Overview: (Please answer each question individually)

In this phase of research, we have experimentally tested energy harvesting concept that is enhanced by the integration of negative capacitance element. We have also investigated sensor networking strategy, i.e., sensitivity and robustness of fault identification with multi-sensor coverage.

Provide context as to how these activities are helping achieve the overarching goal(s) of the project...

This project aims at the development of robust and autonomous sensory network for railway tracks. To enable the sensor autonomy, we have synthesized an energy harvesting strategy that can continuously scavenging useful energy from train passage induced vibratory energy. The enhance the robustness, we have studied integrating negative capacitance element to the piezoelectric sensor to increase the electro-mechanical coupling. Interestingly, we have recognized that the negative capacitance element can enhance both energy harvesting and fault detection, whilst such element itself does consume electrical power. In this phase of research, we have conducted systematical trade-off studies and experimental validations. In order to facilitate sensor networking and take full advantage of long range of inspection of each sensory node with piezoelectric transducer, we have also developed multi-objective optimization algorithm, aiming at facilitating inverse analysis of the damage at a specific location with multiple sensor coverage. We have successfully developed an improved particle swarm optimization algorithm with meta-heuristics. This new algorithm lays down a foundation for developing actual networking strategies.

Describe any accomplishments achieved under the project goals...

The major accomplishments in this phase of research are: 1) performance enhancement analysis with the integration of negative capacitance element and experimental validation; and 2) a new multi-objective optimization through particle swarm with meta-heuristics.

Complete the following tables to document the work toward each task and budget (add rows/remove rows as needed, make sure you complete the Overall Project progress row and include all tasks even if they have ended or have not been started)...

Table 1: Task Progress			
Task Number	**Start Date**	**End Date**	**% Complete**
Task 1:	10/1/2018	9/30/2019	100%
Task 2:	10/1/2019	3/31/2020	100%
Task 3:	4/1/2020	12/31/2021	85%
Task 4:	1/1/2022	6/30/2022	50%
Overall Project:	*Enter Actual Start*	*Enter Planned/Actual End*	

Table 2: Budget Progress		
Project Budget	**Spend – Project to Date**	**% Project to Date***

***Include the date the budget is current to.**

Describe any opportunities for training/professional development that have been provided...

This project has involved one M.S. student, Yixin Yao, who carries out the numerical and experimental investigations, and two Ph.D. students, Yang Zhang and Ting Wang, who focus on fault detection algorithm development and sensor synthesis with energy harvesting capability. Yixin Yao successfully defended his M.S. thesis in December 2020.

Describe any activities involving the dissemination of research results (be sure to include outputs, outcomes, and the ways in which the outcomes/outputs have had an impact during the reporting period. Please use the tables below for any Publications and Presentations in addition to the description of any other technology transfer efforts that took place during the reporting period.)... Use the tables below to complete information about conferences, workshops, publications, etc. **List all other outputs, outcomes, and impacts after the tables** *(i.e. patent applications, technologies, techniques, licenses issued, and/or website addresses used to disseminate research findings).*

Table 3: Presentations at Conferences, Workshops, Seminars, and Other Events				
Title	**Event**	**Type**	**Location**	**Date(s)**
Presentation title	Name of event (i.e. TIDC 1st Annual Conference)	i.e. Conference, Symposium, Seminar,		
N/A				

Table 4: Publications and Submitted Papers and Reports				
Type	**Title**	**Citation**	**Date**	**Status**
i.e. Peer-reviewed journal, conference paper, book, policy paper	Publication title	Full citation		I.e. Submitted, accepted, under review
N/A				

Encouraged to add figures that may be useful (especially for the website)...

Insert figures here

Participants and Collaborators:

Use the table below to list all individuals who have worked on the project.

Table 5: Active Principal Investigators, faculty, administrators, and Management Team Members			
Individual Name	**Email Address**	**Department**	**Role in Research**
	Email is not included in the external report and is only used for internal purposes.		
Jiong Tang	jiong.tang@uconn.edu	Mechanical Engineering	PI

Use the table below to list all students who have participated in the project during the reporting. (This includes all paid, unpaid, intern, independent study, or any other student that participated in this project.)

Table 6: Student Participants during the reporting period				
Student Name	**Email Address**	**Class**	**Major**	**Role in research**
	Email is not included in the external report and is only used for internal purposes.	(i.e. Junior, Master's Ph.D)		
Yang Zhang		Ph.D.	Mechanical Engineering	Carry out inverse identification research
Ting Wang		Ph.D.	Mechanical Engineering	Carry out energy harvesting research

Use the table below to list any students who worked on this project and graduated during this reporting period.

Table 7: Student Graduates			
Student Name	**Role in Research**	**Degree**	**Graduation Date**
N/A			

Use the table below to list organizations have been involved as partners on this project and their contribution to the project.

Table 8: Research Project Collaborators during the reporting period						
Organization	**Location**	**Contribution to the Project**				
		Financial Support	**In-Kind Support**	**Facilities**	**Collaborative Research**	**Personnel Exchanges**
Sperry Rail Service	Shelton, CT		X	X		

List all other outputs, outcomes, and impacts here (i.e. patent applications, technologies, techniques, licenses issued, and/or website addresses used to disseminate research findings). Please be sure to provide detailed information about each item as with the tables above.

Have other collaborators or contacts been involved? If so, who and how? (This would include collaborations with others within the lead or partner universities; especially interdepartmental or interdisciplinary collaborations.)

Table 9: Other Collaborators			
Collaborator Name and Title	**Contact Information**	**Organization and Department**	**Contribution to Research**
N/A			(i.e. Technical Champion)

Who is the Technical Champion for this project?
Name: Jan Kocur
Title: Director of Engineering
Organization: Sperry Rail Service

Location (City & State): Danbury, CT
Email Address: jkocur@sperryrail.com

Changes:

Discuss any actual or anticipated problems or delays and actions or plans to resolve them...
N/A
Discuss any changes in approach and the reasons for the change...
N/A

Planned Activities:

The next phase of the research will focus on the documentation of energy harvesting investigation, and analyze sensor networking strategies under multi-objective optimization based fault identification.