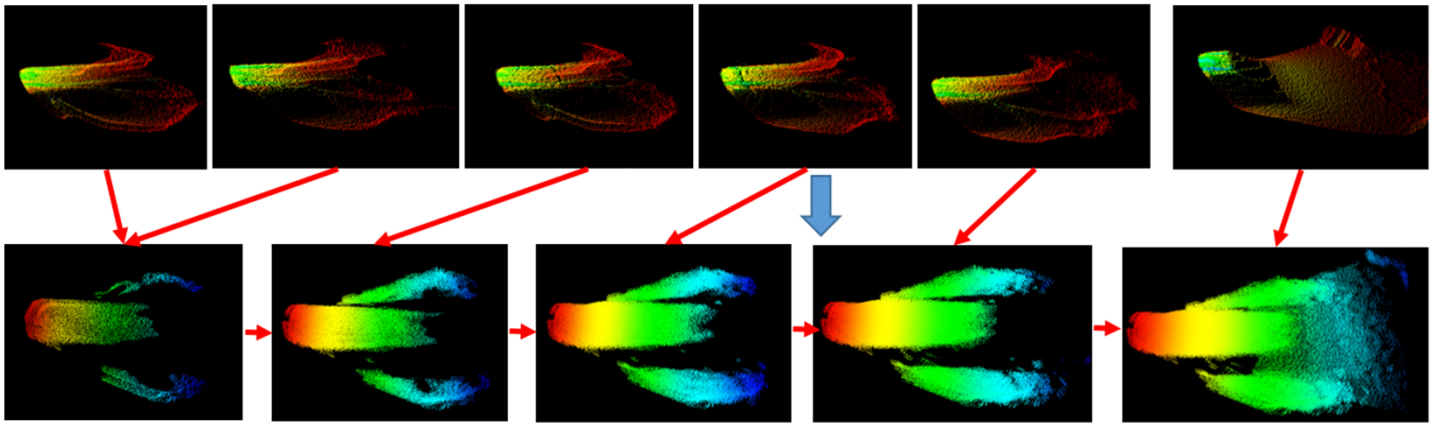


Image Stitching (4)

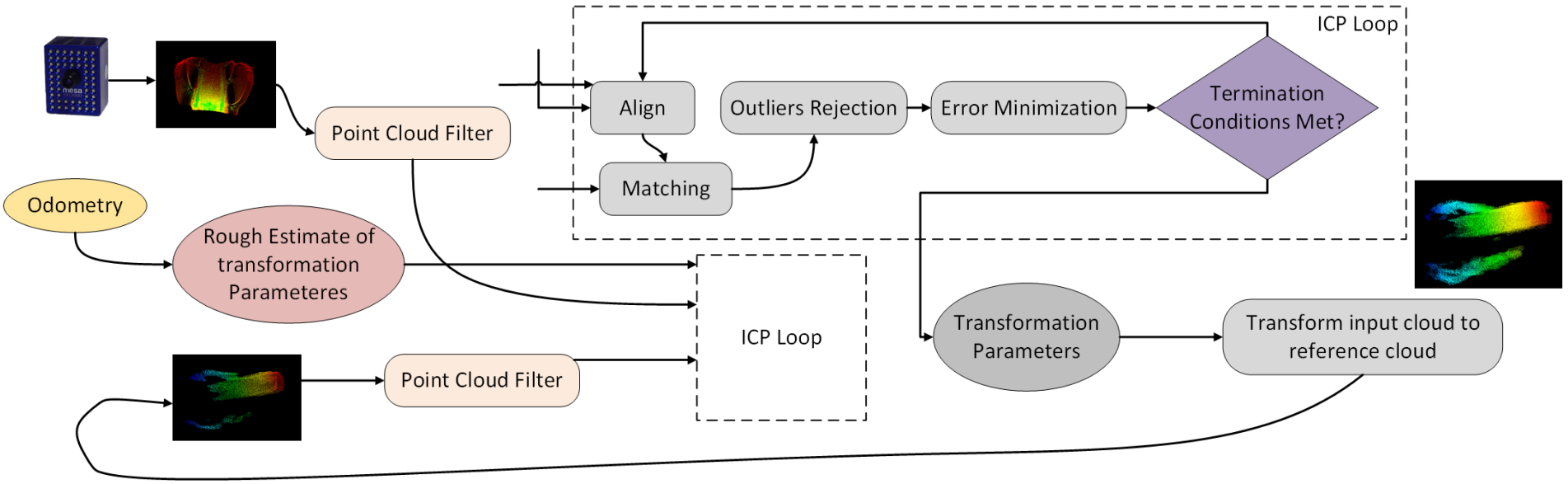


3D Construction (1)

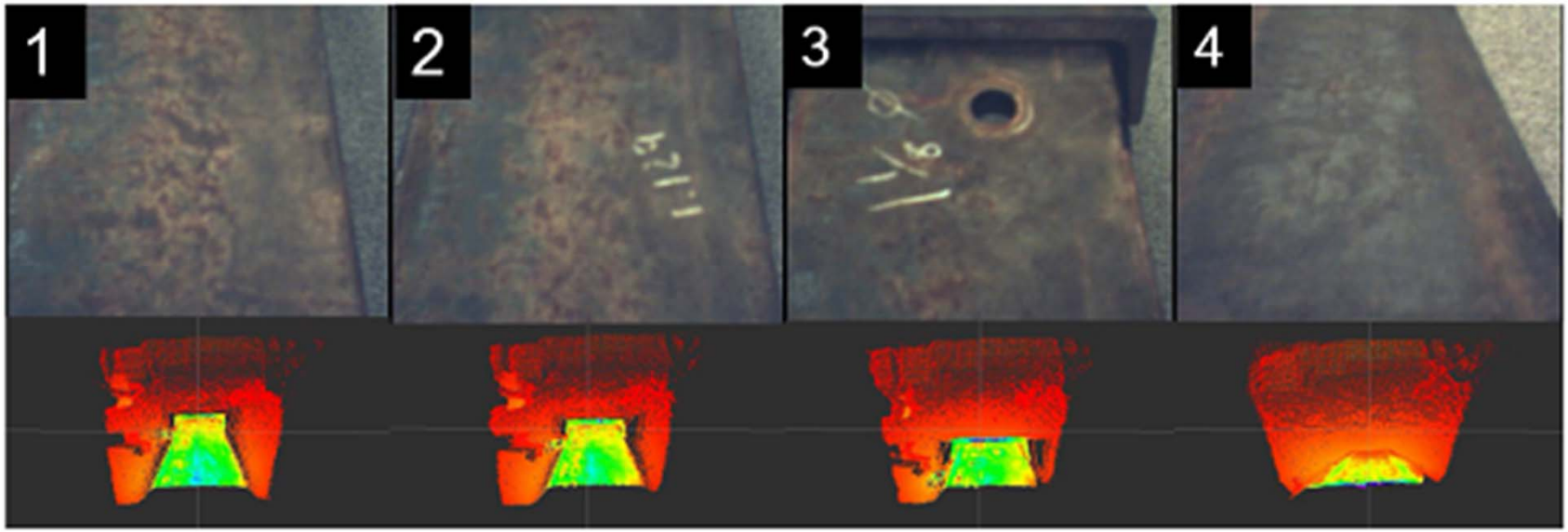
- Based on the Iterative Closest Point (ICP) algorithm
- Goal: find rotation *R* and translation *t* to align input point cloud ($\boldsymbol{p}_i$) to a reference point cloud ($\boldsymbol{q}_i$)
  - $E = \sum_i (R\boldsymbol{p}_i + t - \boldsymbol{q}_i)^2$



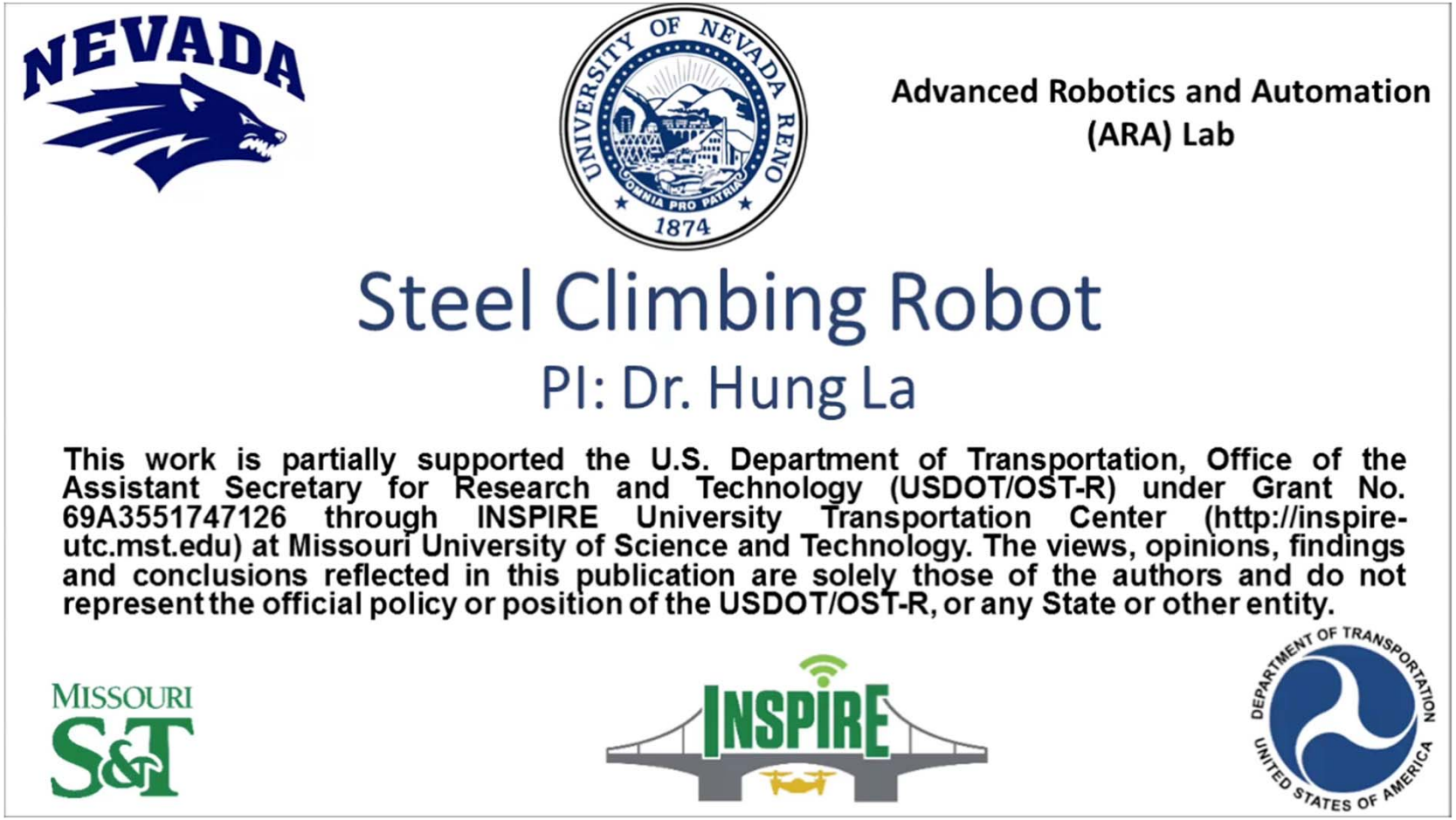
3D Construction (2)



3D Construction (3)



5. Demonstration: Design 1



Climbing Robot: Design 2

Demonstration: Design 2

5. Demonstration: on bridges

Publications

- **Patents:**
  - H. M. La, Steel climbing robot with magnetic wheels. US patent: PCT/US2017/061387. June 07, 2018.
- **Journals/Conferences**
  - H. M. La, T. Dinh, N. Pham, Q. Ha, and A. Pham. Automated robotic monitoring and inspection of steel structures and bridges. *Robotica, Cambridge University Press*, May, 2018.
  - S. Gibb, H. M. La, T. Le, L. Nguyen, R. Schmid, H. Pham. Non-Destructive Evaluation Sensor Fusion with Autonomous Robotic System for Civil Infrastructure Inspection. *Journal of Field Robotics*, April. 2018.
  - L. Nguyen , S. Gibb, H. Pham, and H. M. La. A Mobile Robot for Automated Civil Infrastructure Inspection and Evaluation. *Proceedings of the 16th IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR),* August 6-8, 2018, Philadelphia, PA, USA.
  - S. Gibb, H. M. La, S. Louis. A Genetic Algorithm for Convolutional Network Structure Optimization for Concrete Crack Detection In Proceedings of the 2018 *IEEE Congress on Evolutionary Computation (IEEE CEC)*, July 8-13, 2018, Rio de Janeiro, Brazil.

Future work

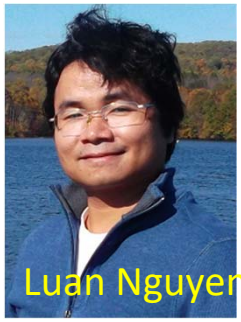
- Test and validation
- Integration with NDE sensors
- Autonomous localization and navigation
- NDE path-planning driven

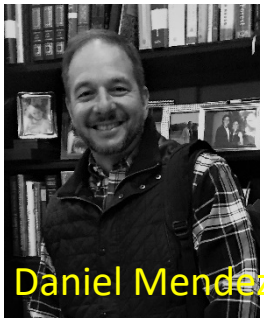
ARA Lab Members

Lab Director

Research Assistant Prof./ Postdocs

PhD Students





MS Students

Undergrad Students

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MISSOURI S&T

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