Reference ID: 11222435998_Starly

Submission Date and Time: 12/14/2019 9:55:23 AM

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Research domain(s), discipline(s)/sub-discipline(s)

Advanced Manufacturing: Digital Design & Manufacturing

Title of Response

Can we Engineer the tools for Anyone to engage in Product Design and have it built Anywhere and Anytime using Data-Focused Cyber-Infrastructure

Abstract

The digitalization of manufacturing has created opportunities for consumers to customize products that fit their individualized needs which in turn would drive demand for manufacturing services. New emerging technology in design automation driven by data-driven computational design, manufacturing-

as-a-service marketplaces and digitally enabled micro-factories holds promise towards democratization of innovation. In this outline, scientific, technology and infrastructure challenges are identified and if solved, the impact of these emerging technologies on product innovation and future factory organization is discussed at high level. Critical to enabling the Science & Engineering research in Advanced manufacturing, the community requires fundamentally new ways of Cyberinfrastructure that can provide the tools and services needed for academia, new startups and even large manufacturing companies to thrive forward in an 'Industry 5.0' environment. We have highlighted specific CI requirements and capabilities that we believe are agnostic to our particular domain but would tremendously benefit the Engineering Community. They are: Decentralized and distributed data storage/compute with tools/services that allow ENG(CMMI, CBET and others) to operate with; computation on encrypted data; virtualization and network connectivity of physical manufacturing machines, interoperability across various types of machines.

Question 1 (maximum 400 words) – Data-Intensive Research Question(s) and Challenge(s). Describe current or emerging data-intensive/data-driven S&E research challenge(s), providing context in terms of recent research activities and standing questions in the field. NSF is particularly interested in cross-disciplinary challenges that will drive requirements for cross-disciplinary and disciplinary-agnostic data-related CI.

Industry 4.0 (the "fourth industrial revolution") promises an information-centric transformation of manufacturing. The emergence of Industry 5.0 – with data, physical systems and the additional component of humans-in-the-loop helps to realize heavily personalized products, one-off manufactured systems along with a tighter integration of humans within automation systems. This engineering challenge requires the convergence of activities within engineering (physical design, simulation & process manufacturing), computer science (co-design with AI algorithms, computational linguistics, human-centered computing), economics (microeconomics), math (operation research), business & legal domains of expertise. Standing questions in the field: How do we enable the Co-design of Products between Humans and Computing Algorithms?: For computing systems to fully augment human creativity in the design and making of things, several engineering hurdles must be overcome. Algorithms must be able to take in high-level human input and then be able to synthesize design intent to create a first draft featured digital model of the product. Combined with human input, the computer iterates through design options and revisions while soliciting human input to allow computing algorithms to understand design intent of the human. For serious Artificial Intelligence (AI) in digital product design, reproducing entirely new design concepts never seen before would fundamentally change the human-technology frontier in terms of the product design process. Can we break down layers of 'middlemen' services between design users and manufacturing services?: Is it even possible to enable a 'one-click' make-buy paradigm akin to how we buy products from online e-commerce platforms? We need: 1) Computing on encrypted data in the form of 3D models, machine information, pricing etc.; 2) Incentivization mechanisms to encourage the two sides to share data through micro-economic approaches to achieve marketplace stability and fairness across all participants; 3) Federated learning approaches when encrypted data (to protect intellectual property) remains in the hands of its owners 4)

Legal strategies and policy approaches to be studied to ensure that digital manufacturing marketplaces can thrive in an inter-connected world. Can we enable distributed manufacturing across a region?: To achieve the vision of automated mini-factories, micro-factories and perhaps regular households owning machines, fundamental advances must be made in how physical machines are designed. Process plans for the designs must be composable, transportable from one machine to the other. It would allow factories to be economically viable in rural regions of the country by cutting down on non-productive tasks as manual supplier sourcing, assessment, certification and compliance will be automated.

Question 2 (maximum 600 words) – Data-Oriented CI Needed to Address the Research Question(s) and Challenge(s). Considering the end-to-end scientific data-to-discovery (workflow) challenges, describe any limitations or absence of existing data-related CI capabilities and services, and/or specific technical and capacity advancements needed in data-related and other CI (e.g., advanced computing, data services, software infrastructure, applications, networking, cybersecurity) that must be addressed to accomplish the research question(s) and challenge(s) identified in Question 1. If possible, please also consider the required end-to-end structural, functional and performance characteristics for such CI services and capabilities. For instance, how can they respond to high levels of data heterogeneity, data integration and interoperability? To what degree can/should they be cross-disciplinary and domain-agnostic? What is required to promote ease of data discovery, publishing and access and delivery?

Limitations & Challenges: 1) No FAIR data principled repository for ENG researchers: There is no repository that allows NSF supported researchers in Engineering/Design & Manufacturing have research data follow the FAIR data principles across the various ENG disciplines – CMMI, ECCS, CBET. Most ENG faculty do not have the training or the skills or the push towards incorporating such principles when they share data through publications or hosted sites. Even if they want to follow FAIR – there are no automated tools/services that would allow NSF supported researchers to share data and have it made reusable by the community. 2) Moving Data to Central Repositories is just impossible by the D&M community: Design & Manufacturing data can range from Gigabytes to PetaBytes. Some of that data can also have Intellectual Property Concerns that sharing data might make it harder. Can we support a distributed data storage across academia? An example of it is NSF supported IRODS – supported by NSF but it is hardly used by those in ENG community – mainly due to the lack of interoperability tools, knowledge, skills and end-point connections to machines/systems that generated data in the first place. User from anywhere should be able to seamlessly access data from machines anywhere in any academic institutions – Manufacturing resources must be virtualized to allow users to interact with virtual components as opposed to actual physical hardware. 3) Moving computation to the end-point rather than data to a centralized system, thereby minimizing issues surrounding privacy and security while facilitating data-driven computational algorithms; 4) Searching across Design & Manufacturing data is nearly impossible. Data in D&M is heterogeneous – ranging from 3D design data, discrete experimental protocols, time-series data, in a way that current indexing mechanisms do not know allow easy accessibility of data. 5) Lack of federated learning technologies. If we cannot move data, and if data is encrypted – can we still enable learning from such encrypted data. If this is solved, it alleviates some of the IP related issues of sharing data while still making data to be learned from. 6) Machines Networks do not exist – the lack of adequate connection from physical machines and various other endpoints in the entire lifecycle is lacking. Example – machine generated data can be created as such high frequencies that current networks in academia may not be able to support such data. In another scenario – data generated during just a single 3D printed metal part from the machine itself can range several hundreds TBs of data. There is no academic institution that we know of that has the ability to even store this data. The data is analyzed and then thrown away. This is such important data so that others in the community could make use of. OEMs of machines themselves do not have interfaces that make such data collection seamless. 7) Cybersecurity in Design & Manufacturing has additional concerns – since we do not deal with just data sitting across Database systems, physical machines themselves need to be protected and secured from unauthorized access. Machines - just as humans – need to be made smarter to protect itself and even beyond protect higher-order human and IT systems from rogue machines that have been compromised. 8) Transfer of Knowledge from Machine to machine – Just as humans can learn from one another – we need ways in which machines can learn from each other. 9) Virtualized of Physical Manufacturing Machines. – Virtualization of software has tremendously advanced IT system access and availability. A similar paradigm in Manufacturing do not exist. How do we virtualize Manufacturing Machines – so that machines are accessible, interoperable, trustworthy and intelligent, while operating in a secure environment.

Question 3 (maximum 300 words) – Other considerations. Please discuss any other relevant aspects, such as organization, processes, learning and workforce development, access and sustainability, that need to be addressed; or any other issues more generally that NSF should consider.

Workforce Development: A new branch of digitally trained students in Mechanical, Industrial, Civil, Chemical Engineering & Material Science disciplines – from undergraduate to graduate students are required in the physical ENG side. Training must be provided to students/faculty/researchers in ENG to be at the very best in Cyberinfrastructure. For example, in CMMI funded research, very very few lack the cyberinfrastructure skills required to function in an Industry 5.0 environment. Sustainability is key. Rather than creating a mono-lithic central organization that manages the data, the software and everything – is it even feasible to think of distributed, decentralized organizations that is virtually connected with only a foundation/non-profit organization responsible for managing the policies/regulations and protocols necessary to keep the decentralized organization functional. In essence the community from academia, govt-labs and industry would sustain the infrastructure needed to support the above mentioned resource and facility. This would allow costs to be distributed, open and decentralized. The Digital Manufacturing Commons (DMC) started by DMDII – (MxD) and funded by DoD failed because it was a central authority that managed everything. An Industrial Data Commons must be decentralized, distributed, open and even as much as possible autonomous.

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