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LLNL-TR-737829

Hyperspectral Sensors Final Report CRADA No. TC02173.0

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Disclaimer

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Hyperspectral Sensors

Final Report
CRADA No. TC02173.0
Date Technical Work Ended: July 18, 2013

Date: January 7, 2014 Revision: 1

A. Parties

This project was a relationship between Lawrence Livermore National Laboratory (LLNL) and Science Applications International Corporation.

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B. Project Scope

This was a collaborative effort between Lawrence Livermore National Security, LLC as manager and operator of Lawrence Livermore National Laboratory (LLNL) and Science Applications International Corporation (SAIC), National Security Space Operations/SRBU, to develop long-wave infrared (LWIR) hyperspectral imaging (HSI) sensors for airborne and potentially ground and space, platforms.

LLNL has designed and developed LWIR HSI sensors since 1995. The current generation of these sensors has applications to users within the U.S. Department of Defense and the Intelligence Community. User needs are for multiple copies provided by commercial industry. To gain the most benefit from the U.S. Government's prior investments in LWIR HSI sensors developed at LLNL, transfer of technology and know-how from LLNL HSI experts to commercial industry was needed.

In December 2010, LLNL was funded by the U.S. Army Corps of Engineers (USACE) to produce one (1) LWIR HSI sensor, coined BIG GREEN (BG), for an airborne application. In March 2011, USACE funded LLNL to build two (2) more copies of BIG GREEN (BG2 and BG3), and asked LLNL to produce yet three (3) more copies (BG4, BG5, and BG6) under a very demanding schedule. LLNL recommended that LLNL be partnered with a commercial company to produce these last three (3) copies of BIG GREEN, to meet the schedule and to transfer technology and know-how to industry.

The overarching purpose of the CRADA project was to facilitate the transfer of the necessary technology from LLNL to SAIC thereby allowing the U.S. Government to procure LWIR HSI sensors from this company. The purpose of the initial activities involving BIG GREEN sensors was to meet the customer's delivery schedule for all of the BIG GREEN sensors. BIG GREEN is a complex and sophisticated instrument, and the requisite technology must be imparted to SAIC to allow them to successfully produce the instrument. It was expected that in the first few months of joint work, sensor models (performance, structural, thermal and optical) would be provided to SAIC. Additionally, existing drawings, assembly procedures, test procedures, test equipment definitions, software descriptions and code, and complete Bills of Material (BOM) would be provided. SAIC would analyze the models, purchase material per the BOM, create its own set of production drawings, models and procedures, and identify areas of concern or where further information transfer is required.

The initial technical objective was to produce three (3) BIG GREEN sensors that would meet the technical specifications identified for BG4, BG5 and BG6. Project scope was later reduced to involve finishing BG5. BG4 responsibility was fully provided to LLNL, and BG6 was partially funded. The duration of the project was twenty-four (24) months, and consisted of five (5) major tasks with subtasks, and the following deliverables:

	Deliverable	Due Date	Provider	Receiver	CRADA Dependent
1	BG 3 Sensor Bom	05/20/11	LLNL	SAIC	No
2	Support Electronics Bom	05/23/11	LLNL	SAIC	No
3	BG 3 Sensor Drawings	05/31/11	LLNL	SAIC	No
4	Support Electronics Drawings	05/20/11	LLNL	SAIC	No
5	Models (Cad, Performance, Optical)	05/13/11	LLNL	SAIC	No
6	Software	05/27/11	LLNL	SAIC	No
7	Assembly Procedures	07/01/11	LLNL	SAIC	No
8	Sensor Test Plans/Procedures	07/01/11	LLNL	SAIC	No
9	Spectrometer Test Plans/Procedures	07/01/11	LLNL	SAIC	Yes
10	Spectrometer Bom	07/01/11	LLNL	SAIC	Yes
11	Spectrometer Drawings	07/01/11	LLNL	SAIC	Yes
12	Spectrometer Module Assembly Procedures	07/01/11	LLNL	SAIC	Yes
13	BG5 Spectrometer Kit	11/16/11	LLNL	SAIC	Yes
14	BG6 Spectrometer Kit –Not Completed	12/29/11	LLNL	SAIC	Yes
15	Final Report and Abstract due within thirty (30) days of completion or termination of the project, as required under Article XI of the CRADA.	1/29/12	LLNL/SAIC	SAIC	

Amendment One, executed on January 11, 2012, added one task and the following deliverable. The term of the CRADA did change.

Task 6: Deliverables are results of the design trades and analyses, and design documentation including monthly and final reports.

All of the tasks were successfully completed with the exception of BG6 work and Deliverable 14 due to lack of funding by the CRADA partner.

C. Technical Accomplishments

The following specific technical accomplishments were achieved through extensive and cooperative collaborations:

- SAIC SD engineers provided substantial and material support to LLNL at LLNL for building, assembling and testing four BIG GREEN sensors
- LLNL and SAIC collaborated to produce engineering solutions that reduced sensor noise levels when installed and operated in a DHC-8 aircraft
- Two SAIC SD engineers developed the skills, knowledge and know-how to assemble and align DS3 1-pack spectrometer modules. The engineers produced the BG5 spectrometer module
- One SAIC engineer developed the skills, knowledge and know-how to characterize a DS3 1-pack spectrometer module. The engineer characterized the BG5 spectrometer module.
- SAIC SD built, assembled and tested the BG5 sensor; integrated it into a DHC-8 aircraft; and executed a large number of tests in the aircraft

D. Expected Economic Impact

As a direct result of the initial BIG GREEN opportunity, SAIC SD received approximately Nine Million Dollars ($9,000,000) from the U.S. Army Corp of Engineers/CRREL. This funding was predicated on a cooperative collaboration between LLNL and SAIC SD, which was successfully accomplished. As a result of this collaboration, SAIC SD has received over One Million, Five Hundred Thousand Dollars ($1,500,000) in additional funds from the U.S. Army for further support to convert BIG GREEN 5 to a Sunpower cryocooler and to produce calibration carts. Additional funds in excess of One Million Dollars ($1,000,000) are anticipated for bringing BIG GREEN 6 into a functioning state. Future Operations and Maintenance (O&M) support in excess of Five Hundred Thousand Dollars ($500,000) may be realized.

D.1 Specific Benefits

Benefits to DOE

This CRADA benefitted DOE when improvements to the BIG GREEN sensors developed under this CRADA were applied to the DOE/LLNL PAHSI LWIR HSI sensor. This occurred in two specific spiral cycles resulting in substantial technical improvements to PAHSI. Subsequently, PAHSI was used at field campaigns sponsored by DOE. Improved PAHSI performance was realized at these field campaigns, benefiting DOE.

Benefits to Industry

This CRADA benefits industry by enabling SAIC to produce solutions for the DOD and positions them to provide solutions for future needs. The U.S. Taxpayer benefits by applying prior investments to current needs, reducing the costs to bring industry to a level of competence needed by the DOD to be a credible supplier of HSI sensors, costs that would be borne by U.S. Taxpayers via Department of Defense.

E. Participant Contribution

- SAIC SD was funded separately from U.S. Army Corp of Engineers/CRREL for their work under this CRADA
- SAIC SD engineers provided substantial and material support to LLNL at LLNL for building, assembling and testing four BIG GREEN sensors
- LLNL and SAIC collaborated to produce engineering solutions that reduced sensor noise levels when installed and operated in a DHC-8 aircraft
- Two SAIC SD engineers developed the skills, knowledge and know-how to assemble and align DS3 1-pack spectrometer modules. The engineers produced the BG5 spectrometer module
- One SAIC engineer developed the skills, knowledge and know-how to characterize a DS3 1-pack spectrometer module. The engineer characterized the BG5 spectrometer module.
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Separate from this CRADA, SAIC SD has plans to convert to a Sunpower CT cryocooler and finish the BG5 sensor, with intentions to produce BG6 in the same configuration. SAIC further intends to pursue additional business opportunities as they may present themselves.

F. Documents/Reference List

None

Reports

No monthly reports were created
Final Technical Report

Copyright Activity

The following copyright codes resulted from this project:

1) deselect_jvb_v.14.pro, (CP01490), LLNL-CODE-491424; Author: Jay V. Bixler
2) BGIC, v1.5, (CP01527), LLNL-CODE-562672; Authors: Ian Kaplan, Aaron Wegner, John G. Donetti. This code has been released to SAIC and USACE with release restricted to the Big Green Project.
3) bg_geo v.2.0.87, (CP01525), LLNL-CODE-533731; Authors: Milton O. Smith; Siddharth Manay

Drawings:

1) BG 3 Sensor Drawings (70)
2) Support Electronics Drawings (7)
3) Spectrometer Drawings (55)

Subject Inventions

None

Background Intellectual Property

LLNL disclosed the following Background Intellectual Property for this project:

IL12195 *Optical Upconversion for Low-Power Detection of Heterodyne Signals from Infrared Radiation*; Inventors: Charles G. Stevens, Joseph W. Tringe [Patent Application not pursued]

U.S. Provisional Patent Application No. 61/361,976 – *BLIPP2: A Bolometric LWIR Imaging Interferometer*; Inventors: Jay V. Bixler, Michael P. Chrisp, Darron P. Nielsen; Filing Date: 7/7/10 (IL12300) [Patent Application not pursued]

U.S. Patent Application No. 13/086,233 – *Echelle Grating Multi-Order Imaging Spectrometer Utilizing a Catadioptric Lens*; Inventors: Michael P. Chrisp, Joel M. Bowers; Filing Date: 4/13/11 (IL11440)

U.S. Patent Application No. 13/076,107 – *Room-Temperature Quantum Noise Limited Spectrometry and Methods of the Same;* Inventors: Charles G. Stevens, Joseph W. Tringe; Filing Date: 3/30/11 (IL12193)

U.S. Patent Application No. 13/076,162 – *Room-Temperature Quantum Noise Limited Spectrometry and Methods of the Same;* Inventors: Charles G. Stevens, Joseph W. Tringe, Christoph T. Cunningham; Filing Date: 3/30/11 (IL12196)

U.S. Patent Application No. 13/046,924 – *Cryogenically Cooled Detector Pin Mount;* Inventors: William Eugene Hunt, Michael P. Chrisp; Filing Date: 3/14/11 (IL12277)

U.S. Patent No. 6,078,048 – *Immersion Echelle Spectrograph*; Inventors: Charles G. Stevens, Norman Leroy Thomas; Issue Date: 4/27/98; Abandoned 6/20/08 (IL09824)

U.S. Patent No. 7,041,979 B2 – *Compact Reflective Imaging Spectrometer Utilizing Immersed Gratings*; Inventors: Michael P. Chrisp; Issue Date: 5/9/06 (IL11127)

U.S. Patent No. 6,922,240 B2 – *Compact Refractive Imaging Spectrometer Utilizing Immersed Gratings*; Inventors: Scott A. Lerner, Charles L. Bennett, Jay V. Bixler, Paul J. Kuzmenko, Isabella T. Lewis; Issue Date: 6/26/05 (IL11135)

U.S. Patent No. 6,980,295 B2 – *Compact Catadioptric Imaging Spectrometer Utilizing Reflective Grating*; Inventor: Scott A. Lerner; Issue Date: 12/27/05 (IL11179)

U.S. Patent No. 6,977,272 B2 – *Compact Imaging Spectrometer Utilizing Immersed Gratings*; Inventor: Scott A. Lerner; Issue Date: 12/20/05 (IL-11180)

U.S. Patent No. 7,016,037 B2 – *Imaging Spectrometer Utilizing Immersed Gratings with Accessible Entrance Slit*; Inventors: Michael P. Chrisp, Scott A. Lerner; Issue Date: 3/21/06 (IL11355)

U.S. Patent No. 7,239,386 B2 – *Compact Imaging Spectrometer Utilizing Immersed Gratings*; Inventors: Michael P. Chrisp, Scott A. Lerner, Paul J. Kuzemnoko, Charles Bennett; Issue Date: 7/3/07 (IL11392)

U.S. Patent No. 7,016,038 B2 – *Compact Imaging Spectrometer Utilizing Immersed Gratings*; Inventors: Michael P. Chrisp, Scott A. Lerner, Paul J. Kuzemnoko, Charles Bennett; Issue Date: 3/21/06 (IL11479)

U.S. Patent No. 7,414,719 B2 - *Imaging Spectrometer Wide Field Catadioptric Design*; Inventor: Michael P. Chrisp; Issue Date: 08/19/08 (IL11545)

U.S. Patent No. 8,165,340 – *Methods for Gas Detection Using Stationary Hyperspectral Imaging Sensors*; Inventors: James Lynn Conger, John Robert Henderson; Filing Date: 10/7/09; Issue Date: 4/24/12 (IL11729)

U.S. Patent No. 7,808,635 – *Wide Swath Imaging Spectrometer Utilizing a Multi-Modular Design*; Inventor: Michael P. Chrisp; Issue Date: 10/5/10 (IL11744)

U.S. Patent No. 8,545,995 – *Systems Having Optical Absorption Layer for Mid and Long Wave Infrared and Methods for Making the Same*; Inventor: Paul Kuzmenko; Issue Date: 9/11/13 (IL11931)

U.S. Patent No. 8,445,838 B1 – *System and Method for Generating a Deselect Mapping for a Focal Plane Array*; Inventors: Jay V. Bixler, Timothy G. Brandt, James Lynn Conger, Janice K. Lawson; Issue Date: 5/21/13 (IL-11967)

U.S. Patent No. 7,916,947 – *False Alarm Recognition in Hyperspectral Gas Plume Identification*; Inventor: Michael P. Chrisp; Issue Date: 10/5/10 (IL12032)

U.S. Patent No. 8,339,600 – *Dual Waveband Compact Catadioptric Imaging Spectrometer*; Inventors: Michael P. Chrisp; Issue Date: 12/25/12 (IL12216)

SAIC has not express an interest in licensing any of the LLNL BIP listed above.

SAIC did not disclose any BIP for this project.

G. Acknowledgement

Industrial Participant's signature of the final report indicates the following:

1) The Participant has reviewed the final report and concurs with the statements made therein.
2) The Participant agrees that any modifications or changes from the initial proposal were discussed and agreed to during the term of the project.
3) The Participant certifies that all reports either completed or in process are listed and all subject inventions and the associated intellectual property protection measures generated by his/her respective company and attributable to the project have been disclosed and included in Section E or are included on a list attached to this report.
4) The Participant certifies that if tangible personal property was exchanged during the agreement, all has either been returned to the initial custodian or transferred permanently.
5) The Participant certifies that proprietary information has been returned or destroyed by LLNL.

Joseph E. Sauvageau

4/15/2014

Joseph E. Sauvageau, Technical Staff Director — Date
Chief Engineer, Space Systems Development Department
Science Application International Corporation (now called Leidos Corporation)

Robert E. Priest, LLNL Principal Investigator — Date
Lawrence Livermore National Laboratory

Richard A. Rankin, Director, Industrial Partnerships — Date
Lawrence Livermore National Laboratory

Attachment I – Final Abstract

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Joseph E. Sauvageau, Technical Staff Director — Date
Chief Engineer, Space Systems Development Department
Science Application International Corporation

7 Apr 2014
Robert E. Priest, LLNL Principal Investigator — Date
Lawrence Livermore National Laboratory

23 May 2014
Richard A. Rankin, Director, Industrial Partnerships — Date
Lawrence Livermore National Laboratory

Attachment I – Final Abstract

Hyperspectral Sensors

Final Abstract (Attachment I)
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E. Project Dates

August 11, 2011 through July 18, 2013