Contract No:

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Disclaimer:

Concrete Inspection in Remote Areas with Robotic Arms

The use of non-destructive examination (NDE) to assess the conditions of concrete structures has received extensive attention in recent years. NDE analysis techniques are used to evaluate the properties of materials and to ensure the integrity of structures without causing damages to them. NDE inspection is often performed manually by certified technicians, however in remote and high hazard environments this is impossible or undesirable for human safety. Development of remote and robotic technologies to perform these essential inspections is of interest to the DOE EM complex due to its aging infrastructure and hazardous environments.

This goal of this seedling was to develop techniques to remotely examine inaccessible concrete structures and to evaluate results collected remotely to those obtained by human hand. Additionally, two promising state of the art NDE instruments were identified to be used for the characterization to include the new Proceq Ground Penetrating Radar (GPR) which generates results in 3D using Augmented Reality. A test bed was built to develop and evaluate deployment techniques of the NDE instruments with a robotic arm, Fig 1. Concrete test forms simulating the rough concrete surfaces, strength, composition and potential structural defects that can be found at our DOE EM facilities were built for the examination. Initial NDE instrumentation data collection has been performed on the concrete test forms.

Fig 1- Test Bed deploying concrete inspection Instruments on custom designed Concrete Test forms

Awards and Recognition – N/A

Intellectual Property Review

This report has been reviewed by SRNL Legal Counsel for intellectual property considerations and is approved to be publically published in its current form.

SRNL Legal Signature

Signature **Date**

Concrete Inspection in Remote Areas with Robotic Arms

Project Team

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MSIPP SRNL Summer Intern: Jeffrey Kim

Thrust Area: ES

Project Start: June 27, 2019

Project End: Sept 30, 2019

Budget: FY19 Funding: $75k

Proposed FY20 Funding: $25k

The goal of this project is to develop state of the art techniques to evaluate conditions of inaccessible concrete structures. Focus is on the examination of remote concrete structures typically found in DOE EM facilities. This seedling included the development of a test bed consisting of a robotic arm capable of deploying concrete NDE instruments to examine custom concrete forms with known defects. Concrete forms simulating the rough concrete surfaces, strength, composition and potential structural defects that can be found at our DOE EM facilities were designed and built for examination. Two state of the art concrete NDE instruments were identified to be tested and characterized as to their ability to provide desired NDE data on the developed test beams and slabs. A collaborative robot arm is being used as they are designed with built in features allowing them to safely operate alongside employees.

FY2019 Objectives

1) Setup Robotic Arm Concrete Inspection Test Bed
2) Build concrete forms designed to simulate DOE aged facilities
3) Test ability of the instruments of interest to collect desired NDE data from test forms
    a) Baseline performance with hand deployment
    b) Test ability to obtain baseline performance using robotic arm

Introduction

This seedling was first submitted for consideration in early 2019, however work was not funded until late June 2019; while much progress was made toward the objectives, not all were completed.

Remote concrete NDE technologies were identified as having broad applicability and high value across the DOE complex by the DOE EM Technology Development Office (TDO). At the Savannah River Site, H-Canyon Exhaust Tunnel (H-CAEX) stakeholders identified remote concrete NDE as the highest priority technology inspection goal to enhance bi-annual Structural Integrity (SI) evaluation of the tunnel. The H-CAEX tunnel is located below grade and does not allow human entry due to its hazardous environment. Current inspections collect visual information using cameras mounted on robotic crawlers, Fig. 2, it is desired to have a more quantitative examination of the concrete structure.

Fig 2- human denied H-CAEX tunnel interior view

This goal of this seedling was to develop and build a test bed to support the evaluation of using a robotic arm to perform remote inspections using concrete NDE instruments. Concrete test forms simulating the rough concrete surfaces, strength, composition and potential structural defects that can be found at our DOE EM facilities were built for examination and use in the test bed.

The test bed can be used as follows:

- to develop techniques and software to perform NDE examination with instruments mounted on a robotic arm
- to design and test custom robotic arm instrument mounts
- to characterize and evaluate state of the art NDE instruments
- to evaluate the ability to acquire desired NDE data
- to evaluate the quality of the acquired data

If the ability to collect the desired data supporting a more thorough SI evaluation can be developed and demonstrated using a robotic arm, the system could be mounted on a crawler for future enhanced remote inspections.

Approach

The LDRD implementing team included SRNL R&D Engineering staff, SRNL SMEs in concrete science and inspection technologies and H-CAEX SI stakeholders to optimize the approach and desired results. Two promising state of the art NDE instruments were identified to be included for evaluation and characterization, the Pundit Live Array and the Proceq GPR, Fig 3. In addition to providing stakeholder identified desired data, the instrument technologies employed were thought to potentially work better on the rough concrete surfaces sometimes found in the remote hazardous environments.

Fig 3- State of the Art NDE Instruments of Interest

The basic LDRD approach is as follows:

1. build the test bed which would include a robotic arm with custom end effector mounts to hold the NDE instruments.
2. Design and build concrete forms simulating the rough concrete surfaces, strength, composition and potential structural defects for testing
3. Collect instrument data on the test beams using traditional manual hand-held methods, then collect the data using the developed test bed robotic arm system, Fig 4.
    a. Data would include instrument performance on smooth, mildly rough and very rough concrete surfaces.

Simplified Test Matrix

CONCRETE INSPECTION PERFORMANCE via Human and Robotic Arm Deployment			
Deployment Method/ Instrument	Concrete Surface		
	Smooth	Mild Roughness (.5" exposed aggregate)	Very Rough (1.5" exposed aggregate)
HAND DEPLOYMENT			
• Proceq Echo Pulse			
• GPR			
ROBOTIC ARM DEPLOYMENT			
• Proceq Echo Pulse			
• GPR			

Fig 4- Simplified Test Matrix

Results/Discussion

TEST BED. A test bed employing the collaborative UR5 robot arm was designed and built, Fig.5; collaborative robotic arms are designed with features to safely operate alongside people. An end effector mount was design and printed to attach the Pundit Live Array instrument to the robotic arm. Software and rudimentary techniques were developed and the ability to collect data from the Pundit Live Array instrument was demonstrated. The Proceq GPR unit was ordered in early July and was not received until late September, so this system was not tested with the robotic arm. More advanced techniques are needed to facilitate readings of rough concrete surfaces.

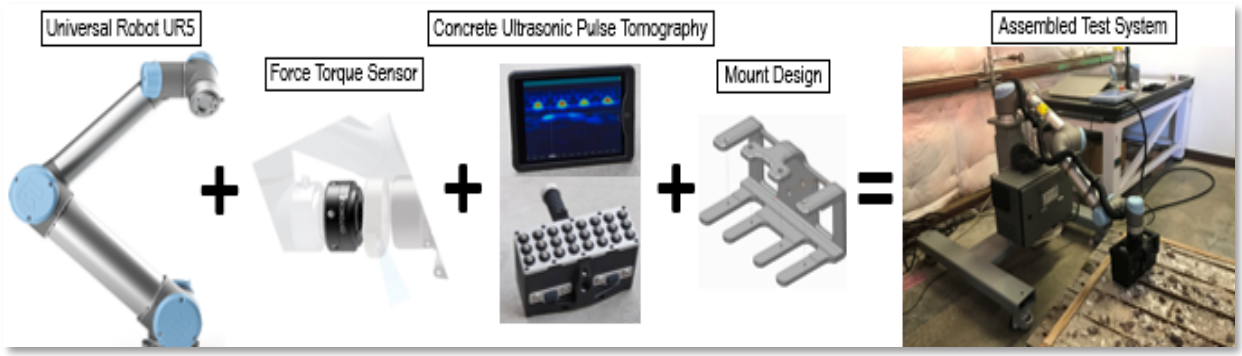

Fig 5 - Test Bed Assembly with Pundit Live Array Instrument mounted

CONCRETE TEST BEAMS. Concrete test beams and forms simulating the rough concrete surfaces, strength, composition and potential structural defects were designed and built for testing. The form design included rebar location and compressive strengths similar to H-CAEX, however the designs were deemed to be universally useful, Fig 6. The test forms and beams were built in N-Area by the System One group, Fig 7.

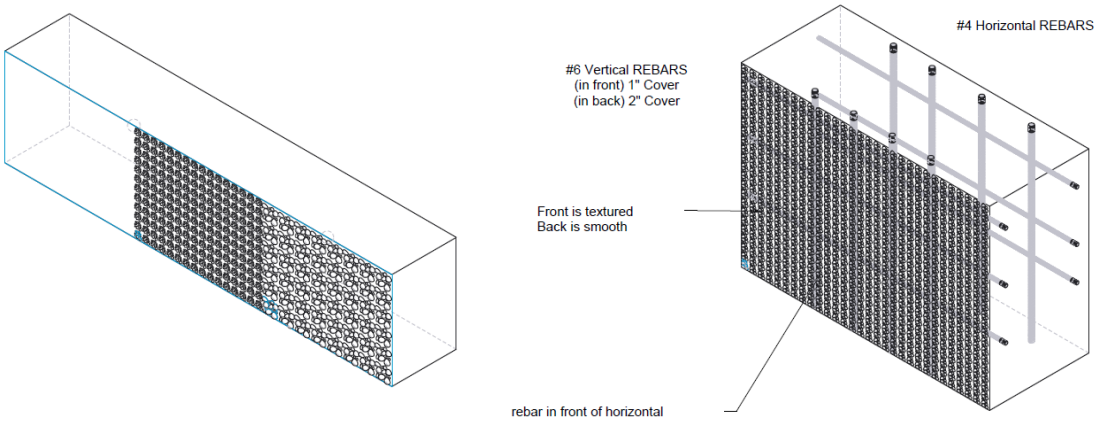

Fig 6 – Concrete Beam (left) and Form (right) Design with varying surface textures and rebar

Fig. 7 - Test Forms with varying compressive strengths: 2000 psi, 3000 psi and 5000 psi

DATA COLLECTION. Initial instrument hand held test data was collected on the concrete forms in N-Area, Fig 8.

Fig 8 - Collection of hand-held instrument data in field on test beam with multiple surface roughness

FY2019 Accomplishments

- Built a Test Bed for evaluating the ability to perform remote concrete NDE inspections using a robotic arm
- Developed software and a methodology for evaluating the performance of state-of-the-art instruments
- Designed and built custom concrete test forms and beams simulating typical DOE facility concrete structures
- Ordered and received the Proceq GPR

Future Directions

Facility stakeholders are highly interested in concrete NDE data that can be obtained using remote technologies. Completion of this LDRD scope would enable stakeholders to make informed decisions on the feasibility and benefit of potential future concrete NDE inspections.

Future desired scope includes:

1. Completion of this LDRD objectives to include the characterization of the identified promising NDE instruments to collect desired data from custom test forms
2. Development of additional software and deployment technologies if required
3. Development of lessons learned and recommendation for field deployment with team

If the ability to collect desired NDE data can be developed and demonstrated using a robotic arm, the system could be mounted on a crawler or other remote deployment device for future inspections.

FY 2019 Publications/Presentations

An Abstract has been submitted for Oral Presentation at the 2020 Waste Management Symposia (WM2020) International Conference.

Acronyms

GPR – Ground Penetrating Radar (GPR)
H-CAEX – H-Canyon Exhaust Tunnel (H-CAEX)
NDE – Non-Destructive Examination (NDE)
SI - Structural Integrity (SI)

Intellectual Property

N/A

Total Number of Post-Doctoral Researchers

0

Total Number of Student Researchers

1 – Undergraduate SRNL Summer Intern through the MSIPP program