

Center for Nanoscale Chemical Electrical Mechanical Manufacturing Systems (NanoCEMMS)

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ABSTRACT: This document reports on the international research experience funded by the IREE grant. This grant enabled a research collaboration between the University of Illinois at Urbana-Champaign (UIUC) and the Singapore Institute of Manufacturing Technology (SIMTech). The proposed research was to design, manufacture, and test a prototype deposition system for a rapid prototyping process. The deposition head was designed and manufactured at SIMTech and is currently being tested and evaluated at UIUC. The continuation of the project at UIUC is extending the collaboration and is expected to further benefit both institutions. An additional outcome of the IREE funded trip was the development of international research experience for the grantees, a valuable lesson considering the expansion of multinational corporations that need researchers with both technical skills and international experience.

INTRODUCTION

The IREE award granted by the NSF facilitated a collaborative effort between the University of Illinois at Urbana-Champaign (UIUC) and the host institution, the Singapore Institute of Manufacturing Technology (SIMTech). The collaboration sent graduate student David Hoelzle to Singapore from September 4th through December 21st 2007. Research goals at the onset of the collaboration were to utilize the expertise of SIMTech researchers to aid Mr. Hoelzle in the design of a prototype deposition head for a rapid prototyping process. Educational goals were to expose Mr. Hoelzle to research activities in Singapore and Asia and to develop international experience. Additional goals were to establish a lasting collaboration between UIUC and SIMTech.

SIMTech is a research lab under the Singaporean government's Agency for Science, Technology, and Research (A*STAR). The SIMTech branch of A*STAR's goal is to enhance the competitiveness of Singapore in the manufacturing industry[1]. Key research initiatives of SIMTech include Forming Technology and Mechatronics, two focuses important to the research performed as part of the IREE grant. At SIMTech, Mr. Hoelzle was advised by a principle investigator in the Forming Technology group, Dr. Tay Bee Yen, and the head of the Mechatronics group, Dr. Lin Wei. Their guidance aided in developing a successful prototype deposition system.

Mr. Hoelzle's two years of successful graduate level research experience made him the best qualified candidate for this collaborative assignment. Specifically, his experience with a rapid prototyping process named micro-Robotic Deposition (μ RD)[2] made him well suited for the development of new hardware for the process. His background has included research in controls, mechatronics design, and ceramic processing, all fundamental concepts in μ RD research and key initiatives at SIMTech.

Currently, the prototype deposition head is part of a functioning μ RD system at UIUC. After further evaluation, the prototype deposition head will be shipped back to SIMTech for future research projects. This trade of resources should maintain collaboration between the two institutions, benefiting both parties.

RESEARCH ACTIVITIES AND ACCOMPLISHMENTS OF THE INTERNATIONAL COOPERATION

The research proposal written was for the design, manufacture, and testing of a prototype deposition head for use in μ RD. μ RD is a rapid prototyping process in which micro-sized structures are built up layer-by-layer by the deposition of a colloidal material[2]. Similar to the more popular Fused Deposition Modeling[3], the coordination of the deposition of material with the motion of the deposition head is critical. Unlike Fused Deposition Modeling which uses polymeric materials, μ RD deposits ceramics making the technology useful for the production of artificial bone structures, piezoelectric actuators, photonic bandgap structures, and other various applications. The researchers at UIUC had developed a general understanding of how to modulate build material deposition in a single material system[4] prior to the grant, but a multi-material system was necessary to advance the capabilities of the artificial bone structure application.

The research goal was to use the expertise of SIMTech in Forming Technology and Mechatronic design to aid in the design of a multi-material deposition head. With this prototype hardware, multi-material artificial bone structures can be fabricated, a project funded by the current NSF grant. SIMTech aided in the production of this prototype by providing design expertise, lab space, and funding the manufacture of the prototype system. The researchers held weekly meetings to discuss design options and to update manufacturing and assembly progress.

Over the course of the onsite collaboration the prototype system was designed and manufactured. The evaluation of the design could not be completed during the trip and testing had to be performed at UIUC. More advanced testing is currently being performed at UIUC where a control algorithm named Iterative Learning Control (ILC)[5] is being applied to the material deposition process. An engineering draft of the design can be seen in Figure 1a. A new technology has emerged from the project. Typical ILC algorithms consider single systems, however the intended application requires the deposition of multiple materials and hence multiple systems. This has necessitated segmenting the ILC algorithm into multiple parts to handle multiple systems, an extension of the ILC technology that has not been broached by the control community. A conference paper[6] detailing this approach has been written and a journal paper combining this and previous results is being written, both which should be worthwhile contributions to the ILC community. An example of a simple structure fabricated by the segmentation of the ILC algorithm is shown in Figure 1b.

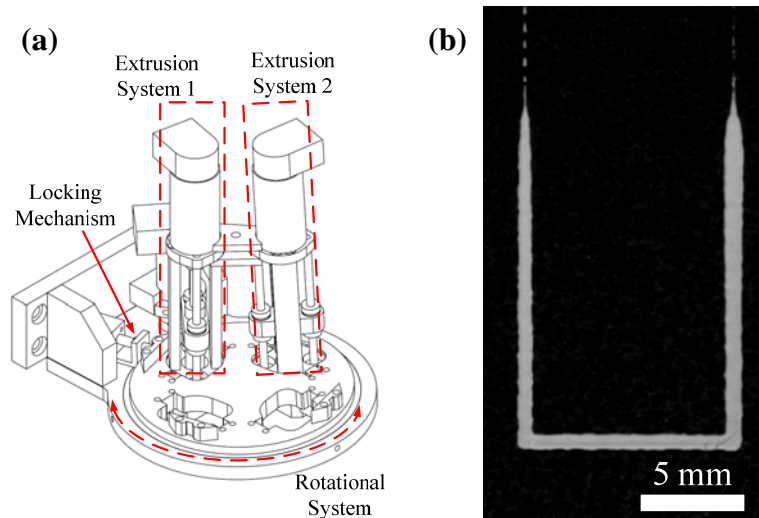


FIG. 1: (A) ENGINEERING DRAWING OF THE DESIGN FOR THE PROTOTYPE DEPOSITION HEAD COMPLETED AT SIMTECH. BASIC COMPONENTS ARE EXTRUSION SYSTEMS ORIENTED IN A ROTATIONAL ARRAY AND A ROTATING AND LOCKING MECHANISM TO INDEX BETWEEN EXTRUSION SYSTEMS. (B) EXPERIMENTAL RESULTS FROM THE CONTINUATION OF WORK PERFORMED AS PART OF THE IREE TRAVEL GRANT. HERE A SIMPLE STRUCTURE IS DEPOSITED TO DISPLAY THE CAPABILITIES OF THE NEW EXTENSION OF THE ILC ALGORITHM. UNLIKE THIS STRUCTURE, μ RD FABRICATION REQUIRES MULTI-MATERIALS AND LENGTHY BUILD TIMES; THEREFORE THE ILC ALGORITHM HAS TO BE SEGMENTED INTO SIMPLER PARTS. HERE THIS SIMPLE STRUCTURE WAS SEGMENTED INTO A START, STEADY-STATE, CORNER, AND STOP PHASE. FUTURE RESEARCH WILL EXPAND ON THIS SIMPLE EXAMPLE INTO MORE COMPLEX STRUCTURES.

BROADER IMPACTS OF THE INTERNATIONAL COOPERATION

The international cooperation provided an excellent exposure of technical research being performed in one of the leading technological countries in Asia. The experience was also a global experience. SIMTech hires engineers and students from all over the world. Notable, Mr. Hoelzle either collaborated with or interacted with researchers from China, Hong Kong, Malaysia, India, Indonesia, France, the Netherlands, and the U.K. Not only did this global experience expand the research breadth of the individuals supported by the grant, but cultural knowledge as well. Cultural knowledge is paramount in an ever increasingly global marketplace where respect of traditions, culture, and business protocol increase the likelihood of a successful working relationship. The culture sharing with international colleagues will allow Mr. Hoelzle to participate in more informed and natural interactions in any future collaboration.

Although it was not stated in the original research proposal, future collaborations emerged as a result of the project. The prototype deposition head is now in use at UIUC for further research with the agreement that upon completion the hardware will be sent back to SIMTech to be used in their testbeds. Along with the sharing of hardware, there is a sharing of information so that both parties gain in research knowledge and capability. Progress reports are being exchanged regularly to keep both parties updated with new developments. Over the course of a short period of time, a respect and trust has been developed between the two parties and hopefully this will lead to even more prosperous collaborations.

The primary intention of the trip was for research, but the trip also enabled travel to neighboring countries that enhanced international perspective. Singapore is situated in a culturally rich area of the world where it is easy to jump between countries with vastly different languages, traditions, religions, etc. Some eye-opening experiences were the realization of the ubiquity of cellular phones and other communication technology in Singapore and Malaysia (more widespread than the US), wealth disparity in Vietnam and China, and the focus on education in Singapore and China. These experiences have highlighted both the opportunities and challenges in Asian countries.

DISCUSSION AND SUMMARY

The research abroad experience funded by the IREE grant has been valuable to the individuals involved, UIUC, and SIMTech. SIMTech will use the developed hardware to explore their own research endeavors, primarily in manufacturing, and UIUC will be able to build off the knowledge gained from the design and testing stages to develop successful control algorithms. The opportunity has opened up the possibility of future collaboration beyond the scope of the proposed project. The international experience gained has increased the likelihood of success of future collaborations with either SIMTech or other international institutions.

The researchers believe that the current grant format, where participants are required to attend a conference and write a paper but the project scope is loosely defined, is the best approach because intellectual freedom is not inhibited. The researchers involved found the experience valuable in both research progress gained and international experience obtained.

ACKNOWLEDGEMENTS

This work was supported by NSF Grants DMI-0328162 and CMI-0749028. Shaochen Chen is the NSF program officer.

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BRIEF BIOGRAPHIES OF RESEARCHERS

David J. Hoelzle received his B.S. degree in Mechanical Engineering from the Ohio State University in 2005. He received his M.S. in Mechanical Science and Engineering from the University of Illinois at Urbana-Champaign in 2007. Currently he is pursuing a doctorate from the University of Illinois, working on a collaborative assignment with the Alleyne Research Group and the Applied Biomaterials and Biomechanics Lab led by Dr. Andrew Alleyne and Dr. Amy Wagoner Johnson, respectively.

Prof. Andrew G. Alleyne received his B.S. in Engineering Degree from Princeton University in 1989 in Mechanical and Aerospace Engineering. He received his M.S. and Ph.D. degrees in Mechanical Engineering in 1992 and 1994, respectively, from The University of California at Berkeley. He joined the Department of Mechanical and Industrial Engineering at the University of Illinois, Urbana-Champaign in 1994 and is also appointed in the Coordinated Science Laboratory of UIUC. He is currently the Associate Dean for Research in the College of Engineering and holds the Ralph M. and Catherine V. Fisher Professorship. Dr. Alleyne was awarded the ASME Dynamics Systems and Control Division's Outstanding Young Investigator Award in 2003 and was a Fulbright Fellow to the Netherlands where he held a Visiting Professorship in Vehicle Mechatronics at TU Delft. He is a Fellow of ASME. His research interests are a mix of theory and implementation with a broad application focus. In addition to research he has a keen interest in education and was recently awarded the UIUC College of Engineering's Teaching Excellence Award for 2008.

Prof. Amy J. Wagoner Johnson received her BS in Materials Science and Engineering from Ohio State in 1996, and MS and PhD in Engineering from Brown University in 1998 and 2001, respectively, with a major in materials science and minor in mechanics. Her thesis topic was related to the deformation behavior of composites for ballistic applications. In August 2001 she joined the Department of Mechanical Science and Engineering at the University of Illinois as Research Faculty and joined as tenure-track faculty in May of 2005 where she now works in the area of bone tissue engineering. She received the Alice L. Jee Memorial Award at the Sun Valley Workshop on Skeletal Tissue Biology in 2008 and an Honorable Mention for the 2009 Early Career Faculty Fellow from the Minerals, Metals, and Materials Society. She has affiliations with the Beckman Institute for Advanced Science and Technology, the Institute for Genomic Biology, the Department of Materials Science and Engineering, and the Department of Bioengineering at UIUC.

Dr. Lin Wei obtained his B.Sc. degree from University College London, UK in 1985, and the M.Sc. and Ph.D. degrees from University of Florida, in 1988 and 1992, respectively, all in mechanical engineering. He has been with the Singapore Institute of Manufacturing Technology since 1992 and now is a Senior Scientist with the Mechatronics Group. Dr. Lin currently serves as an Adjunct Associate Professor at both National University of Singapore and Nanyang Technological University, Singapore. His current research interests include large scale ultra-precision systems, and multi-scale manufacturing systems control and sensing.

Dr. Tay Bee Yen graduated with Bachelor in Engineering (Hon) and Masters of Engineering from the National University of Singapore (NUS) and Nanyang Technological University, respectively. Subsequently, she obtained her PhD in freeforming of ceramic by ink-jet printing from the Queen Mary College, University of London, UK in 2001. Since 2001 (after re-joining SIMTech), she has been conducting research in powder associated processing technologies for engineering metal and ceramic with different level of porosity from high porous to nearly full dense. She is a Research Scientist in SIMTech. Current research topics include nanostructured porous ceramic, micro powder injection moulding, processing of nanoparticle and manufacturing of large, dense ceramic frame.