NSF REU SITE: Collaborative Research: Integrated Academia-Industry Research Experience for Undergraduates in Smart Structure Technology

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Abstract

With increasing demands for high performance in structural systems, Smart Structures Technologies (SST), which includes advanced sensing, modern control, smart materials, optimization and novel testing, is receiving considerable attention as it has the potential to transform many fields in engineering, including civil, mechanical, aerospace, and geotechnical engineering. Currently, there is a significant gap between the engineering science with fundamental research in academia and engineering practice with potential application in the industry.

To respond to this challenge, San Francisco State University and the University of South Carolina will collaborate with industrial partners to establish a Research Experiences for Undergraduates (REU) Site program, focusing on academia-industry collaborations in SST. This REU program will train undergraduate students to serve as the catalysts to facilitate the research infusion between academic and industrial partners. This student-driven joint venture between academia and industry will establish a virtuous circle for knowledge exchange and contribute to advancing both fundamental research and implementation of SST. The program will feature: formal training, workshops, and supplemental activities in the conduct of research in academia and industry; innovative research experience through engagement in projects with scientific and practical merits in both academic and industrial environments; experience in conducting laboratory experiments; and opportunities to present the research outcomes to the broader community at professional settings. This REU program will provide engineering undergraduate students a unique research experience in both academic and industrial settings through cooperative research projects. Experiencing research in both worlds is expected to help students transition from a relatively dependent status to an independent status as their competence level increases.

The joint efforts among two institutions and industry partners provide the project team with extensive access to valuable resources, such as expertise to offer a wider-range of informative training workshops, advanced equipment, valuable data sets, experienced undergraduate mentors, and professional connections, that will facilitate a meaningful REU experience. Recruitment of participants will target 20 collaborating minority and primarily undergraduate institutions (15 of them are Hispanic-Serving Institutions, HSI) with limited science, technology, engineering, and mathematics (STEM) research capabilities. The model developed through this program may help to exemplify the establishment of a sustainable collaboration model between academia and industry that helps address the nation's need for mature, independent, informed, and globally competitive STEM professionals and is adapted to other disciplines.

In this poster, the details of the program will be described. The challenges and lesson-learned on the collaboration between the two participating universities, communications with industrial partners, recruitment of the students, set up of the evaluation plans, and development of the program will be discussed.

Motivation

To match the demand forecast for skilled STEM professionals, graduating sufficient numbers of well-prepared graduates in STEM occupations is a high priority in the U.S. [1-2]. To fill this demand, it is predicted that the U.S. needs to increase the yearly production of undergraduate STEM degrees by 34%. Thus, there is an urgent need to provide undergraduates top-quality training and prepare them for the transition to graduate school and/or to enter professional engineering careers. However, training in industrial environment is currently lacking in most undergraduate curricula.

With increasing demands for high performance in structural systems, SST that includes advanced sensing, modern control, smart materials, optimization and novel testing, is receiving considerable attention as it has the potential to transform many fields in engineering, including civil, mechanical, aerospace, and geotechnical engineering. In civil engineering, for example, extreme events such as earthquakes, hurricanes, and tsunamis can have fatal effects on structures, and, as consequence, have devastating influences on occupants, society, and the economy as a whole. A smart structure is a structure that is capable of sensing, control and actuation. These systems are able to withstand these hazards by reacting to the environment, just like a biological body. National efforts are underway to develop and build the next generation of smart structures. In the academic world, researchers are developing, for example, new sensing schemes (structural health monitoring) [3-4], smart dampers and corresponding controllers (structural control) [5-6], and evaluating innovative experimental testing methods (real-time hybrid testing) [7-8]. In the industrial world, investigators emphasize on the practical applications and conduct SST research on, for example, adopting unmanned aerial systems (UAS) for non-contact vision-based health monitoring [9], applying ideas learned from nature to build more resilient structures [10], and utilizing modern computer power and topology optimization techniques to design more efficient structures [11].

The author knows from first-hand experience working as a structural engineer that many brilliant ideas brainstormed in industry are not pursued in the actual design practice due to the lack of theoretical support, immediate economic benefits, and manpower to pursue fundamental research ideas. Similarly, academic groups focusing on fundamental research do not always leverage the industrial perspective to identify new demanding research fields and recognize the challenges associated with transferring the new knowledge to practical applications.

Proposed Solution

To fill the above-mentioned knowledge gap and enable undergraduates to acquire the fundamental knowledge that they need for the U.S. to retain its preeminence in STEM, seven faculty members from San Francisco State University, a HSI, and the University of South Carolina will collaborate with mentors from industrial partners, such as Arup Group Limited (Arup), ASSET Intelligent Infrastructure (ASSET), Exponent Inc. (Exponent), FTF Engineering Inc (FTF), Geosyntec Consultants (Geosyntec), Rutherford + Chekene (R + C), Skidmore, Owings & Merrill LLP (SOM), STV Group, Inc. (STV Group) to establish a REU Site program, focusing on academia-industry collaborations in SST. The joint efforts among two institutions

and industry partners provide the project team with extensive access to valuable resources, such as expertise to offer a wider-range of informative training workshops, advanced equipment, valuable data sets, experienced undergraduate mentors, and professional connections, that will facilitate a meaningful REU experience.

This REU IAIRESST will train undergraduate students to serve as the catalysts between engineering science with fundamental research and engineering practice with potential implementation, to facilitate the research infusion between the academic and industrial partners, and to promote the research outcomes to be adopted in actual design practice by providing a better understanding of the needs and demands in both academia and industry. It will provide students invaluable opportunities to enhance their core engineering knowledge, to experience the excitement of research in both the academic and industrial settings, to gain insights into the opportunities and challenges awaiting them in their industrial careers, and to establish a network in both academia and industry in their field of interest.

Program Objectives and Outcomes

The main objectives of this REU program are to:

1. Provide undergraduates participants a unique and exciting summer research experience in both academic and industrial environments;
2. Prepare students to become the catalysts to help close the gap between academia and industry; and
3. Motivate the participants, especially those from underrepresented groups, not only to complete their undergraduate degrees, but also to pursue advanced degrees and/or careers in engineering.

Secondary objectives are to:

1. Strengthen the collaboration between academia and industry and establish a collaborative environment to provide students unique the research experiences;
2. Provide participating students a better understanding of different research opportunities and expectations in academia and industry; and
3. Improve students' professionalism and autonomy.

The expected outcomes of this REU program are:

1. Students will be able to demonstrate core knowledge in SST related areas (i.e. structural control, structural health monitoring, signal processing, etc.);
2. Students will be able to understand and identify the differences between engineering science and engineering practice;
3. Students have publications co-authored with academic/industrial mentors.

Program Activities

The program will feature: formal training, workshops, and supplemental activities in the conduct of research in academia and industry; innovative research experience through engagement in projects with scientific and practical merits in both academic and industrial environments; experience in conducting laboratory experiments; and opportunities to present the research outcomes to the broader community at professional settings.

The REU participants will spend a total of 10 weeks in the program. In the first two weeks, the students are at the academic institution receiving training for the upcoming research activities. During weeks 3-9, the students will spend the first two days (Monday and Tuesday) at the academic institution and the next two days (Wednesday and Thursday) in industry partners working on the research projects. On Friday, they will come back to academic institution for progress reports and extracurricular activities. The participants will be back at the academic institution in week 10 to wrap up the program. Supplemental activities including student formal presentations, roundtable discussion, technical tour and cultural activities will be arranged in the program.

Student Recruitment

The REU program will initiate the collaboration from junior and senior students, the future change makers, at their most curious stages in their academic careers. Underrepresented groups will be the main targets of the program and will be engaged by recruitment at identified minority and primarily undergraduate institutions with limited STEM research capabilities. Twenty of such institutions have agreed to support the REU program and work closely with the authors to recruit participants. The program will have 8 students each year (4 at each institution). The program will be broadly advertised through the following mechanisms:

1. The identified 20 collaborating minority and primarily undergraduate institutions with limited STEM research capabilities (15 of them are HSI).
2. Public advertising at websites such as those at the host institutions and Pathways to Science [12], which places particular emphasis on connecting underrepresented groups with STEM programs, funding, mentoring and resources.
3. A public website specially created for the REU program.
4. Recruitment letters posted at the websites of the industry partners.
5. Flyers with relevant information sent to engineering departments across the country.

Program Organization

The funded period of this REU program is from October 1, 2017 to September 30, 2020. This upcoming summer (2018) will be the first time this program is offered. The following paragraphs discuss how the project leadership has managed and prepared for this year's program.

Project management – The PIs have been actively preparing for the 2018 program since August 2017. This includes preparing promotional materials, reserving rooms for REU students, defining projects with industrial partners, etc. Given the large number of tasks in preparation and the collaborative nature of the project, effective and efficient management would be one of the keys to the success of the project. The project leadership has adopted a Kanban project management system. This project management style was first developed by Toyota Engineers and takes every task through the same process. Tasks start from a list of concepts all to completely accomplished, similar to how a car is assembled. The team uses Trello [13] as a tool to

implement this project management style. Its bulletin board style allows for visually dividing the tasks into stages including Backlog, To Do, Doing, Blocked, Quality Check, and Done . Trello is equipped with rich Application programming interface (API) that makes it possible to integrate with other cloud-based services like Slack [14] and Zapier [15] for prompt communication and task automation.

Program promotion – Being able to attract qualified participants is another critical factor to the success of the program. Duration the preparation process, several strategies have been used to promote the program. A promotion flyer is developed and sent through emails to the identified 20 collaborating minority and primarily undergraduate institutions with limited STEM research capabilities, and colleagues of the PIs. These connections are carefully selected to cover universities with different geographical distribution as well as student bodies. Besides, a dedicated public website [16] is created for the REU program to facilitate the application process. In addition to the general information of the program, the website also hosts a promotion video, which is made specially to promote the program in a fun and interactive way and thus stimulating students' interests. Public advertising is also done at Pathways to Science [12], which places particular emphasis on connecting underrepresented groups with STEM programs, funding, mentoring and resources. Furthermore, communications have been made with the REU program manager to ensure the funded program is listed and searchable from NSF website [17].

The application deadline for the 2018 summer program is Feb. 16. Through the promotion strategies listed above, the total number of applicants received is 82 when the application was cut off at the deadline. To provide more insights on how to better attract and retain potential applicants (e.g. website reviewers), Google Analytics was adopted to quantitatively evaluate how different activities (e.g. e-mailing colleagues) affect website usage and video viewers. Fig.1 shows the number of sessions on the website since the beginning of the year. The large spike observed in mid-January corresponds to the response obtained after the program leadership e-mailed colleagues with information about the REU program.

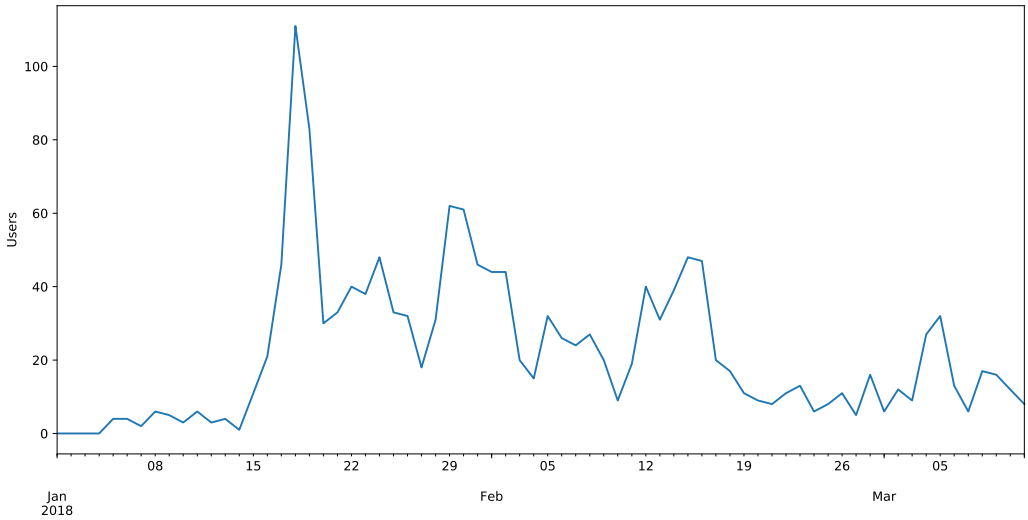

Figure 1. Google Analytics – Number of Session

Communication – Given this program is a geographically distributed REU program, communication is crucial in program preparation and management. Weekly or bi-weekly meeting is hold through teleconferencing platform (e.g. ZOOM) to facilitate the communication. In addition, Slack, a popular cloud-based team collaboration tool among students, is recently adopted into the program. By using a program/app that is used by students daily, we intend to promote prompt and timely communication between the faculty members and students.

Reference

[1] Chen, X. (2013). "STEM Attrition: College Students' Paths Into and Out of STEM Fields (NCES 2014-001)." *National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education*. Washington, DC.

[2] Xue, Y. and R. C. Larson (2015). "STEM crisis or STEM surplus? Yes and yes." *Monthly Lab. Rev.* 138 (2015): 1.

[3] Lynch, Jerome P., and Kenneth J. Loh. (2006). "A summary review of wireless sensors and sensor networks for structural health monitoring." *Shock and Vibration Digest* 38, no. 2: 91-130.

[4] Spencer, Billie F., Manuel E. Ruiz-Sandoval, and Narito Kurata (2004). "Smart sensing technology: opportunities and challenges." *Structural Control and Health Monitoring* 11, no. 4 (2004): 349-368.

[5] Housner, GWea, Lawrence A. Bergman, T. Kf Caughey, Anastassios G. Chassiakos, Richard O. Claus, Sami F. Masri, Robert E. Skelton, T. T. Soong, B. F. Spencer, and James TP Yao. (1997). "Structural control: past, present, and future." *Journal of engineering mechanics* 123, no. 9: 897-971.

[6] Spencer Jr, B. F., and S. Nagarajaiah. (2003). "State of the art of structural control." *Journal of structural engineering* 129, no. 7: 845-856.

[7] Mahin, S. A., P. B. Shing, C. R. Thewalt and R. D. Hanson. (1989). "Pseudodynamic test method-current status and future directions." J. Struct. Eng. 115 2113–28.

[8] Shing, P. B., M. Nakashima and O. S. Bursi. (1996). "Application of pseudodynamic test method to structural research." Earthq. Spectra 12 29–56.

[9] Ham, Youngjib, Kevin K. Han, Jacob J. Lin, and Mani Golparvar-Fard. (2016). "Visual monitoring of civil infrastructure systems via camera-equipped Unmanned Aerial Vehicles (UAVs): a review of related works." *Visualization in Engineering* 4, no. 1: 1.

[10] Sarkisian, M. (2011). "Tall Building Design Inspired by Nature." *Proceeding of 36th Conference on Our World in Concrete & Structures*, Singapore.

[11] Baker, William F., Lauren L. Beghini, Arkadiusz Mazurek, Juan Carrion, and Alessandro Beghini. "Structural Innovation: Combining Classic Theories with New Technologies." *Engineering Journal-American Institute of Steel Construction* 52, no. 3 (2015): 203-217.

[12] Pathwaystoscience.org. (2018). Pathways To Science. [online] Available at: http://www.pathwaystoscience.org [Accessed 28 Feb. 2018].

[13] Trello.com. (2018). Trello. [online] Available at: https://trello.com [Accessed 28 Feb. 2018].

[14] Slack. (2018). Where work happens. [online] Available at: https://slack.com [Accessed 28 Feb. 2018].

[15] Zapier. (2018). Zapier | The easiest way to automate your work. [online] Available at: https://zapier.com [Accessed 28 Feb. 2018].

[16] Sdii.ce.sc.edu. (2018). Home | Smart Structures Technologies REU. [online] Available at: http://sdii.ce.sc.edu/REU_SST/ [Accessed 28 Feb. 2018].
[17] Nsf.gov. (2018). REU Sites | NSF - National Science Foundation. [online] Available at: https://www.nsf.gov/crssprgm/reu/list_result.jsp?unitid=10006&d-8001259-p=2 [Accessed 28 Feb. 2018].