RESEARCH PERFORMANCE PROGRESS REPORT

SUBMITTED TO:

U. S. Department of Energy
National Energy Technology Laboratory

WORK PERFORMED UNDER AGREEMENT: DE-FE0029020

PROJECT TITLE:

Smart Methane Emission Detection System Development

SUBMITTED BY:

Maria Araujo, PI
maria.araujo@swri.org
(210) 522-3730

SUBMISSION DATE: January 30, 2019

DUNS NUMBER: 007936842

RECIPIENT ORGANIZATION:

Southwest Research Institute
6220 Culebra Road
San Antonio, TX 78238

PROJECT/GRANT PERIOD:

October 1, 2016 through October 31, 2019

REPORTING PERIOD END DATE:

December 31, 2018

REPORT TERM OR FREQUENCY: Quarterly

SIGNATURE OF SUBMITTING OFFICIAL:

Maria S. Araujo

ACCOMPLISHMENTS

What was done? What was learned?

Activities during this quarter focused on adaptation of the SLED/M hardware for drone operation. During this period, we adapted and fit the SLED/M processor and cameras for operation on a DJI Matrice M600 Pro platform.

- **What are the major goals of the project?** The major objective of this DOE research project is to develop an autonomous, real-time methane leak detection technology, the SLED/M, which applies machine learning techniques to passive optical sensing modalities to mitigate emissions through early detection. The goal during Phase 1 was to develop the prototype methane detection system with integrated optical sensors and the embedded processing unit. The goal for Phase 2 was to integrate and field-test the prototype system, and then demonstrate the capabilities to DOE. The goal for Phase 3 will be to adapt the system developed under previous phases for use on a mobile aerial drone platform.

To accomplish these goals, SwRI has identified a comprehensive schedule with milestone dates for important activities that will evidence progress on the project. The milestone schedule, with actual completion dates, is shown below.

Phase	Milestone Description	Verification Method	Planned Completion	Completion Date
1	Prepare and Submit the PMP	Delivery to DOE	10/29/16	10/29/2016
1	Update PMP with DOE Comments	Delivery to DOE	12/2/16	11/16/2016
1	Update the Data Management Plan	Delivery to DOE	12/16/16	12/16/2016
1	Develop the Algorithm	Assessment Results	9/15/17 (revised per PMP submitted on 6/13/17)	9/15/17
1	Develop and Assemble Prototype	Testing Results	9/22/17 (revised per PMP submitted on 6/13/17)	9/22/17
2	Integrate and Test Prototype	Testing Results	9/15/18	9/15/18
2	Demonstrate the System to DOE	Demonstration	9/15/18	9/28/18 (via test report)
3	Deployment of System to Drone	Testing Results	1/10/18	
3	Develop Drone Algorithm	Assessment Results	6/1/18	
3	Detection of Methane from Drone	Demonstration	8/1/18	

On September 28, 2018, project deliverables for Budget Year (BY) 2 for the project were submitted to NETL, as noted below:

Milestones:

- System Test Plan
- System Drawings and Documentation
- System Test Report, Final Algorithm
- Phase 2 Deliverables Report

Number	Task/Subtask	Deliverables	Completion Date	Revised Date
Pd6	4.0	Mechanical Drawings	1/26/18	6/30/18
Pd7	5.0	Electrical Drawings and System Design Document	1/26/18	6/30/18
Sd1	6.0	System Test Plan, System Test Report, Updated Drawings, Updated Software Executable and Source Code	4/20/18	9/15/18

What was accomplished under these goals?

<u>Conducting Initial Integration of Drone Hardware, Camera, and Flight Computer</u>

- During this reporting period, SwRI procured a DJI Matrice M600 Pro for use in collection of aerial methane leak data and algorithm testing. The drone has been fitted with a Ronin gimbal system. An embedded flight board was selected, and a software driver for the optical gas imager (OGI) was written to support data collection from the drone platform. Initial flights have been conducted to test the off-the-shelf control software and gimbal system.

Figure 1. DJI Matrice 600 Pro. This platform is capable of 20 minutes of sustained flight under the anticipated sensing payload.

Figure 2. Ronin gimbal outfitted with an OGI camera. The gimbal allows for controlled omnidirectional pointing of the camera.

<u>Re-Evaluation of DOE Phase 2 Datasets</u>

- During this quarter, SwRI labelled the remaining portions of the large Phase 2 validation dataset (over 1.5M frames). This data can now be used for further training to improve the algorithm performance moving forward.

What opportunities for training and professional development has the project provided?

None

How have the results been disseminated to communities of interest?

- With the concurrence of the DOE PM, Mr. Joseph Renk III:
  - Maria Araujo presented at the Western Regional Gas Conference in San Diego, CA on August 30, 2017 with a presentation titled “Bringing Smarts to Methane Emissions Detection: An Update on the DOE Smart Methane Emissions Project.”
  - Daniel Davila presented at the Machine Learning for Oil and Gas Conference in April 2018 with presentation titled “Enabling Edge Solutions with Deployable Machine Learning.”
  - Maria Araujo presented at the Pipeline and Energy Expo in Tulsa, OK in April 2018 with a presentation titled “Automated Leak Detection Using Machine Learning and Multi-Platform Remote Sensing.”
  - Maria Araujo presented at the World Gas Conference in June 2018 with a presentation titled “Real-Time Automated Methane Leak Detection Using Remote Sensing and Machine Learning on the Edge.”
  - Maria Araujo presented at the American Gas Association Conference in June 2018 with a presentation titled “Using Remote Sensing and Machine Learning for Automated Methane Leak Detection.”
  - Heath Spidle presented at the ASME Robotics for Inspection and Maintenance Forum with presentation titled “Case Study: Real-Time Detection of Small Hazardous Liquid Pipeline Leaks Using Remote Sensing and Machine Learning.”
  - Maria Araujo presented Phase 2 results at the CH4 Connections conference in Ft Collins, CO.

- The team is also looking at additional conferences/venues to divulge this work.
- Additionally, several high-level articles regarding the work being done on this project were published and aired on television. Some references are noted below:
  - https://pgjonline.com/2017/10/02/teaching-technology-solution-finds-small-pipeline-leaks/
  - https://www.talkingiotinenergy.com/single-post/2017/06/08/Machine-learning-improves-oil-and-gas-monitoring
  - https://www.asme.org/engineering-topics/articles/energy/machine-learning-applies-pipeline-leaks
  - http://www.naturalgasintel.com/articles/108067-texas-laboratory-developing-methane-leak-detection-system-for-doe
  - http://www.rigzone.com/iPhone/article.asp?a_id=147295
  - http://www.klrn.org/blogs/station-news/swri-developing-smart-technology-to-detect-methane-leaks/
  - http://www.oilandgaslawyerblog.com/2017/02/high-tech-detect-pipeline-leaks.html
  - https://www.ksat.com/news/swri-working-on-oil-and-gas-leak-detection

What does SwRI plan to do during the next reporting period to accomplish the goals?

During the next reporting period, SwRI will:

- Conduct further test flights in preparation for live data collection.
- Conduct live data collection from aerial platform.
- Cleanse and label data collected from aerial platform.
- Begin development of algorithm for quick sensing of methane from a mobile platform.

PRODUCTS

What has the project produced?

Publications, conference papers, and presentations:

- **Journal publications -**
  - Teaching Technology: Solution Finds Small Pipeline Leaks, Pipeline and Gas Journal. October 2017, Vol. 244, No. 10.
  - Machine Learning Applies to Pipeline Leaks, American Society of Mechanical Engineers (ASME). August 2017.
  - Machine learning improves oil and gas monitoring, Talking IoT in Energy, June 2017.
- **Books or other non-periodical, one-time publications** - Nothing to Report During This Period.
- **Other publications, conference papers and presentations** -
  - Maria Araujo presented at the Western Regional Gas Conference in San Diego, CA on August 30, 2017 with a presentation titled "Bringing Smarts to Methane Emissions Detection: An Update on the DOE Smart Methane Emissions Project."
  - Daniel Davila presented at the Machine Learning for Oil and Gas Conference in April 2018 with presentation titled "Enabling Edge Solutions with Deployable Machine Learning."
  - Maria Araujo presented at the Pipeline and Energy Expo in Tulsa, OK in April 2018 with a presentation titled "Automated Leak Detection Using Machine Learning and Multi-Platform Remote Sensing."
  - Maria Araujo presented at the World Gas Conference in June 2018 with a presentation titled "Real-Time Automated Methane Leak Detection Using Remote Sensing and Machine Learning on the Edge."
  - Maria Araujo presented at the American Gas Association Conference in June 2018 with a presentation titled "Using Remote Sensing and Machine Learning for Automated Methane Leak Detection."
  - Heath Spidle presented at the ASME Robotics for Inspection and Maintenance Forum with presentation titled "Case Study: Real-Time Detection of Small Hazardous Liquid Pipeline Leaks Using Remote Sensing and Machine Learning."
  - Maria Araujo and Daniel Davila presented at the CH4 Connections in Fort Collins, CO and had a booth showcasing the SLED/M technology.
- **Website(s) or other Internet site(s)** –
  - https://www.spe.org/en/ogf/ogf-article-detail/?art=3639
  - https://pgjonline.com/2017/10/02/teaching-technology-solution-finds-small-pipeline-leaks/
  - https://www.talkingiotinenergy.com/single-post/2017/06/08/Machine-learning-improves-oil-and-gas-monitoring

        - https://www.asme.org/engineering-topics/articles/energy/machine-learning-applies-pipeline-leaks
        - http://www.naturalgasintel.com/articles/108067-texas-laboratory-developing-methane-leak-detection-system-for-doe
        - http://www.rigzone.com/iPhone/article.asp?a_id=147295
        - http://www.klrn.org/blogs/station-news/swri-developing-smart-technology-to-detect-methane-leaks/
        - http://www.oilandgaslawyerblog.com/2017/02/high-tech-detect-pipeline-leaks.html
        - https://www.ksat.com/news/swri-working-on-oil-and-gas-leak-detection
- **Technologies or techniques –** A technique for autonomously detecting methane using MWIR cameras and machine learning is currently under development, with promising results.
- **Inventions, patent applications, and/or licenses –** SwRI filed an invention disclosure of the technique for autonomously detecting methane using MWIR cameras and machine learning.
    - United States Patent and Trademark Office (USPTO) Patent Application 62/724,354 entitled "Detection of Methane Leaks Using Optical Imaging and Neural Network Processing"
- **Other products -** Nothing to report during this reporting period.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS (optional)

Who has been involved?

What individuals have worked on the project?

The following individuals were the main contributors to this project during this reporting period:

1. **Name:** Maria Araujo
    a. **Project Role:** PI
    b. **Nearest person month worked:** 1
    c. **Contribution to Project:** Ms. Araujo oversees the project and technical direction. She participated on the simulated tests and holds periodic meetings with the project team.
    d. **Funding Support:** N/A
    e. **Collaborated with individual in foreign country:** No
    f. **Country(ies) of foreign collaborator:** N/A
    g. **Travelled to foreign country:** No
    h. **If traveled to foreign country(ies), duration of stay:** N/A
2. **Name:** Daniel Davila
    a. **Project Role:** Developer
    b. **Nearest person month worked:** 3
    c. **Contribution to Project:** Mr. Davila assisted with tests performed and algorithm development during this reporting period.
    d. **Funding Support:** N/A
    e. **Collaborated with individual in foreign country:** No
    f. **Country(ies) of foreign collaborator:** N/A
    g. **Travelled to foreign country:** No
    h. **If traveled to foreign country(ies), duration of stay:** N/A
3. **Name:** Heath Spidle
    a. **Project Role:** Developer
    b. **Nearest person month worked:** 1
    c. **Contribution to Project:** Mr. Spidle assisted with tests performed and algorithm development during this reporting period.
    d. **Funding Support:** N/A
    e. **Collaborated with individual in foreign country:** No
    f. **Country(ies) of foreign collaborator:** N/A
    g. **Travelled to foreign country:** No
    h. **If traveled to foreign country(ies), duration of stay:** N/A

What other organizations have been involved as partners?

There are no other planned partner organizations besides the cost share partners.

Have other collaborators or contacts been involved?

No other collaborators or contacts have been involved. However, a variety of potential industry partners have been in contact with interest in commercializing SLED/M.

IMPACT (optional)

What is the impact of the project? How has it contributed?

With the approval of the DOE, the team has already been engaging in conversations with oil and gas companies about how the SLED/M technology could potentially improve their efficiency and safety and help in the reduction of methane emissions through early detection of methane leaks. The Smart Methane Leak Detection System (SLED/M) is an autonomous, reliable, real-time methane leak detection technology that utilizes machine learning techniques and a commercial-off-the-shelf (COTS) optical sensor to mitigate emissions through early detection. SLED/M can monitor various regions of a pipeline facility and easily integrate with existing and new suites of natural gas mitigation technologies.

Feature	Details
Low False Alarm Rates	Less than 0.5% (number of events incorrectly classified as leaks).
Autonomous Detection	No need for a human to be in the loop • Minimizes human error • Minimizes response time to a leak event (early detection) • Reduces operational costs • Operates at the edge – no need for video streaming to the cloud or to a central facility
Works with Existing Operator-Owned MWIR Cameras	• SLED/M has been shown to work with MWIR cameras from multiple manufacturers • SLED/M can be integrated with existing operator-owned equipment
Near Real-Time Detection	The time between acquiring data and obtaining an output from the system is only a few seconds
Non-Intrusive, Passive Technology	No need to retrofit existing equipment and facilities. The proposed technology is passive in nature, thus eliminating safety and operational restrictions.
Reliable Detection	Ability to detect methane leaks that could go unnoticed by current technologies

What is the impact on the development of the principal discipline(s) of the project?

The development of the SLED/M technology allows for mitigation of fugitive emissions via the early detection of methane leaks. The technology is real-time and autonomous, thus allowing for facilities to be monitored with minimal human resource involvement and, therefore, reducing the overall monitoring costs and improving the reliability of detections.

What is the impact on other disciplines?

The technology being developed in this project has a variety of applications beyond methane emissions monitoring, such as carbon monoxide monitoring; agricultural land use analysis and crop prediction; water management and soil moisture analysis; natural hazards monitoring and prediction; and ecosystem monitoring and conservation.

What is the impact on the development of human resources?

Nothing to Report

What is the impact on physical, institutional, and information resources that form infrastructure?

Nothing to Report

What is the impact on technology transfer?

Commercial partners have expressed interest in commercializing the technology developed under this contract. SLED/M is garnering significant interest in industry due to:

- Its ability to operate autonomously
- Its use of COTS parts
- Its ability to detect methane that might go undetected by state-of-the-art OGI equipment
- Its ability to work with a variety of OGIs from different manufacturers

What is the impact on society beyond science and technology?

The byproducts of this project will allow for more effective mitigation of methane emissions, which are a major greenhouse effect contributor. By reducing fugitive methane emissions, climate change impacts caused by greenhouse gas emissions are also reduced.

What dollar amount of the award's budget is being spent in foreign country(ies)?

Nothing to Report

CHANGES/PROBLEMS

SwRI does not anticipate any significant changes in the project or its direction. If this should occur, SwRI is fully aware of its responsibility to provide all relevant details, and to obtain prior written approval from the Contracting Officer.

Changes in approach and reasons for change –

Nothing to report during this reporting period.

Actual or anticipated problems or delays and actions or plans to resolve them –

Nothing to report during this reporting period.

Changes that have a significant impact on expenditures –

Nothing to report during this reporting period.

Significant changes in use or care of human subjects, vertebrate animals, and/or biohazards –

Nothing to report during this reporting period.

Change of primary performance site location from that originally proposed –

Nothing to report during this reporting period.

SPECIAL REPORTING REQUIREMENTS

SwRI is not aware of any special reporting requirements in the award terms and conditions.

BUDGETARY INFORMATION

The cost status is provided on the next page. It identifies the baseline cost plan, actual incurred costs, and variance.

Budget Reporting Quarter	Budget Period 2																	
	Q1		Q2		Q3		Q4		Q1		Q2		Q3		Q4		Q1	
	10/1-17 - 12/31/17		1/1/18 - 3/31/18		4/1/18 - 6/30/18		7/1/18 - 9/30/18		10/1-18 - 12/31/18		1/1/19 - 3/31/19		4/1/19 - 6/30/19		7/1/19 - 9/30/19		10/1-19 - 10/31/19	
	Q1	Total to Date	Q2	Total to Date	Q3	Total to Date	Q4	Total to Date	Q1	Total to Date	Q2	Total to Date	Q3	Total to Date	Q4	Total to Date	Q4	Total to Date
Budget Cost Plan																		
Federal Share	$27,748	$545,155	$27,747	$572,902	$27,747	$600,649	$27,747	$628,396	$20,000	$648,396	$76,000	$724,396	$90,000	$814,396	$80,000	$894,396	$23,235	$917,631
Non-Federal Share	$0	$157,379	$0	$157,379	$0	$157,379	$0	$157,379	$0	$157,379	$21,692	$179,071	$21,692	$200,763	$21,692	$222,455	$7,233	$229,688
Total Planned	$27,748	$702,534	$27,747	$730,281	$27,747	$758,028	$27,747	$785,775	$20,000	$805,775	$97,692	$903,467	$111,692	$1,015,159	$101,692	$1,116,851	$30,468	$1,147,319
Actual Incurred Cost																		
Federal Share	$18,727	$478,174	$43,311	$521,485	$56,192	$577,677	$45,219	$622,896	$16,604	$639,500								
Non-Federal Share	$4,682	$119,543	$10,828	$130,371	$14,048	$144,419	$12,960	$157,379	$0	$157,379								
Total Incurred Costs	$23,409	$597,717	$54,139	$651,856	$70,241	$722,096	$58,179	$780,275	$16,604	$796,879								
Variance																		
Federal Share	$9,021	$66,981	-$15,564	$51,417	-$28,445	$22,972	-$17,472	$5,500	$3,396	$8,896								
Non-Federal Share	-$4,682	$37,836	-$10,828	$27,008	-$14,048	$12,960	-$12,960	$0	$0	$0								
Total Variance	$4,339	$104,817	-$26,392	$78,425	-$42,494	$35,932	-$30,432	$5,500	$3,396	$8,896								

The variance for Fiscal Year 2019 Q1 is shown above.

For historical reference, below is the variance for Budget Period 1.

Budget Reporting Quarter	Budget Period 1							
	Q1		Q2		Q3		Q4	
	10/1-16 - 12/31/16		1/1/17 - 3/31/17		4/1/17 - 6/30/17		7/1/17 - 9/30/17	
	Q1	Total to Date	Q2	Total to Date	Q3	Total to Date	Q4	Total to Date
Budget Cost Plan								
Federal Share	$49,000	$49,000	$160,000	$209,000	$165,000	$374,000	$143,407	$517,407
Non-Federal Share	$39,345	$39,345	$39,345	$78,690	$39,345	$118,035	$39,345	$157,379
Total Planned	$88,345	$88,345	$199,345	$287,690	$204,345	$492,035	$182,752	$674,786
Actual Incurred Cost								
Federal Share	$9,846	$9,846	$128,947	$138,793	$151,515	$290,308	$169,138	$459,446
Non-Federal Share	$2,461	$2,461	$32,237	$34,698	$37,879	$72,577	$42,284	$114,862
Total Incurred Costs	$12,307	$12,307	$161,184	$173,491	$189,394	$362,886	$211,422	$574,308
Variance								
Federal Share	$39,154	$39,154	$31,053	$70,207	$13,485	$83,692	-$25,731	$57,961
Non-Federal Share	$36,884	$36,884	$7,108	$43,992	$1,466	$45,457	-$2,940	$42,517
Total Variance	$76,038	$76,038	$38,161	$114,199	$14,950	$129,149	-$28,671	$100,478