NASA/TM–2015-218996

Applied Operations Research: Augmented Reality in an Industrial Environment

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December 2015

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Available from:

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NASA Langley Research Center
Hampton, VA 23681-2199
Fax: 757-864-6500

ABSTRACT

Augmented reality (AR) is the application of computer generated data or graphics on a real world view. Its use has been applied routinely in the DOD, research, and emerging gaming applications to provide the operator additional information or a heightened situational awareness. While advancements have been made in automation and diagnostics of high value critical equipment (HVCE) to improve readiness, reliability and maintenance, the need for assisting and support to Operations and Maintenance staff persists. Further, use of AR in scientific research can improve the human machine interface where computer capabilities can maximize the human experience and analysis capabilities. NASA and the LaRC Research Directorate operates multiple facilities with complex ground based HVCE in support of national aeronautics and space exploration, and the need exists to improve operational support and close a gap related to capability sustainment where key and experienced staff consistently rotate work assignments and reach their expiration of term of service. Considering a representative case for operation and maintenance of HVCE, the initiation of an AR capability to augment and improve human abilities and training experience in the industrial environment requires planning and establishment of a goal and objectives for the systems and specific applications. This paper explored use of AR in support of Operation staff in real time operation of HVCE and its maintenance. The results identified include the identification of case specific goal and objectives, challenges related to commercial market availability and computer system infrastructure.

I. Introduction and Background

Augmented Reality (AR) combines computer generated data and graphics overlain to real world view. The purpose for use of AR is to provide the user a meaningful interpretation of the view space in a way that allows data and information to be applied without the need for other interpretation or reference. There is a level of complexity for presenting this computer generated data or graphics onto the real world space and especially in an industrial environment where high value critical equipment (HVCE) which typically includes many parts, components or mechanisms are present to comprise a completely functional equipment system. This research considered the use of AR for the HVCE located at the LaRC Compressor Station where each of the compressors contains up to 10,000 individual parts. Recognizing that the HVCE is used to support the national aerodynamics and space program, the need exists to incorporate computer systems using AR to improve HVCE reliability and operational readiness. This research included research into AR capabilities, market research, and use of the LaRC Compressor Station facility as the research test bed. The Compressor Station was considered an ideal representative facility for application of AR in an industrial environment due to the recent automation of one compressor in 2014, and an impending replacement 2015-2019 with two commercial-off-the-shelf compressors of three existing compressors that were originally installed, circa 1958.

The defined goal for use of AR at the LaRC Compressor Station, was to: Exploit the use electronic computer capabilities coupled with AR to sustain and support Operations Staff in the operation, training, and maintenance of HVCE, i.e. compressors.

The objectives identified to support the goal included:

1. Identify the HVCE operations where AR can be applied for Operator use and interpretation of equipment operational status and condition.

2. Identify the computer system architecture as infrastructure within the existing NASA and LaRC enterprise system that can support AR applications.

3. Identify and list the requirements considered for AR development in an operating industrial environment.

4. Identify the desired capabilities for AR application.

The LaRC Compressor Station was characterized as an industrial facility equipped with multiple reciprocating compressors where each operating compressor is operated by a two Operations Staff. The compressors typically run continuously during the day until the maximum field pressure is attained and then the equipment is shut down. The air use demands result in varied starts and stops of the compressor equipment. Operations staff use Standard Operating Procedures to start up, operate, and shut down the HVCE. During operation, routine hourly checks are made where temperature and pressure readings are recorded, liquid levels identified, adjustments made, and if necessary the blow down of liquid collection systems are made.

The amount of data and information attributed to operating of the HVCE at the Compressor Station was found voluminous. For example, one compressor contains 84 suction and discharge valves. These valves are read hourly during operation. If three machines are operated during an eight hour period, there can be as many as 2,016 individual readings taken during a single eight hour shift. Transients in the system do occur and can be experienced predominantly in both mechanical and pressurized systems over long and short periods of compressor operating time. In some instances, the transients may occur instantaneously. These transients can be attributed to parts failing from normal wear, deferred maintenance, or equipment exceeding their expected design life. The transients can lead to equipment shut down and lengthy repairs. The avoidance of conditions where these transients occur have been given to an Operator's astute monitoring of real time conditions, analysis of the readings taken, and awareness of temperature and pressure conditions using instrumentation, sounds, vibrations, and an asset condition based monitoring system. Expanding the HVCE Operator's capability to assimilate and interpret the operating data would be considered essential for improving the overall HVCE operational posture and readiness. The use of AR to increase the Operator's capability for real time data interpretation at the point in the field where the equipment is monitored with field instrumentation would be understood to improve operations.

Maintenance of HVCE includes trouble shooting, routine inspections of components, and knowledge of those system components with respect to their arrangement, location in the building and on the equipment, and dimensional analysis or physical condition of parts. The capability for expanding the Operators' knowledge of various parts and their intricate disassembly and assembly was considered essential for training, maintenance, reducing the time during maintenance outages, and continuing overall operational readiness. Operators and maintenance staff routinely use two dimensional paper drawings, parts diagrams, and exploded diagrams for both operation and maintenance. For example, Operators may use a pump curve to compare the operating performance of a pump against the pressure and flow performance identified in the field. In other cases, the assembly of compressor piston ring gaskets follows a drawing for the specific order of placement based of a series of gaskets along with the gasket type and mandatory installation sequence. Many drawings for Commercial-Off-the-Shelf equipment are not in configuration management, and three dimensional drawings in electronic format are not normally available from Commercial-Off-the-Shelf equipment manufacturers as they may be considered proprietary. Providing detailed three dimensional features of equipment components in their relative spatial position using AR was expected to elevate the quality of maintenance and significantly reduce time especially for those staff who are qualifying or re-qualifying for their positions, or maintenance staff who need a just in time refresher prior to a complex overhaul.

I. Approach

The use of AR in an industrial environment to support operations and maintenance was considered in this research requires consideration of the computer system architecture that would be deployed, and the stated objectives.

Objective 1 - The HVCE operations where AR could be applied for Operators use and interpretation of a reciprocating compressor equipment operational status and condition included consideration of the following parameters versus time, listed in Table 1. The real time observation point would be viewable to the Operator in the field real time with associated data for status and condition.

Table 1
Compressor Monitoring Parameters To Be Viewed by and Operator via AR
(One Compressor)

Parameter vs. time	Real Time Observation Points (In the Field, Real Time)
Suction and Discharge Valve Temperatures (84 Ea.)	84
Internal Stage Pressure (6 Ea.)	6
Stage Inlet Pressure (6 Ea.)	6
Stage Discharge Pressure (6 Ea.)	6
Frame Oil Pumps (2 Ea.) Pressure	2
Closed Loop Cooling Pump Flow and Pressure (2 Ea.)	4
Cooling Tower Pump Flow and Pressure (2 Ea.)	4
Heat Exchanger - Coldest Temperature Differential (18 HEXs for Compressors 5 and 6, Dryers 4 and 5)	9
Inlet Filter Differential Pressure	1
Coalescing Filter Between Compressor and Dryer Differential Pressure	1
Motor Data – Amps, voltages,	1
Maintenance Stats (Individual Components from CMMS)	27
Total Points to be Monitored in the field real time	151

Objective 2 - The computer system architecture or infrastructure to be used within the existing NASA and LaRC enterprise system that could support the AR applications would be similar to Figure 1. The architecture would be highly adaptable to any human machine interface that is commercial-off-the-shelf. The future Business Server (Figure 1) will be capable to broadcast data and information via Wi-Fi to a field deployed AR i.e., Operator's Assistant.

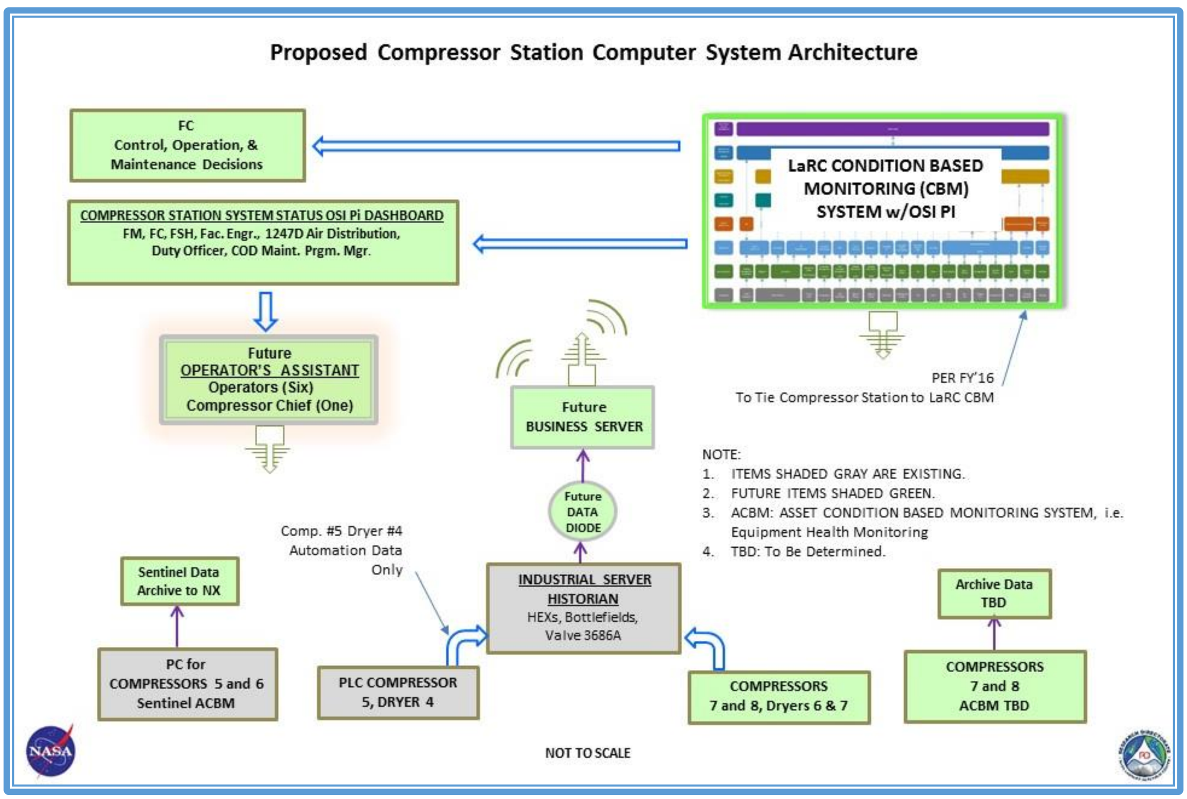

Figure 1. Proposed Compressor Station Computer System Architecture

Objective 3 - The requirements considered for AR development in an operating industrial environment were identified in this research. Market research was also performed to identify and locate potential human machine interface (HMI) where AR could be applied. The requirements for use of AR in an industrial environment include items in Table 2.

Table 2
AR HMI in an Industrial Environment - Requirement and Condition

Requirement	Condition
Suitable for ambulatory use	Cannot restrict movement by walking and seeing where you are going
Hands Free	Heads up type display worn on helmet or bump hat
Comfort/Lightweight	Worn on the head without fatigue, suitable when perspiring or cold
Comply w/OSHA Z87.1 for eyewear	Viewing window must fit over safety glasses, or be OSHA rated
Minimum 8 hours use	Battery charge suitable for complete shift
Viewing unaffected by ambient light	AR applications are crisp and clearly seen in all ambient light conditions
AR icons, screen text, colors uniform/ easily read	Use NASA standard (to be developed), consider Color Blindness
Screen changes by hand gesture or finger mouse	Suitable for use with gloves
Haptic and visual alarm notification	Alarm notifications tailored to individual, alarms can be interrogated
Distortion and connectivity	Continuous service without falter or loss of signal
Thermographic imaging	View screen can be changed to full thermographic imaging

Objective 4 - The desired capabilities for AR application would be configured to provide the user real time information in the environment. Given that an AR system considered herein includes many of the capabilities for real time information, Table 1, and those identified under the Condition in Table 2, the added benefit for use of AR in maintenance activities was considered as an invaluable tool. The capability to fully see a part or component to be replaced within an overall system and overlain to real world view exercises the essence of computer aided devices to expand human capability to maintain complex HVCE. For example, the United Stated Coast Guard, Design and Development Branch, Yorktown, Virginia initiated an electronic computer program where the *Electronic Performance Support Solution* (EPSS) provided a hallmark solution and capability for technicians to use in maintenance activities of mission critical equipment. The EPSS was applied using simple but effective commercial-off-the-shelf software products uniquely packaged for ease of use by service technicians. Using EPSS, considered a highly effective maintenance aid solution, as a roadmap of an applied capability in a future field deployed AR application will provide new and re-certifying maintenance staff the needed and training as a foundation to improve and increase HVCE reliability and readiness.

II. Challenges

The near term challenges identified in application of AR in the industrial environment for operation and maintenance of HVCE include:

- Industrial Commercial-off-the-shelf market AR applications was found to be a new development
- Lack of multiple commercial-off-the-shelf heads up display manufacturers specifically for industrial use
- Current market for AR was found experiencing rapid changes in offerings and types of HUD display
- Low or non-existent commercial industrial market demand for AR
- Difficulties for registration of the real time data being monitored graphically displayed to the specific point on the HVCE
- Obtaining drawing(s) for COTS components or parts were complicated by proprietary rights of the manufacturer

III. Results

This research for use of AR in an industrial environment identified the goal and objectives for use of AR in an industrial environment. The technological challenges were identified and provides guidance for near term applications. Use of AR within an existing ground facility test bed was considered to allow immediate benefits and provides lessons learned for future mission applications. The AR research supports three distinct areas of AR fundamentals including: knowledge system, technical situational awareness, and 3D Modeling / AR Environment.

Future AR application is shown on Figure 2, where it supports a capability for:

Operation,	Operating planetary surface vehicle, or planetary flight craft
Control,	Control of life and support systems
Engineering,	Engineering and surveying capabilities for planetary exploration
And	
Navigation	Planetary surface navigation, planetary positioning system (PPS)
Science	Scientific instrumentation and resource capability.

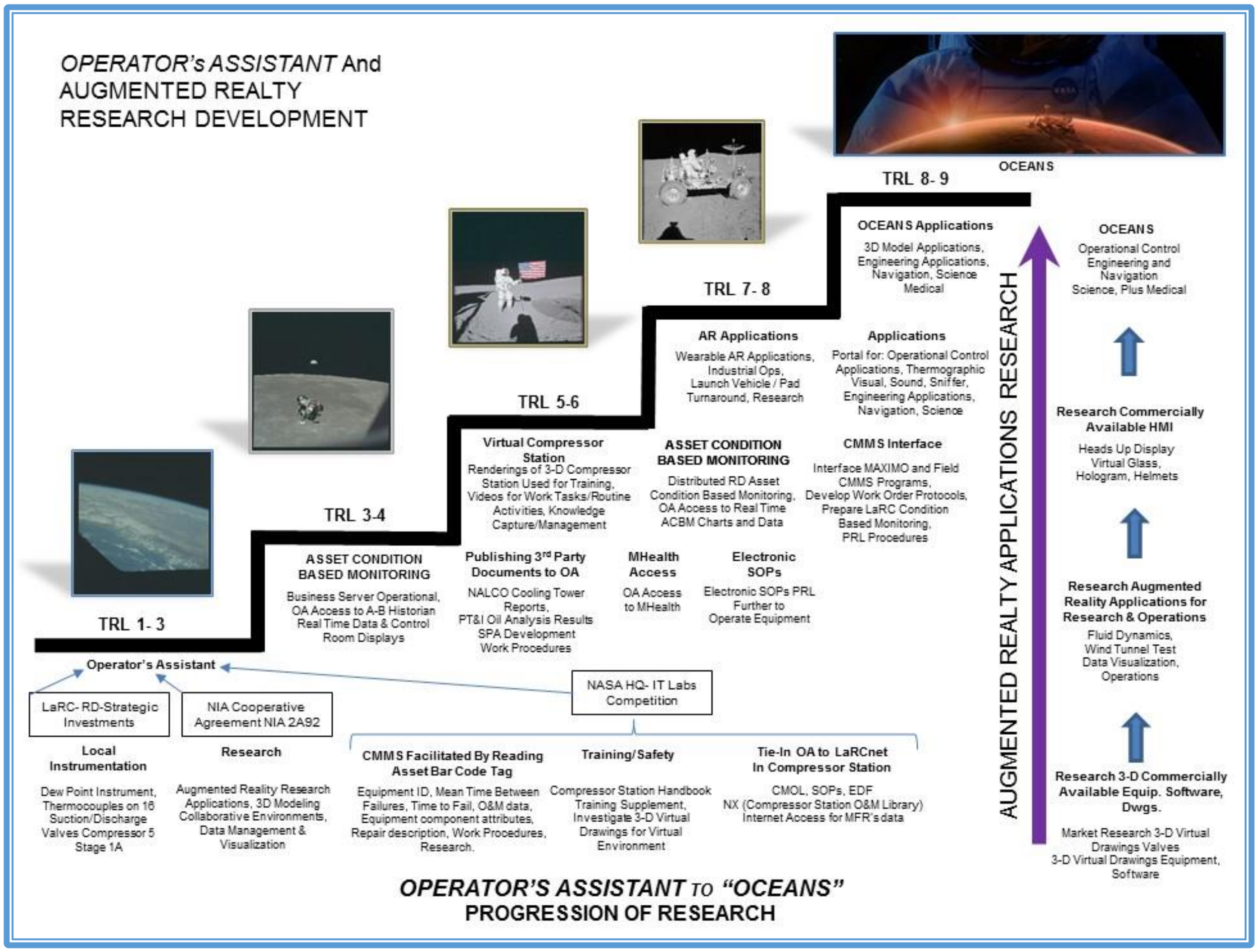

Figure 2. AR Research Opportunities

The future technology spinoff from AR development includes potential applications where three dimensional surveys of orbital space craft are needed for refueling or repair, or where extra-terrestrial planetary surfaces features are needed.

Acknowledgement

This research was performed as a collaboration between the NASA Office of the CTO for IT, Office of the Chief Information Officer, Technology and Innovation Labs; and the NASA LaRC Research Directorate, to fulfill the need for meeting the Center's digital transformation goals, and furthering technological advances and research, recommending future research initiatives that fill gaps, and promoting opportunities for NASA Centers and NASA. Special acknowledgement is provided to the USCG, Office of Design and Development, Yorktown, Virginia; Old Dominion University, Dr. Yuzhong Shen and Bill Shull Doctoral Candidate of the Dept. of Modeling, Simulation & Visualization Engineering under NIA Cooperative Agreement NIA 2A92; Lui Wang, Spacecraft Software Engineering Branch, JSC NASA who provided Technical Direction; Thomas E. Hegland ARC NASA; Brannon Lane Standridge MSFC NASA; Doug C. Cook, Jacobs for Newport News Shipbuilding; all who provided their valuable comments and professional review of the work; and notably Edward L. McLarney, T&I Labs Project Champion and LaRC Digital Transformation Lead who was an inspiration, and ardent supporter.

Appendix A

Acronyms:

AR Augmented Reality

ARC Ames Research Center

CMMS Computerized Maintenance Management System

CMOL Configuration Management Online

COD Center Operations Directorate

COTS Commercial Off The Shelf

CTO Chief Technologist Office

Dwgs. Drawings

EPPS Electronic Performance Support Solutions

FC Facility Coordinator

Fac. Engr. Facility Engineer

FSH Facility Safety Head

FM Facility Manager

FY Fiscal Year

HEXs Heat Exchangers

HVCE High Value Critical Equipment

IOS Internetwork Operating System

IT Information Technology

JSC Johnson Space Center

LaRC Langley Research Center

LaRCNet Langley Research Center Network

Maint. Maintenance

MSFC Marshal Space Flight Center

NASA National Aeronautics and Space Administration

NIA National Institute of Aeronautics

NTRS NASA Technical Report Server

OA Operator’s Assistant

OCEANS Operation, Control, Engineering and Navigation, Science

O&M Operations and Maintenance

OSHA Occupational Safety and Health Administration

PC Personal Computer

PRL Procedure Representation Language

PSIG Pounds per Square Inch Gage

PPS Planetary positioning system

RD Research Directorate

SOPs Standard Operating Procedures

STI Scientific and Technical Information

T&I Technology and Information

TM Technical Memorandum

™ Trade Mark

TRL	Technology Readiness Level
US	United States
USCG	United States Coast Guard
VA	Virginia
Wi-Fi	Wireless Fidelity
WBS	Work Breakdown Structure
2D	Two Dimension
3D	Three Dimension

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
01- 12 - 2015

2. REPORT TYPE
Technical Memorandum

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Applied Operations Research: Augmented Reality in an Industrial Environment

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Cole, Stuart K.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
342466.02.03.01.07

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER
L-20642

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
NASA-TM-2015-218996

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 14
Availability: NASA STI Program (757) 864-9658

13. SUPPLEMENTARY NOTES

14. ABSTRACT
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15. SUBJECT TERMS
AR; Augmented reality; Computer; Industrial; Knowledge management; Maintenance; OCEANS; Operations; Operator's Assistant; Training

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	14	STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER *(Include area code)*
					(757) 864-9658

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18