

UH-HIT Joint Research in Smart Materials – an IREE Supplement Award to Collaborative Research: Hysteresis Compensation Using Linear Parameter Varying Control Methods

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ABSTRACT: The classical definition of job qualifications for engineers is changing as U.S. economy becomes more global. In addition to technical qualifications, there is a great need for multi-national, interdisciplinary, and multi-cultural competence for engineers. In this project, three U.S. engineering students gained valuable research experiences at Harbin Institute of Technology (HIT), a top engineering university in China. China has a fast growing economy and is the largest trading partner with U.S. By combining the expertise of highly qualified faculty members from both University of Houston (UH) and HIT, innovative research related to smart materials, structural health monitoring, and structural control were conducted by using the-state-of-the-art facilities at HIT. One student performed research on the topic of hysteresis characterization of shape memory polymer. The other student performed the novel research of damage detection of a composite wind blade using piezoceramic transducers. The last student conducted research in structural vibration control using MagnetoRheological (MR) fluid dampers. Additionally, the students also visited five other Chinese universities and joint student symposiums were organized during each visit. Through their summer research stay in China, the U.S. students were exposed to a totally different culture and learned the Chinese education and research systems, which will increase their readiness for a job in a global economy. One of the participants was a minority student and this IREE supplementary fund increased the participation from the underrepresented population in engineering. In addition, this IREE project strengthened UH-HIT collaboration in the area of smart materials, composites and structural health monitoring and stimulated innovative interdisciplinary research.

INTRODUCTION

This report summarizes the work carried out under the NSF IREE award granted to the Department of Mechanical Engineering at the University of Houston to collaborate with Harbin Institute of Technology (HIT) in China. Under the award, research projects pursuing advancement of smart materials, hysteresis characterization, and structural health monitoring (SHM) techniques using piezoceramics were conducted. With the rapid expansion of the Chinese economy, large, structurally complicated buildings are planned to serve China's growing needs for space, opening an unprecedented opportunity for the implementation of SHM, novel construction materials, and structural vibration control technologies. HIT is among the leading Chinese universities in the field of smart materials, SHM, and structural vibration control. HIT's recent projects include SHM of the Chinese National Aquatics Center (Water Cube) and the National Athletics Center (Bird's Nest). Structural vibration control projects include stay cable vibration suppression using MR dampers and vibration reduction of the Guangzhou TV Tower using a combine Active Mass Damper (AMD)/Tuned Mass Damper (TMD) technology. The implementation expertise HIT complement perfectly with the smart materials, sensor and instrumentation development expertise of the Smart Materials and Structures Laboratory (SMSL) at UH. With extensive laboratory experience in sensor system integration with structures, the partnership of SMSL with HIT would allow the two universities to further research and

implementation of cost-effective, robust, and integrated sensor systems for SHM and structural vibration control.

To fulfill the mission of the IREE grant, three students were selected to travel to China and conducted research projects hosted at HIT by their Department of Civil Engineering. Oliver Rivera, a rising undergraduate senior, tested shape memory polymer materials for feasibility in structural damping applications. Kevin Weaver, a rising undergraduate senior, tested the use of piezoceramic sensors for acoustic emission sensing of cracking in fiberglass composite wind turbine blades. Claudio Olmio, a graduate student, conducted research in structural control. With another IREE supplementary grant, two more students participated. Christiana Chang, an entering graduate student, conducted research on the development of a self-heating composite/concrete system using carbon nanofiber paper. Michael Fernandez, a rising undergraduate senior, implemented fiber optic sensors on fiberglass composite wind turbine blades for damage detection. The IREE project includes **four Phases** :

Phase 1 (May 7-20, 2008). During this phase, the students receive training in both the research that they will conduct at Harbin Institute of Technology (HIT) and the culture that they will experience in China from Dr. Song's graduate students and postdoctoral fellows with Chinese culture background.

Phase 2 (May 21-June 8, 2008). During this phase UH students, led by Dr. G. Song, visited seven technical and engineering universities and one company in China. These seven universities include Shenzhen Polytechnic, Harbin Institute of Technology – Shenzhen Graduate School, Hunan University, Wuhan University of Science and Technology, Beijing University of Science and Technology, Dalian University of Technology, and Harbin Institute of Technology – Main Campus. In each university, UH students visited related engineering and technology laboratories and had joint culture events with local students. In five universities, joint student symposiums were held. In these symposiums, UH students and students from the hosting universities presented their previous research findings. These student symposiums functioned as effective platforms for students from both countries to exchange technical information.

Phase 3 (June 8 – July 27, 2008). During this phase, students conducted seven-week research at HIT in China. Oliver Rivera characterized shape memory polymer and shape memory polymer composite and observed the effect of the addition of carbon fibers on the polymer at different temperatures. Kevin Weaver designed and performed a static loading test to failure, and perform rudimentary and fractal analysis on the collected acoustic emissions data using piezoceramics. At the end of the program, both of them made a presentation to report their research finding at HIT. Due to emergency research issues back at the UH campus, Claudio Olmio was required to return to the United States before research at HIT could be conducted.

Phase 4 (July 28 – August 12, 2008). Students wrote reports on their research finding and essay about their IREE trip in china. Phase 4 activities were conducted at UH after students returned to USA

In summary, with such a broad range of activities, the students left China with a broadened view of international research culture and have exchanged scientific and world views with the various students they would meet on their journey. With a rich research experience, it was hoped that the undergraduate students would seek further academic and research careers in graduate school. For the graduate student, it was hoped that the international research experience would equip her for international research collaborations in her own career in the future. Through the HIT hosted research, both of these goals were reached beyond the project's expectations.

RESEARCH ACTIVITIES AND ACCOMPLISHMENTS OF THE INTERNATIONAL COOPERATION

The host laboratory at Harbin Institute of Technology was very welcoming to each of UH visitors during the international research experience. Once at Harbin Institute of Technology, UH visitors had the privilege to meet Dr. Hui Li, a chair professor and smart materials and SHM expert who would offer general guidance and strong support for the joint research, Dr. Wensong Zhou, a young professor with whom UH students would be initiating the research on structural health monitoring and damage detection within wind turbine blades, and Chenxi Mao, a recent PhD recipient who would monitor the shape memory polymer project. UH students were graciously given desks close to the students whom UH students would be working the most with; in Kevin's case, Huang Young, a graduate student who finished his master's degree during the research stay. UH visitors quickly became friends with many of the exceptionally courteous students in the lab, and settled into a daily routine of literature research, group meetings,

developing experiments, observing other students research and presentations, and the occasional match of ping pong after lunch. The student's were integral part of the project planning process. Professor Zhou kept us very engaged in planning and developing the wind turbine experiment; UH students would meet at least twice a week to openly discuss problems and exchange ideas, and UH students would often confer with Dr. Yewchin Koay, a visiting lecturer from Australia who shared Dr. Zhou's office.

One of the greatest hurdles to overcome from UH students being American students visiting China was the language barrier, since most of them did not speak enough Chinese to convey the ideas. Professor Li's laboratory was very helpful in this respect, since all the students are required to learn English, and write reports in English. This made many things easier, such as trying to figure out a restaurant menu with no pictures of the food. Many times UH researchers would have to purchase parts or materials for the experiments they were conducting, and the students from Professor Li's laboratory were more than happy to help us get around the city and acquire the necessary items. Since the students at the host laboratory were writing research reports in English, UH students were able to return the favor by revising their research reports and papers; where Huang taught Kevin how to prepare the electrodes on the piezoceramic wafers and bond the constructed piezoelectric sensors to the surface of the blade, as well as walk Kevin through a fractal based damage detection algorithm. Kevin helped proofread Huang's associated paper.

Professor Li's laboratory is a Civil Engineering laboratory, and since the students were all Mechanical Engineering majors coming from a laboratory that focuses on smart materials, they were able to bring a different method of problem solving to the table. This included structural damping applications, structural health monitoring and self heating concrete, for example. Since the test Oliver conducted required making his own test specimens, he was able to use another department on campus that specialized in composites and polymers to help us fabricate the specimens. This turned out to be quite convenient when he needed a specimen mixed with carbon fibers. After testing, Oliver found that adding chopped carbon fibers at 3 wt. % lead to an increase in the damping capacity, as well as an increase in shear modulus above the glass transition temperature, and an increase in the cooling recovery force. UH researchers determined that this material may be useful as a small scale structural damper. UH researchers were also able to narrow down goals for testing. The research carried out at HIT was helpful in determining for the first time if a shape memory polymer could be used in a structural damping application. There had also been no previous work on the shear properties of this material, which was the method UH students used to test the material.

Professor Zhou, Huang, Michael and Kevin were able to research literature, obtain a small wind turbine blade, bond lead zirconate titanate (PZT) and fiber bragg grating sensors to the surface, design and perform a static loading test to failure, and perform rudimentary and fractal analysis on the collected acoustic emissions data. About a week before UH researchers left, Dr. Zhou, Michael, Huang and Kevin spent a late night in the civil engineering lab carrying out the static failure test of the turbine blade. Kevin, equipped with a hard hat, sat next to the blade extending a mechanical jack and load cell while Michael manned the fiber optic interrogator, and Huang monitored the data acquisition unit for the PZTs. Two attempts and four hours later, they finished the destructive testing of the blade.

The students made regular updates to Professor Hui Li, the director of the laboratory and the host. She host a small laboratory social just before UH visitors left where UH students were able to meet students from other civil engineering labs, a few of which were undergraduates. Before the students left, they made presentations on their work before Dr. Li, and Kevin continues to correspond with Dr. Zhou on the project.

BROADER IMPACTS OF THE INTERNATIONAL COOPERATION

Originally, the scope of the project was to further development of the use of MR dampers for structural control. However, once on site at HIT, it was found that research topics in other areas would be more fitting for the current research conducted at the host site and with the backgrounds of the IREE students. However, HIT is still a leader in structural control and the use of smart materials, therefore the scope of the project remained in the areas of smart materials, structure damage detection, and structure control.

This trip helped to facilitate the students' ability to interact and work with people from a different culture who spoke a different language. The language was clearly the main problem when dealing with people outside of the laboratory. The IREE students were very interested in the language, and the students from the host laboratory were equally as interested in teaching the UH students their language. The hosts were very good in teaching the students about Chinese culture. The IREE students looked forward to having dinner and lunch with the students from the laboratory since even at the cafeteria on campus there was quite a wide selection of food. When they would go off campus to have lunch, they would get to try

various styles of Chinese food. Some of the students at the laboratory were eager to learn about American culture, and therefore they exchanged things like music and had movie nights to further the cultural interaction. For example, the UH students were invited to “KTV” (known as karaoke in the US) which is extremely popular in China. The students were also taught how to cook dumplings from scratch. Each of these things helped to broaden UH students’ cultural scope and facilitate international interaction. They also met and made a variety of friends at the foreign student’s dormitory, including a number of Russian students and a young woman from France, all of whom they took out to eat at one point and of all things played cards with.

Most importantly, the experience overseas has greatly increased the students’ understanding of Chinese culture, not as some foreign body of history and mannerism but something recognizably human. While in Harbin, they had the opportunity to attend a dragon boat race on the Songhua River, and observed local teams race traditional boats while powered paragliders circled overhead. Vendors sold drinks and snacks the same way one would expect to see anywhere in America. The IREE students attended the campus’ familiar but massive graduation ceremony, as well as an end of semester concert put on by students. While they could not understand a word of either, it became obvious how much students across any language have in common one another.

The supplement award promoted diversity by providing funding to allow American students to visit a country where the culture and language is completely different from UH students’. By placing the student in this environment there is a natural desire to want to learn more about the culture. UH students were able to learn about the Chinese culture by being immersed in it, which is much more exciting than learning about it from a book. During the visit UH students were fortunate enough to be able to interact with other international students from other parts of the world, such as South Korea and Taiwan, Russia, and even a student from France. Without the supplement, this social and scientific interaction would not take place.

This award allowed one minority student to travel to China to further their goals of continued academic careers. The cultural exchange aspects of the travel program also helped the students become more aware of cultural differences between them and their Chinese peers and to be more aware of culture and diversity on the international research stage.

DISCUSSION AND SUMMARY

The research accomplishments include studying the durability of glass fiber reinforced polymer wind turbine blades, characterizing the performance of specimen blades through static tests, and planning for future dynamic durability experiments. Also, the characterization of shape memory polymers with carbon fiber mixture was performed to prove the feasibility of the material as a structural damper. One of the most significant accomplishments during the international visit was developing the skills to work with people that come from a completely different cultural background than what UH researchers came from. This helped the students to be more acceptable towards the different cultures and would make it easier to interact with cultures other than the Chinese culture. The students’ background in smart materials and the host laboratory’s background in structures helped us to combine the two for smart control of structures. This was a great combination and helped participants build on each other’s knowledge. Also, one of the greatest elements the students took from this program was insight into how the scientific community interacts on an international scale and the recognition of just how similar the IREE students are to students pursuing degrees overseas.

The experience in the IREE program was very smooth; however, future operations of the IREE program could be made even smoother by allowing the visiting students and host laboratory to communicate a week or two in advance to coordinate assignments and other logistics. This would allow the research to be conducted more productively.

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BRIEF BIOGRAPHIES OF RESEARCHERS

Kevin Weaver is currently pursuing a B.S. degree in Mechanical Engineering with membership in the Honors College from the University of Houston, where his graduation is anticipated in spring 2010. A member of Tau Beta Pi, Kevin enjoys hiking and staying ahead of his coursework. Ongoing projects he is involved with include developing piezoelectric damage detection strategies for composite materials under the advice from Dr. G. Song.

Oliver Rivera is currently pursuing a B.S. degree in Mechanical Engineering from the University of Houston, where his graduation is anticipated in December 2009. Ongoing research he is involved with includes discovering new uses for shape memory polymers with the Smart Materials and Structures Laboratory at the University of Houston under the guidance of Dr. G. Song. He was actively involved with the University of Houston 2007 Formula SAE entry and is currently an officer of his student section of the Society of Women Engineers.

Claudio Olmi is a Ph.D. candidate in the Department of Electrical and Computer Engineering at University of Houston. He is conducting research in structural control using MR dampers and SMA (Shape Memory Alloy) devices, instrumentation, remote experiment, and wireless sensor network at the Smart Materials and Structures Laboratory at UH under the guidance of Dr. G. Song. Claudio obtained his B.S. and M.S. degrees from UH.

Dr. Gangbing Song is now a professor of both Mechanical Engineering and Electrical and Computer Engineering at UH. Dr. Song was an associate professor when the IREE project was applied for and executed. Dr. Song is also the funding director of the Smart Materials and Structures Laboratory at UH. Dr. Song's research interests include smart materials and structures, structural health monitoring, structural control, hysteresis modeling and compensation, and various control methods.