DARPA DMACE (Digital Manufacturing Analysis, Correlation and Estimation) CHALLENGE

Fiscal Year 2010 Report

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Defense Advanced Research Projects Agency

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1 BACKGROUND

Section 2374a of Title 10 of the United States Code authorizes the Secretary of Defense, acting through the Director, Assistant Secretary of Defense for Research and Engineering (ASD(R&E)), and the Service Acquisition Executive of each military department, to conduct programs to award up to $10 million in cash prizes to recognize outstanding achievements in basic, advanced, and applied research; technology development; and prototype developments that are potentially applicable to the military missions of the Department of Defense (DoD) (see Appendix A). ASD(R&E) delegated this authority to the Director of the Defense Advanced Research Projects Agency (DARPA) and authorized the conduct of the DARPA DMACE Challenge featuring a $50,000 cash prize for the winner.

This document describes DARPA's FY 2010 activities under the delegated prize authority.

The DARPA Digital Manufacturing Analysis, Correlation and Estimation (DMACE) Challenge was a prize-based competition that explored the development of models that correlated inputs for defined digital manufacturing processes to the corresponding structural characteristics of two complex, digitally manufactured structures. The Challenge began on October 29, 2010, when data for model development was released incrementally, and continued through December 1, 2010. The final parameter change requiring correlation prediction was posted via the Challenge website on December 3, 2010. Participants had until 4:30 PM EST December 6, 2010, to submit their predictions for the final structures. A total prize purse of $50,000 was offered to the person or team that developed a correlation model that accurately correlated digital manufacturing machine inputs to output structural test data. Participant models were evaluated by their ability to predict the test results of the final digital manufacturing structures. The model that most accurately predicted the final test results won the Challenge.

A team from the University of California, Santa Barbara (UCSB) modeled correlations in digital manufacturing processing using finite element models for the Challenge's metallic and polymer structures. This achievement may lead to advances in manufacturing and cut costs for the Department of Defense.

2 PROGRAM GOALS

The DMACE Challenge was a competition designed to use crowd sourcing to advance knowledge of the potential capabilities and limitations of digital manufacturing. The DMACE challenge introduced the science and engineering community to a family of structures that have unique architectures and mechanical properties fabricated using digital manufacturing techniques. The Challenge could be solved by applying any of a wide variety of engineering, mathematical, or other approaches to predictive modeling.

DARPA digitally manufactured several complex structures composed of metallic and polymer materials and conducted a series of structural load tests on them. The metallic structures were hollow mesh spheres. The polymer structures consisted of complex cubes and two-dimensional test specimens (e.g., coupons). The two-dimensional test specimens were used to investigate basic material properties of the polymer. Data from the manufacturing process and load tests were posted on the challenge website.

Competitors were challenged to develop models that predicted the maximum compressive load that could be supported by digitally manufactured titanium spheres and polymer cubes. A wide variety of mathematical and engineering methods were used to develop predictive models, with the goal of advancing knowledge of the potential capabilities and limitations of digital manufacturing processes.

3 PRIZE AUTHORITY UTILIZATION

To execute the DARPA DMACE Challenge, an incentive scheme was required to catalyze the creation of teams capable of completing the Challenge. To accomplish this goal, a cash prize was offered to an individual or group able to develop models that could accurately predict test outputs to given corresponding digital manufacturing machine inputs. The models that most accurately predicted the final test results for both a metallic sphere and a polymer cube with the lowest sample Mahalanobis distance were awarded the prize.

Participation incentives and wide scale outreach required the prize authority mechanism; the event would not be possible with standard authorities, such as contracts, grants, or cooperative agreements.

4 CASH PRIZES AWARDED

The winner was announced, and the prize was awarded at the completion of the Challenge on December 14, 2010.

Of 21 entries, a team from the University of California, Santa Barbara (UCSB) used finite element methods to most accurately predict the compressive strength of the titanium spheres and polymer cubes. The titanium spheres had a compressive strength of 30,800 newtons, with a standards deviation of 820 newtons. The UCSB prediction was 31,100 newtons. The polymer cube had a compressive strength of 58,700 newtons, with a standard deviation of 2,700 newtons. The UCSB prediction was 61,800 newtons.

The UCSB team was awarded $50,000 for having successfully constructed models that accurately predicted the output properties of both structures created by the digital manufacturing processes.

5 SOLICITATION AND EVALUATION METHODS

A DARPA DMACE press release on November 1, 2010, announced the challenge; it was also posted on the DARPA homepage.

A total of 21 entries were received for both the metallic sphere and polymer cube configurations. All participants had access to both metallic and polymer data sets.

Oak Ridge National Laboratory (ORNL) provided data sets for the metallic-based structures. ORNL performed several tasks in support of the DMACE Challenge: (1) designed and modeled components; (2) fabricated components using direct manufacturing (electron beam melting technology); (3) evaluated mechanical properties under compression utilizing planar platens; and (4) constructed models to correlate the mechanical behavior of each component against processing parameters.

The Naval Post Graduate School (NPGS) provided data sets for the polymer-based structures. NPGS performed several tasks in support of the DMACE Challenge: (1) measured the mechanical properties (i.e. strength and stiffness) of samples fabricated using a 3-D digital printer as a function of processing parameters; (2) determined predictive model connecting the input parameters to the 3-D digital printer and mechanical properties of the fabricated samples by using a statistical design of experiments and multivariate regression; (3) validated the model using crush-strength experiments on the NPGS DMACE structure; and (4) hosted the DMACE challenge.

6 RESOURCES USED

The DARPA DMACE Challenge was conducted over several days and made use of Government staff members, military interns, and support contractors to carry out the event. DARPA also contracted with Oak Ridge National Laboratory (ORNL) and the Naval Post Graduate School (NPGS).

Prize funds were drawn from the program elements (PE) and projects as follows:

PE	Project	Title	FY10	Total
61101E	BLS-01	University of California, Santa Barbara (UCSB)	50,000	50,000
				$50,000

7 TECHNOLOGY TRANSITION

The DARPA DMACE Challenge was a successful demonstration of understanding the capabilities of digital manufacturing. The Challenge introduced the material science community to the possibility of using predictive correlation models for understanding the mechanical behavior of complex structures.

Subsequent to the event, DARPA discussed the results, methods employed, and potential ramifications with several organizations. In addition, the eight DARPA Service Chief Fellows, who were essential to the planning and execution of the event, took the lessons of this experience to their respective military services.

8 CONCLUSION

The DARPA DMACE Challenge achieved its goals, and the data provided formed the nascent understanding of properties of structures created by additive digital manufacturing. This Challenge initiated the development of digital manufacturing models that describe the mechanical behavior as a function of process parameters. The Challenge also demonstrated the effectiveness of crowd sourcing to advance knowledge of the potential capabilities and limitations of digital manufacturing technology.

APPENDIX A PRIZE AUTHORITY STATUTE

The prize authority statute, section 2374a of U.S. Code Title 10 was amended by Section 257 of the National Defense Authorization Act of 2006 and Section 212 of the National Defense Authorization Act of 2007 as follows:

§ 2374a. Prizes for advanced technology achievements

(a) Authority. The Secretary of Defense, acting through the Director of the Assistant Secretary of Defense for Research and Engineering and the service acquisition executive for each military department, may carry out programs to award cash prizes in recognition of outstanding achievements in basic, advanced, and applied research, technology development, and prototype development that have the potential for application to the performance of the military missions of the Department of Defense.

(b) Competition requirements. Each program under subsection (a) shall use a competitive process for the selection of recipients of cash prizes. The process shall include the widely-advertised solicitation of submissions of research results, technology developments, and prototypes.

(c) Limitations.

(1) The total amount made available for award of cash prizes in a fiscal year may not exceed $10,000,000.

(2) No prize competition may result in the award of more than $1,000,000 in cash prizes without the approval of the Under Secretary of Defense for Acquisition, Technology, and Logistics.

(d) Relationship to other authority. A program under subsection (a) may be carried out in conjunction with or in addition to the exercise of any other authority of an official referred to in that subsection to acquire, support, or stimulate basic, advanced and applied research, technology development, or prototype projects.

(e) Annual report.—

"**(1) In general.**—Not later than March 1 of each year, the Secretary shall submit to the Committee on Armed Services of the Senate and the Committee on Armed Services of the House of Representatives a report on the activities carried out during the preceding fiscal year under the authority in subsection (a).

"**(2) Information included.**—The report for a fiscal year under this subsection shall include, for each program under subsection (a), the following:

"(A) A description of the proposed goals of the competitions established under the program, including the areas of research, technology development, or prototype development to be promoted by such competitions and the relationship of such areas to the military missions of the Department of Defense.

''(B) An analysis of why the utilization of the authority in subsection (a) was the preferable method of achieving the goals described in subparagraph (A) as opposed to other authorities available to the Department, such as contracts, grants, and cooperative agreements.

''(C) The total amount of cash prizes awarded under the program, including a description of the manner in which the amounts of cash prizes awarded and claimed were allocated among the accounts of the Department for recording as obligations and expenditures.

''(D) The methods used for the solicitation and evaluation of submissions under the program, together with an assessment of the effectiveness of such methods.

''(E) A description of the resources, including personnel and funding, used in the execution of the program, together with a detailed description of the activities for which such resources were used and an accounting of how funding for execution was allocated among the accounts of the Department for recording as obligations and expenditures.

''(F) A description of any plans to transition the technologies or prototypes developed as a result of the program into an acquisition program of the Department.

(3) Suspension of the authority for failure to include information.—For each program under subsection (a), the authority to obligate or expend funds under that program is suspended as of the date specified in paragraph (1) if the Secretary does not, by that date, submit a report that includes, for that program, all the information required by paragraph (2). As of the date on which the Secretary does submit a report that includes, for that program, all the information required by paragraph (2), the suspension is lifted.

(f) Period of authority. The authority to award prizes under subsection (a) shall terminate at the end of September 30, 2013

APPENDIX B

OFFICIAL RANKINGS FOR THE DMACE CHALLENGE:

Listed below are the teams and individuals that submitted their estimations to the Final Challenge, ranked by how close they came to correctly answering those questions using a sample Mahalanobis distance (SMD). The average compression load for the Final Spheres is 30879.44 newtons, with a standard deviation of 820.41 newtons. The average compression load for the Final Cubes is 58678.61 newtons, with a standard deviation of 2733.34 newtons.

Rank	Display Name	Cube	Sphere	SMD
1	UCSB	61806.4	31120.95	1.18157
2	kondor002	57275.72	29415.58	1.85665
3	Dan	53688.21	29316.38	2.63879
4	Jacob Simmons	51996.48	28601.27	3.69965
5	kj989018	51463	28698	3.74684
6	oyku.asikoglu	62045	27025	4.85692
7	Johannes_de_Silentio	61518.07	26891.5	4.97066
8	SnowballsChance	45160.52	32007.5	5.13320
9	JamMetalJam	45728.03	29176	5.17298
10	LamarRed	45193	28395	5.78898
11	swi	40617.91	30808.88	6.60811
12	bgraybill	78866.4	31428.01	7.41596
13	JR	42300	26740.36	7.83321
14	Jay	83392.35	33620.1	9.63896
15	Eccentric Crushers	30176.18	27196.04	11.35314
16	sfdez	38805	23065	11.98292
17	GRC	25744	30950.1	12.04951
18	pschauppner	65271.31	21067.27	12.20081
19	PAM - Predictive Additive Manufacturing	34178	23750	12.48452
20	Team Cavanaugh	13789.13	24947.78	17.94398
21	danielelyrankin	163184.5	29506.49	38.27034