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2021 Annual Meeting
Graduate Student Poster Competition Results

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INSPIRE
INSPECTING & PRESERVING INFRASTRUCTURE
THROUGH ROBOTIC EXPLORATION

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Third Place Award

PRESENTED TO

Pu Jiao

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Director, INSPIRE University Transportation Center

INSPIRE
INSPECTING & PRESERVING INFRASTRUCTURE THROUGH ROBOTIC EXPLORATION

INSPIRE UTC Bridge Inspection Field Campaign Update, 2021

Pu Jiao, Liujun Johnny Li, Rafael Cardona, Genda Chen

INTRODUCTION

Bridge inspection activities using robotic sensing system are surging in the recent years due to the increasing demand of infrastructure maintenance and development of commercial drones and open-source robotic platforms. On the other hand, the data acquired through bridge inspection is also booming, which stimulated the application of machine learning in infrastructure.

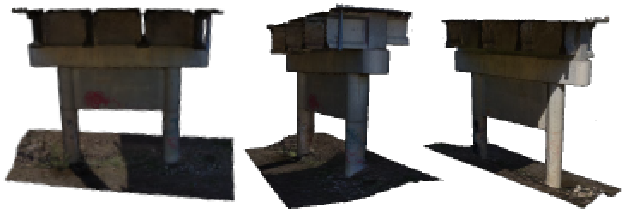
At INSPIRE UTC of Missouri University of Science and Technology, bridge inspection equipment's are being developed and tested for comprehensive data collection using multiple sensing technologies. This paper presents and evaluates the drone-carried sensors' abilities and applications after 3 bridge inspections in Missouri in 2021 and sketches the future inspection plans and database construction.

METHODS

(1) Photogrammetry
Structure-from-Motion (SfM) is the process of reconstructing 3D structure from its projections into a series of images taken from different viewpoints. The resulting 3D models can be used for digital documentation and developing Augment Reality (AR) applications for measurement and inspection training.
(2) Passive IRT images
Passive IRT is applied to calculate the thermal overall heat transfer coefficient and to analyze moisture, cracking, thermal bridges and air infiltration, which can give us the information under the surface of the infrastructure.
(3) Machine learning assisted crack detection
a pre-trained neural network based on 20000 concrete pictures with cracks and 20000 concrete pictures without crack is used to detect the captured pictures. The pre-trained neural model is based on ResNet50, which has the best performance compared with counterparts like GoogleNet and AlexNet.

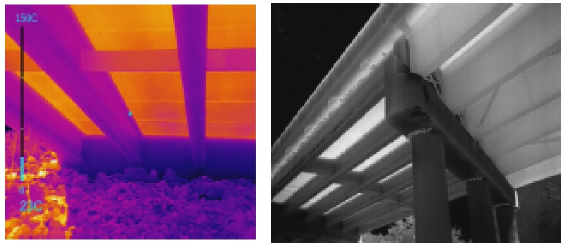
RESULTS

(1) 3D reconstruction



3D reconstruction results

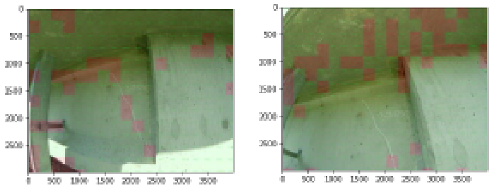
(2) Passive IRT images



IR image in colored mode and grey-scale mode

(3) Prediction by pre-trained machine learning model

Elios 2 during inspection



Elios 2 results processed by the pre-trained model

DISCUSSIONS

Capturing the images for the bridge element 3D reconstruction using drones was made possible during the tests. However, the results also show the following problems (1) the shadows due to the sunlight and superstructure can affect the image quality, (2) manual control solves the GPS signal issue but increase the probability of image motion blurs.

Elios 2 can get into confined space for close-up inspection to take advantage of the ultra-wide-angle fisheye lens. However, the resulting images will have distortion compared with the other two drone's cameras' results. Lots of the existing machine learning model are based on images without significant torsion. Therefore, it is worth investigation to see how these new data will affect the performance of the existing models.

By using the pre-trained crack detection model with the data collected by the three drones, a deeper understanding of the acquired data as well as the existing concrete crack datasets is obtained. The model still has difficulty in dealing with homogenously illuminated regions.

Passive IRT imaging under the bridge can give information of the thickness or depth of the inspected targets, which can provide an extra layer for RGB images to assist member identification or semantic segmentation.

FUTURE PLAN

1. Improve inspection plans based on data processing, annual meeting feedback.
2. Start to construct inspection database. Develop software to assist the tagging work. Include more damage classes like crack, delamination, corrosion, spalling and others.
3. Data fusion with different sensors to gain a comprehensive evaluation of the bridge condition.
4. Work with state DOTs on data masking to share the inspection data with general public.

ACKNOWLEDGEMENTS

Financial support for this study was provided in part by Missouri Department of Transportation TR202004 and FHWA pooled fund TPF-5(395), S064101S under the auspices of the Center for Transportation Infrastructure and Safety at Missouri S&T.

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Second Place Award

PRESENTED TO

Yu Otsuki

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Director, INSPIRE University Transportation Center

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Autonomous ultrasonic thickness measurement using *Martlet* wireless sensing system integrated with a steel climbing mobile robot

[1] Yu Otsuki, [1,2] Yang Wang

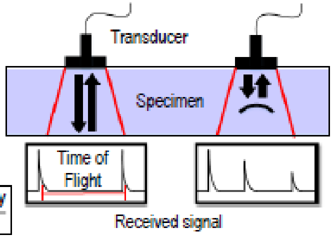
[1] School of Civil and Environmental Engineering, Georgia Institute of Technology

[2] School of Electrical and Computing Engineering, Georgia Institute of Technology

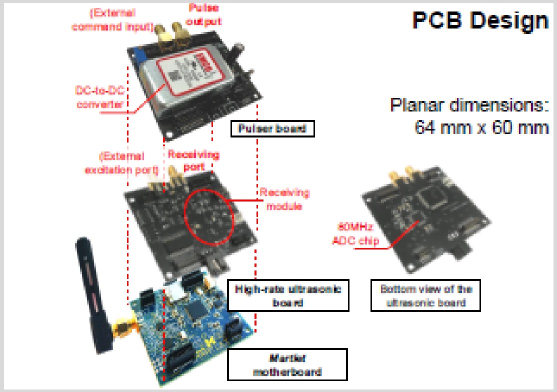
INTRODUCTION

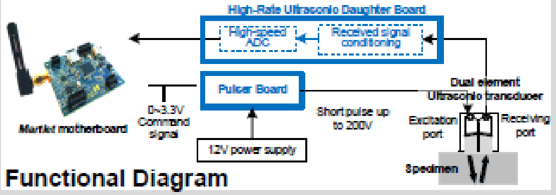
The objective of this research is to develop an autonomous ultrasonic thickness measurement system for steel bridge members through the integration of wireless sensing and robotics. The ultrasonic thickness measurement is achieved using a transducer that requires access to only one side of a steel bridge member. Building upon the *Martlet* wireless sensing platform, this project first develops pulser and ultrasonic daughter boards to generate a pulse excitation and to filter and amplify the received ultrasonic signal. The developed *Martlet* wireless ultrasonic device is next integrated with a steel climbing mobile robot developed by University of Nevada, Reno (UNR). The accuracy of the measurement is verified through laboratory testing.

$$\text{Thickness} = \frac{\text{Time of Flight (ToF)} \times \text{Velocity}}{2}$$



DEVELOPMENT OF *Martlet* ULTRASONIC DEVICE

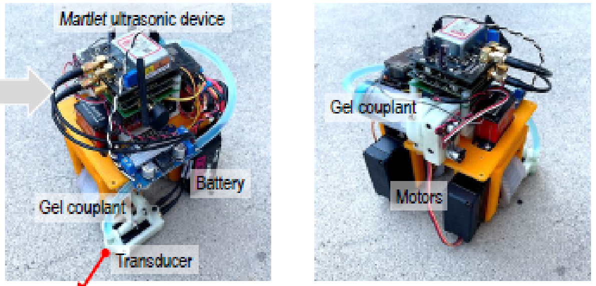




Functional Diagram

- The pulser board generates a high-voltage (up to 200V), short-pulse excitation signal to the transducer.
- The high-rate ultrasonic board is capable of filtering/amplification of the received ultrasonic signal and high-speed analog-to-digital conversions (up to 80 MHz).

INTEGRATION WITH A STEEL CLIMBING ROBOT DEVELOPED BY UNIVERSITY OF NEVADA, RENO



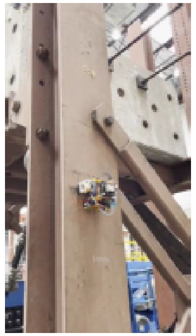
Pumping gel couplant & mounting a transducer

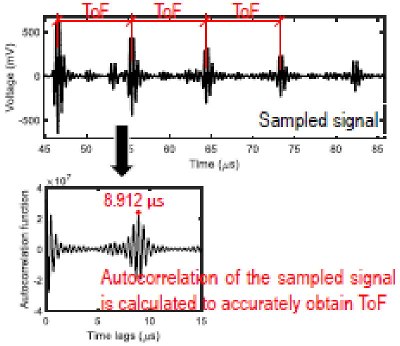
Climbing capability

- In May 2021, Prof. Hung La's lab at UNR hosted the 3-week stay by GT graduate student Yu Otsuki, working with UNR student Son Thanh Nguyen to integrate the *Martlet* ultrasonic device with a UNR bicycle mobile robot [1].
- A pumping mechanism is developed to apply an appropriate amount of gel couplant between the transducer and the steel surface. A mounting/retrieving mechanism of the transducer is designed to ensure the reliable contact between the transducer and the steel surface.

EXPERIMENTAL RESULTS

- 1-inch thick steel plate measured at the UNR Earthquake Engineering laboratory
- The developed system obtained good ultrasonic waveforms, which provide 1.04 inch thickness, nearly equal to the nominal 1 inch thickness





$$\text{Thickness} = \frac{\text{ToF} \times \text{Velocity}}{2} = \frac{8.912\ \mu s \times 0.2339\ \text{in}/\mu s}{2} = 1.04\ \text{in}$$

* Nominal velocity of 0.2339 in/μs for carbon steel is used

CONCLUSIONS

A compact ultrasonic thickness measurement device is developed based on the *Martlet* wireless sensing system. The device is capable of high-voltage excitation, filtering/amplification of the received ultrasonic signal, high-speed analog-to-digital conversions (up to 80 MHz), and wireless data transmission. After integration with a steel climbing robot developed by UNR, the mobile sensing system successfully obtained accurate thickness measurement in laboratory testing.

REFERENCE

[1] Nguyen, S.T., Nguyen, H., Bui, S.T., Ho, V.A., & La, H.M. (2021). "Multi-directional bicycle robot for steel structure Inspection". arXiv: 2103.11522.

ACKNOWLEDGMENTS

This material is based upon work sponsored by the INSPIRE University Transportation Center through USDOT/OST-R grant #69A3551747126. The authors would also like to thank collaborators Prof. Hung La and Son Thanh Nguyen at University of Nevada, Reno.

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First Place Award

PRESENTED TO

Dongbin Kim

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Genda Chen, Ph.D., P.E., F.ASCE, F.SEI, F.ISHMII
Director, INSPIRE University Transportation Center

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A Human-Embodied Drone for Dexterous Aerial Manipulation

Dongbin Kim, Paul Y. Oh.,
Drones and Autonomous Systems Lab, UNLV

INTRODUCTION

Current drones *passively surveil*. Drones equipped with robotic arms shift this paradigm: the drone is actively interacting with the environment rather than simply sensing it. This would be needed to robotically enhance bridge-related work, called dexterous aerial manipulation: drones could hose decks; drilling on surfaces; and epoxy cracks. Such research is important to advancing bridge maintenance and repair.

Recently, the worker's experience was integrated in aerial manipulation using haptic technology. The net effect is such system could enable the worker to leverage drones to collaborative perform haptic assessments of the objects and complete tasks on the bridge remotely. However, the tasks were completed within the operator's line-of-sight.

Research gap: an immersive framework based on AR/VR is rarely integrated in aerial manipulation. Such framework allows drones to transport the operator's senses, actions, and presence to a remote location in a real-time. Hence, the operator can physically interact with the environment and socially interacts with actual workers on the work site.

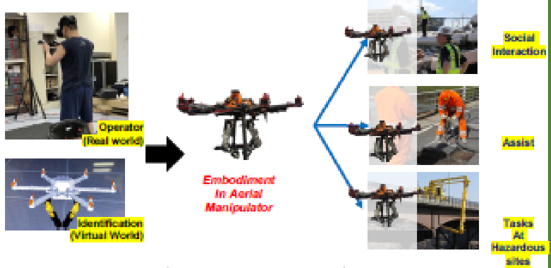

Fig 1: Overall scheme of the human-embodied drone interface

METHODS

Design a *"Human-Embodied Drone Interface"* (Figure 1):

Dual-Arm Aerial Manipulator: For dexterous manipulation. Visual sensing. Capture reaction forces from physical interactions.

Virtual Reality (VR) System: A visual immersion into the work-site. Human body motion capture. Haptic feedback to the operator.

Voice Communication System: Bandpass filter to eliminate drone propeller noises.

Flight trial scenario: Operator-Sender collaboration for a package delivery to validate the performance

RESULTS

Two 3-DOF robotic arms with parallel grippers were mounted on a rotorcraft drone to synthesize human arm motions. The gripper sensed reaction forces while interacting with objects. VR controller served as the haptic interface. A camera was attached to a motor on top of the arms to provide 2D visual feedback in real time. The motor tilted the camera following the operator's head motions. In addition, a 3D model of the test-site was pre-captured and rendered in the VR headset to provide better situational awareness. The key result was that the operator could use a drone to perform tasks and socially interact with people on the task-site. (**Figure 2**)

Figure 3 showed summary from the flight trial scenario. **Figure 4** successfully captured arm trajectories and haptic feedback. **Figure 5** showed the voice communication was barely interfered by drone propeller

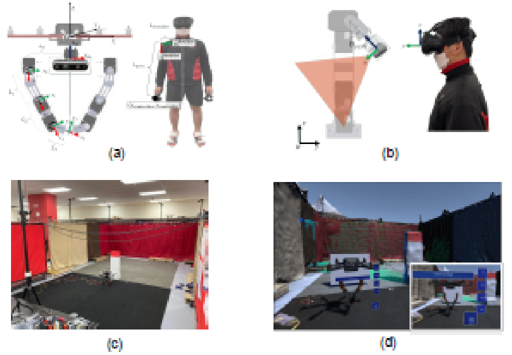

Fig 2: (a)-(b) Human arm/head motion mapping to aerial manipulator. The red triangle shows field-of-view of the camera, (c) Test-site in the real world, (d) Test-site and the aerial manipulator rendered in the VR headset

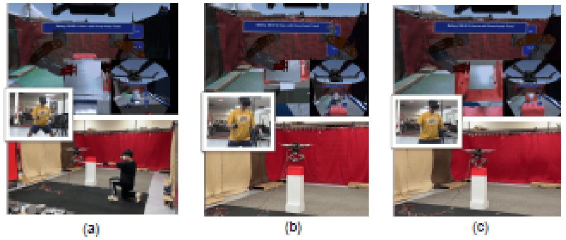

Fig 3: Flight trial summary, VR headset view (top), Operator (center left), Test-site in real-world (bottom): (a) Received the package from the sender after voice communication; (b) Arrival at the target delivery point; (c) Package delivery complete

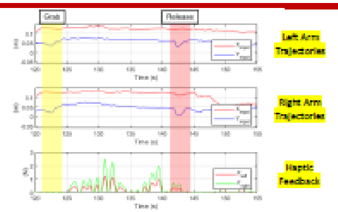

Fig 4: Arm motions and haptic sensing results during the flight trial

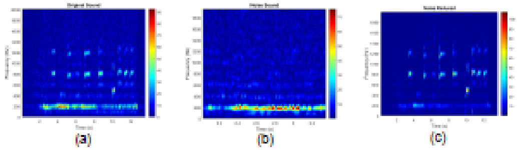

Fig 5: Propeller noise filter results during voice communication. (a) Original sound, (b) Noise sound, (c) Noise-filtered sound

CONCLUSIONS

Key contribution of this research is "*Embodiment*". Flight trial well demonstrated promising results. The operator successfully performed package delivery with no *a priory* information about the package or the environment. The operator could also socially interact with the package sender during the flight.

Future work:
- Improvements of the robotic arm design for bridge-related dexterous manipulation tasks: epoxy cracks; horizontal drilling; tool manipulation
- Integrate 360 camera to provide real-time 3D visual feedback

Human-embodied drone interface would help workers augment their *intelligence* for the desired tasks

REFERENCE

[1] D. Kim, P. Oh, "Testing-and-Evaluation platform for Haptic-based Aerial Manipulation with drones," IEEE American Control Conference (ACC), July 2020
[2] D. Kim, P. Oh, "Human-Drone Interaction for Aerially Manipulated Drilling using Haptic Feedback," IEEE International Conference on Intelligent Robots and Systems (IROS), October 2020
[3] D. Kim, P. Oh, "Toward Avatar-Drone: A Human-Embodied Drone for Aerial Manipulation," IEEE International Conference on Unmanned Aircraft Systems (ICUAS), June 2021

ACKNOWLEDGEMENTS

Thank you INSPIRE teams and U.S. Department of Transportation (DoT) for the support

Thank-you to all presenters!