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Additive Manufacturing in Naval Domain: Innovation, Adoption and Taxonomy of Cybersecurity Threats

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ADDITIVE MANUFACTURING IN NAVAL DOMAIN: INNOVATION, ADOPTION AND TAXONOMY OF CYBERSECURITY THREATS

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EXECUTIVE SUMMARY

Project Summary
A growing potential and promise that additive manufacturing (AM) brings to the naval domain is matched with a set of activities focused on service members' innovation, experimentation and rapid prototyping with a range of technologies including AM. Increased level of warfighters readiness and self-sustainment in Department of Navy (DoN) operations are at the center of those efforts. We investigated select elements of innovation and adoption process, and added much needed understanding in domain of cybersecurity. Our research included collaboration and visits to Naval Fabrication Laboratories (FabLab), Maker spaces and units with AM capabilities. We collected a comprehensive data sets relevant to innovation, adoption and cybersecurity, and documented examples of innovation efforts done by the Sailors and Marines. The work produced a set of recommendations with guidance directed towards most effective approaches in support of bottom-up innovation process, large scale adoption strategies, elements of self-sustainable and scalable adoption process, guidance for distribution of efforts, resources and programs, as well as management of cybersecurity infrastructure and needed approaches, all geared towards achieving maximum use of the technology and innovation practices without sacrificing on cybersecurity. The results of this work - data points and insights acquired through our work with the stakeholders - are used to further refine our model of Diffusion of Innovation in Military Domain.

Keywords: *additive manufacturing, cybersecurity, 3D printing, fabrication laboratory, rapid prototyping, diffusion of innovation*

Background
The potential that additive manufacturing brings to the naval domain, and military domain in general, is well recognized; AM technology continues to improve in terms of variety and sophistication of 3D printing techniques, quality of printed artifacts, and scale (size) of printed artifacts. A 30 foot long 3D printed proof-of-concept submersible, developed by a team from the Naval Surface Warfare Center (NSWC) and Carderock Division's Disruptive Technology Laboratory (DTL) and produced using massive industrial 3D Pinter called Big Area Additive Manufacturing (BAAM), as well as very recent example in August 2018, when the world's largest concrete 3D printer was used to construct a 500-square-foot barracks hut at the U.S. Army Engineer Research and Development Center in Champaign, Illinois (effort led by Marine Corps Systems Command), are the best illustrations of the scale of advancement that AM technology currently enjoys. As the Navy increases its AM portfolio and expands implementation of this time, cost, and energy saving technology, there is increased need to ensure that this technology successfully engages a large number of innovators and that the data they produce and manipulate throughout the AM workflow are secure as well.

The characteristics of the innovation and benefits it brings to its users are important elements that influence adoption of that innovation among its intended users (Rogers, 1995). Additional elements that significantly impact the rate of adoption are user-perceived usefulness of innovation, its ease of use and final user acceptance - these characteristics were studied and incorporated in Technology Acceptance Model (TAM) introduced by Davis, (Davis, 1986)(Davis, 1989)(Davis, 1993), as well as Venkatesh (Venkatesh, 2000). A new theory - Unified Theory of Acceptance and Use of Technology or UTAUT - also incorporate these types of considerations (Venkatesh, 2003). Adoption of any new technology, idea, process or other solution can engage different number of individuals who operate in a given domain. The reason why a large-scale adoption remains of special interest is "...the collective change in the way adopters act and behave once the adoption occurs on a large scale, and the potential that such a change may bring to them and their community" (Sadagic, 2015).

Findings and Conclusions

The following methodology has been proposed and used in support of this research project and included the following activities:

1. Study of literature in the domains of innovation, technology adoption, and cybersecurity threats in AM (digital thread framework).
2. Cataloging and development of cybersecurity taxonomy in AM. Identification of issues, concerns, tools, data sharing strategies, potential vulnerabilities and collaborative processes. Research in this domain was reported in a student thesis (LT Grimshaw).
3. Field visits to Fabrication Laboratories, Maker spaces, units that own AM capabilities, as well as base commands and other institutions relevant to AM activities in the naval domain. Major goal: enable face-to-face discussions with colleagues and support data collection efforts.
4. Work with the Naval Postgraduate School (NPS) RoboDojo laboratory and execution of a series of focus groups and activities with NPS students (active duty Department of Defense (DoD) officers and international students) and faculty.
5. Data collections organized in Fab Labs, Maker spaces and Department of Navy (DoN) units, focused on innovation, adoption and cybersecurity.
6. Practical work and experience with a range of devices associated with AM and Fab Labs.
7. Collaboration with NPS Modeling, Virtual Environments and Simulation (MOVES) colleagues who work on implementing data portal, and study of its adoption and use by naval personnel.
8. Collaboration with stakeholders in this domain, including our topic sponsor DCNO for Material Readiness & Logistics (N4), Naval Facilities Engineering Command (NAVFAC), National Institutes of Health (NIH) and industry representatives. The project Principal Investigator (PI) participated in monthly teleconferences organized by the topic sponsor's team.
9. Collaboration with forums and other colleagues who actively work in the AM domain.
10. Design of theoretical and methodological principles (development of Diffusion of Innovation in Military Domain model).
11. Design and development of the instructional modules to be made available to NPS students and faculty, as well as materials produced to support activities in the Fab Labs (manuals that documented

our experiences with 3D scanning and 3D printing technologies). Resulting manuals were written having in mind the needs and skills of a large majority of Sailors and Marines – individuals who have limited technical knowledge and no prior experience with 3D printers and 3D scanners. The same manuals were made available to Fab Labs across the naval domain.

Events supported: The project team supported and actively participated in the following events:

1. Institute of Electrical and Electronics Engineers (IEEE) Virtual Reality (VR) 2018 conference in Reutlingen, Germany (18-22 March): Dr. Sadagic was a member of International Program Committee for this conference.
2. Naval Research Working Group - NRWG 18 (10-12 April, 2018): Dr. Sadagic presented several posters that highlighted the work on the project and illustrated the activities of the AM team at NPS. She also supported two lab tours and introduced project activities to the visitors (10 April and 12 April).
3. MOVES Research Working Group (MAWG) - MAWG event organized by MOVES Institute in May 2018. Dr. Sadagic presented a talk titled "Additive Manufacturing in Naval Domain: Large Scale Adoption and Innovation by Masses of Domain Users." She also produced two AM-themed posters, hosted a lab tour, and introduced AM research efforts conducted by MOVES faculty.
4. Interactive 3D Content Embedded into Web Pages (WEB3D) 2018 conference in Poznan, Poland (17-20 June, 2018). Dr. Sadagic was a Program Committee Member for this conference.
5. Discover NPS Day (Dec 1st, 2017): Dr. Sadagic designed a number of demo stations that were made available to NPS visitors in MOVES laboratories. They included one 3D printer (this was made operational on the day so that visitors could see the way 3D printing works), AM-related posters developed for the needs of our project, and a number of 3D printed objects. Final demos were supported by Dr. Sadagic and three other project team members – Erik Johnson, Ryan Lee and Eric Heine, as well as a number of MOVES students. The elements of this project will be featured during upcoming Discover NPS Day on Oct 26, 2018.

Recommendations for Further Research

The adoption of any technology by masses of intended users is a process that happens over a longer period of time. A need to commit to and execute a series of longitudinal studies and data collection efforts, is inevitable part of the work in this domain.

We propose following research activities:

1. New round of data collection: Data collection efforts should continue to be organized; they should include data from users (adopters, innovators, leadership of all levels) and fabrication labs.
2. Definition of metrics and measurement of adoption process: Over the course of this project we acquired initial understanding about the metrics that can be used to measure the success of the adoption process. New research should include more extensive effort in this domain.
3. Comprehensive study of return on investment (ROI).

4. Additional functionality in the ModelExchange portal: We recommend continuing collaboration with colleagues who work on the ModelExchange portal.
5. Refine our model of Diffusion of Innovation in Military Domain.

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Acronyms

AM - additive manufacturing
BAAM - Big Area Additive Manufacturing
DTL - Disruptive Technology Laboratory
DoD – Department of Defense
DoN – Department of Navy
Fab Lab – Fabrication Laboratory
IEEE - Institute of Electrical and Electronics Engineers
MAWG - MOVES Research Working Group
MOVES - Modeling, Virtual Environments and Simulation
NPS – Naval Postgraduate School
NSWC - Naval Surface Warfare Center
PI - Principal Investigator
ROI - return on investment
WEB3D – interactive 3D content embedded into web pages
DCNO – Deputy Chief of Naval Operations
N4 - DCNO for Material Readiness & Logistics
NAVFAC - Naval Facilities Engineering Command
NIH - National Institutes of Health
VR – virtual reality