CAREER: Optically Transparent Gripper for Microassembly

J, BERTING, E. T. ENIKOV, V.GLOWACKA, and E.WHITE
University of Arizona, Aerospace and Mechanical Engineering Dept., Tucson, AZ 85721, USA. E-mail: enikov@engr.arizona.edu

ABSTRACT: A guest researcher at the Budapest University of Technology and Economics is developing hardware and methods to use the PIC16F684 microcontroller for use in data acquisition. This application aims to replace expensive data acquisition equipment, like the oscilloscope, with an economically priced component kit that can be used for student laboratory experiments. The PIC16F684 has already been implemented in a control systems experiment for college students.

INTRODUCTION (LIMIT: 1 PAGE)

Although MEMS devices are usually fabricated via massively parallel photolithographic techniques, sequential assembly is required in some instances. For example, heterogeneous integration for vertical cavity surface emitting lasers (VCSELs) with silicon-based CMOS circuitry requires placement of the laser die onto a silicon substrate containing the electronic circuitry. Further applications include the assembly of dense arrays of high aspect-ratio structures, such as IC probe cards or light-emitting diodes, in display applications. These assembly and packaging operations are costly and usually constitute the largest portion of the device's total cost. In order to increase the manufacturing throughput and reduce the re-tooling costs, it is desirable to develop flexible assembly schemes, allowing for quick adaptation to various part geometries and configurations. Therefore, the objective of this CAREER award is to develop new micro-assembly tools based on electrostatic gripping and manipulation that will allow more efficient manipulation of parts at the sub-millimeter scale.

Our work on this project produced a variety of gripping and manipulation devices based on transparent glass substrates and electrodes (see Fig 1.) Successful assembly of micro-electrodes under optical feedback was also demonstrated; however, the broad application of this technology is hampered by the strong presence of surface forces such as capillary condensation, van-der Waals, and residual electrostatic charges. Measurement and analysis of these forces have shown that full utilization of the self-aligning properties of

the electrostatic gripper and improvement of its part-release capability are only possible through the use of some sort of active excitation technique. In this project we have utilized an acoustic excitation as a means to levitate the part and allow it to self-align to its desired position.

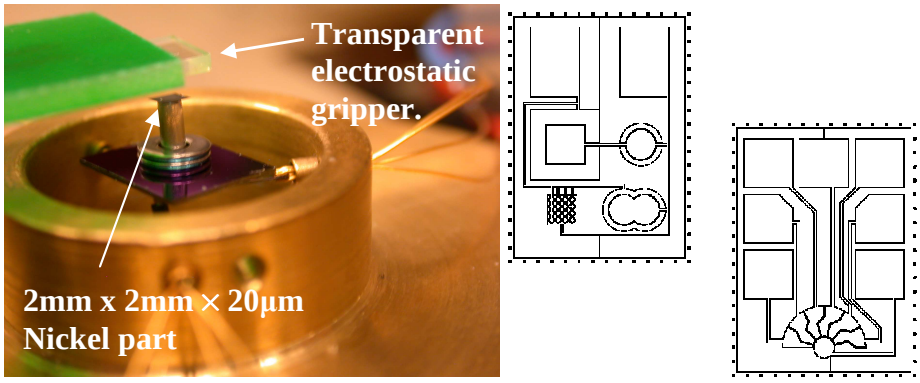

Figure 1. Gripping experiment using a custom-built force/torque cell (left); and variety of self-aligning electrode patterns (right).

Experiments under different initial conditions, however, have produced significantly different behavior, leading sometimes to repelling the part from the surface of the gripper. Analysis of the possible causes of this phenomenon include the non-linear dynamics of the part-gripper interaction, and the so-called acoustic streaming effect, which is a second-order effect due to the interaction of the solid surface and the effect first analyzed by Nyborg [1]. Using acoustic fields, it is possible to achieve part levitation [2], thus reducing the strong capillary adhesion forces. Therefore, the primary scientific-objective of this international collaboration is to develop a numerical model of the part-gripper interaction including the force and acoustic non-linearity. The work is conducted jointly by US and Hungarian researchers, with the US group providing the experimental data and measurement tools and the Hungarian group assisting in the development of a numerical model describing the phenomenon. Further objectives of the project are to develop joint curriculum on MEMS and mechatronics and to disseminate it at a suitable European venues, including the 2007 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, Zurich, Switzerland.

The history of the Department of Applied Mechanics (http://www.mm.bme.hu/mm_en/) can be traced back to 1782, when the first courses in mechanics were taught there in Latin. At that time, the department was called Institutum Geometricum-Hydrotechnicum (IGH), which later became Department of Mechanics and Machines (1857). Subsequently, Béla Bresztovszky (1914-1941) established the Applied Mechanics Department. After the destructive impact of World War II, the department was restored under the leadership of professor Ádám Muttnyánszky, who also wrote the classical textbooks on Statics (1951), Strength of Materials (1956), and Kinematics and Kinetics (1957). In 1953, the modern era of this department was ushered in by Prof. Endre Reuss, one of the founders of modern plasticity and co-author of the Prandtl-Reuss theory. He worked in this institution until 1967. His successor, Prof, Gyula Béda (1971-1995), introduced new subjects (continuum mechanics, analytical mechanics) in the curriculum.

Currently, the department is headed by Prof. Stépán, whose research is focused on non-linear dynamics and time-delayed systems. Currently, the department has 21 professors, 4 support engineers, and a growing graduate program consisting of 7 PhD students. Research in the department is focused in seven different areas:

- Nonlinear dynamics (Stépán, Szabó Zs., Csernák, Insperger, Wohlfart);
- Machine tool vibrations, stability of motions (Stépán, Szabó Zs., Insperger);
- Differential equations (Stépán, Szabó Zs., Csernák, Insperger);
- Continuum mechanics, Plasticity (Béda, Szabó L.);
- Thermo-mechanics (Szekeres);
- Polymers, composites (Uj); and
- Structural mechanics (Vörös, Kovács).

The following researchers took part in this IREE project:

Vincent Glowacka, graduate student, University of Arizona, travelled from 8/22/07 through 01/12/08. Mr. Glowacka is implementing a variety of MEMS and mechatronics teaching modules including a control systems student experiment, and a vibrations experiment for students based on microcontrollers.

Jesse Bertin, undergraduate student, University of Arizona, travelled from 08/22/07 thorough 01/12/08. Mr. Bertin is working towards development a numerical simulation model of the part-gripper interaction.

Edward White, graduate student, University of Arizona, travelled 9/01/07 through 9/08/07. Mr. White presented the results of self-aligning studies of the gripper and a hands-on module on MEMS education at the 2007 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, Zurich, Switzerland.

Eniko T. Enikov, Associate Professor, University of Arizona, travelled 08/12/07-01/03/08. Dr. Enikov developed a student exchange program between Budapest University of Technology and Economics (BUTE) and the University of Arizona, he presented the results of this project at the 2007 International Conference on Engineering Education (ICEE) in Coimbra, Portugal, delivered a short course on MEMS and mechatronics, and participated in the research of his students in conducting the research at BUTE.

RESEARCH ACTIVITIES AND ACCOMPLISHMENTS OF THE INTERNATIONAL COOPERATION (LIMIT: 1-1/2 PAGES)

Development of a numerical model of part-gripper interaction (J. Bertin)

While at the Budapest University of Technology and Economics Mr. Bertin has been developing a computer program to model the vibration of a micro-component on the surface of an electrostatic gripper. During experiments performed at the University of Arizona, micro-components vibrating on the surface of the electrostatic gripper have exhibited both stable and unstable behavior. Because of this a method is needed to determine what characteristics will force the gripper system to become unstable. While in Hungary Mr. Bertin has created a two-dimensional computer model in MatLab which takes into account the dynamics of rigid body motion, force conditions acting on the micro-component, and material properties of the vibrating system. He is currently in the process of verifying the model by performing simulations and comparing it to data collected at the University of Arizona. Once the accuracy of the computer model has been established the identification of critical characteristics will be made possible by running the simulation for different initial conditions. Figures 1 and 2 are examples of the types of results gained by inputting different initial conditions into the current two dimensional model.

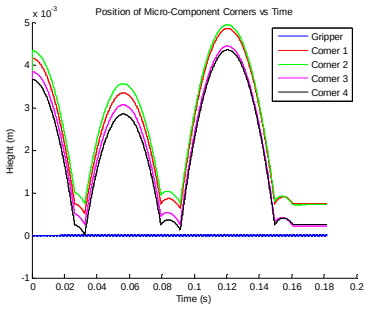

Figure 2

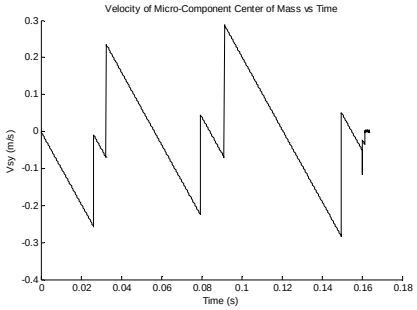

Figure 3

While performing his research Mr. Bertin has had the opportunity to work with members of the Budapest University of Technology and economics faculty and a few graduate students. He has received one on one instruction on rigid body dynamics and collisions, had access to technical papers authored by Budapest University of Technology and Economics faculty on the subject impact physics, attended special lectures on vibration dynamics given by Budapest University of Technology faculty, and learned about potential research projects for future exchange students by learning about the research being performed by Budapest University of Technology and Economics graduate students. Before leaving the Budapest University of Technology and Economics Mr. Bertin will also be working to expand this program into a three dimensional model and eventually to a model allowing the full six degrees of motion.

Development and demonstration of laboratory modules on MEMS and mechatronics (V. Glowacka)

Typically, the hardware used to acquire data for student and laboratory experiments is expensive, ranging anywhere from 800-2000 dollars. This is cost prohibitive to many institutions, especially in developing parts of the world, and therefore valuable student experiments cannot be performed. To solve this problem, PIC microcontrollers can provide an economical alternative to expensive data acquisition hardware since a 15 dollar component kit can provide similar capabilities.

So far, a student experiment for a control systems engineering course has been built and demonstrated. The student experiment kit includes a breadboard, computer serial cable, motor and potentiometer assembly, and a package of electronic components. With these items, the student can build the project at home, and collect the relevant data using MATLAB on their personal computer. The motivation behind this project is to inspire and encourage BUTE students to participate in this research project. Local students will provide invaluable insight into the development of the student laboratory experiments, and they will learn the skills necessary to carry on the project ends on January 8, 2008.
The specific goal of this project is to develop a PIC electronics kit to allow BUTE students to perform previously inaccessible experiments for their courses. Already, a preliminary PIC-based control systems experiment has been built and demonstrated. The setup uses a closed loop analog control circuit that is designed to use a motor to set one potentiometer to the position of a second reference potentiometer. The data acquisition circuit uses a PIC16F684 microcontroller to read and digitize the voltages of each potentiometer. The binary result is sent using the RS-232 protocol to a laptop where MATLAB is used to collect the data. This setup is shown in Figure 4.

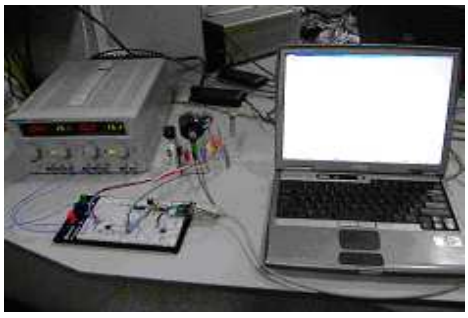

Figure 4. Student Control Systems Experiment using PIC microcontroller

The host laboratory has been very accommodating for this project, providing all necessary space and equipment. Several demonstrations of the project have also been performed for the local researchers. Additionally, an Estonian and a Czech student have been involved in the construction of the project.

Visit to the Institute of Robotics and Intelligent Systems (IRIS) and presentation at the Advanced Intelligent Mechatronics 2007 Conference (E. White).

This task presented the work conducted at the University of Arizona at the conference on Advanced Intelligent Mechatronics (AIM 2007) in Zurich, Switzerland in September of 2007. During the travel to this presentation, E.White had the opportunity to discuss the research with the personnel of IRIS, and evaluate possible cooperation between the two labs in the future. Given IRIS's experience in the field of microassembly, they have both the expertise and equipment to support future work in this area. During the visit to IRIS, we discussed the current state of this research, including a review of the paper as presented at the conference, as well as an in-depth discussion as to how additional information could be collected to aid in future modeling and analysis. As a result of that discussion, we have determined processes and facilities which could be utilized at IRIS in support of the work underway at the University of Arizona. Given the high frequency of the part movement (<30kHz) and small displacements expected (~10 um), laser vibrometers at IRIS could be utilized to enhance the current understand of part motion through 3-dimentional space (with 6 measured coordinates including rotations of the part). This experimental data would be used in conjunction with current research at the University of Arizona, which is aimed at mapping the electrostatic fields around charged grippers through measurements of forces exerted on test parts. These two sets of measurements, in turn, will be used in conjunction with finite element modeling of the electric field to create a more complete picture of electrostatic alignment than is currently available in the literature.

BROADER IMPACTS OF THE INTERNATIONAL TRAVEL

The main impact of this IREE award has been on the graduate and udregraduate students participating in the project. Inspired by the positive effect this experience has had on them, the PI has arranged a long-term student and researcher exchange agreement with BUTE (signed) and ETH, Zurich (under negotiations). While the long-term results of this project are not yet available, the following statements from each of the participating students summarizes their experience from the project.

Vince Glowacka

Performing research in a foreign country like Hungary is vastly different from research at the University of Arizona. Differences in the language, culture, and attitudes provide a catalyst for personal and professional growth. Furthermore, living among students from different countries allows one to compare their own skills to foreign educated engineers.

From a personal standpoint, this experience has made me more aware of the rest of the world and more understanding of foreign people's customs and beliefs. The opportunity to socialize with other international students studying at BUTE has exposed me to a diverse set of beliefs, culture and attitudes. Through my conversations with these students, it has made me aware of some of the things the rest of the world is concerned about and why some people feel the way they do about world events. It has allowed me a way to compare my beliefs with those of others and see things with new eyes. Most

importantly, I have also realized how much I have in common with people from different parts of the world.

The student organization has also organized trips and events that have allowed me to explore local and nearby cultures. So far, I have traveled to three different parts of Hungary with local students who knew the area, and I have journeyed to Poland and the Czech Republic. We visited historical landmarks, museums and participated in Hungarian festivals. The organization also organized an event that taught the international students Hungarian folk dancing, history, music and cuisine. All of the trips and events were enjoyable and have deepened my understanding and appreciation of the Hungarian people.

Taking classes at BUTE has given me a more academic perspective on foreign students. Through conversations with my classmates, I have learned about the European education system and how it contrasts with American universities. Through homework assignments and projects, I had the chance to compare my skills against my European counterparts. Furthermore, graduate students have discussed their master's theses with me. This knowledge has shown me what I need to work on to make myself more competitive in the global economy.

As discussed earlier, one of the goals of this research project is to recruit foreign students to work on research projects that have a complementary element at the University of Arizona. This would create a common thread between the two institutions and allow them to cooperate on the same research projects, and also allow Hungarian students to study in Arizona and vice versa. The arrangement would be mutually beneficial since it would give Hungarian students, who are more skilled in theoretical aspects of engineering, a chance to learn practical skills. Likewise, American students could benefit from the more theoretical Hungarian curriculum.

Jesse Bertin

While studying at the Budapest University of Technology and Economics I have been given opportunities to interact with and learn about other cultures in ways which would not have been possible in the United States. I have had the privilege of becoming friends with students from countries such as Estonia, France, Cyprus, Finland, Spain and Hungary to name a few. I have traveled to different parts of Hungary, the Czech Republic, and Poland. And I have been able to visit cultural and historical sites in Budapest. Including; The Budapest Museum of Fine Art, the Roman village of Aquincium and the Budapest Museum of History. These experiences have exposed me to different views about life, politics, religion, education. Living in a foreign country and not speaking the local language has forced me to become more self-reliant and taught me how to work around language barriers and cultural differences.

Academically speaking, by going to the Budapest University of Technology and Economics, as opposed to simply communicating through emails or conferences, University of Arizona has been able to establish a personal relationship with members of the Budapest University of Technology and Economics. It has created a better understanding of each other's research while fostering intellectual inspiration which can only be achieved by day to day interaction. While at the Budapest University of Technology and Economics I have had the opportunity to speak with graduate students

about their research and I am currently exploring ways in which those programs might be brought back to the University of Arizona. Because I share the same office as those graduate students I get to see on a daily basis what it is that they do, not just read a technical paper about what they have already accomplished.

Edward White

Prior to the paper presentation part of the AIM conference, a full-day workshop was held which focused on mechatronics in higher education. The visiting researcher was able to attend this workshop, as well as host a demonstration of a low-cost MEMS sensor experiment. This opportunity expanded the value of the travel significantly, since the researcher was able to interact with educators from around the world, and learn about methods for bringing research into the classroom. This experience is extremely relevant to work currently on-going at the University of Arizona, where researchers from the Advanced Microsystems Laboratory are working to incorporate research into the laboratory section of upper-level undergraduate classes.

Completing the experience was the opportunity the visiting researcher had to explore Zurich, Switzerland. During the visit, the researcher was able to interact with locals in various settings. Already, he has had the opportunity to integrate his experience in Zurich into a report, greatly increasing the currency and relevancy of the material presented.

DISCUSSION AND SUMMARY

This IREE award has allowed the PI and his students to establish new collaboration with one of the top schools in Eastern Europe. The research and teaching activities undertaken under this grant has served as a catalyst to the creating of a 5-year student and researcher exchange program between the two schools. The project has had a tremendous impact on the personal development of the participating students, in particularly in demonstrating to them the value and personal satisfaction one can gain from a research project. It has inspired them to pursue graduate work (J. Bertin).

Several improvements that could result in better integration of the two partners could be considered for future IREE awards. These include matching funds from ERASMUS Atlantis, a joint program between EU and US Department of Education. Availability of such funds will allow NSF grantees to better engage their hosts in a joint research project, as often teaching duties at the host institution detract the local research assistants from fully committing to a foreign project. Alternatively, NSF should consider implementing its own version of the ERASMUS Atlantis program through its directorates in Europe and Japan.

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Profs. Stepan, Margit from the Department of Applied Mechanics as the Budapest University of Technology Economics.

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BRIEF BIOGRAPHIES OF RESEARCHERS

Vincent Glowacka has held a BS in mechanical engineering from the University of Arizona since May 2007. Prior to his NSF award to conduct research in Budapest, he has worked in the Advanced Microsystems Laboratory at the University of Arizona.

Jesse Bertin is an undergraduate student pursuing degrees in Mechanical and Aerospace Engineering at the University of Arizona. He will be graduating in May of 2008 and is planning on pursuing a Master's Degree in Mechanical Engineering after graduation. He has performed research in the Advanced Heat Transfer Laboratory at the University of Arizona and worked as an Aerospace Engineering Intern at Sargent Controls and Aerospace. He has been working in the Advanced Microsystems Laboratory at the University of Arizona since May of 2007.

Edward L. White is a M.S. student in the Mechanical Engineering department at the University of Arizona. He graduated from the University of Arizona with undergraduate degrees in mechanical and aerospace engineering. In addition to the M.S. in mechanical engineering he is pursuing his MBA from the Eller College of Management.

Eniko T. Enikov received his M.S. degree from Technical University of Budapest in 1993 and Ph.D. degree from University of Illinois at Chicago in 1998. As a Postdoctoral Associate at University of Minnesota, Dr. Enikov has Associate Professor at the Aerospace and Mechanical Engineering Department at the University of Arizona. His current research is focused on the design and fabrication of micro-electromechanical systems (MEMS), the development of theoretical models of active actuator materials used in MEMS and development of relevant applications of these. Dr. Enikov's group at the University of Arizona has an ongoing research and development program on tactile displays, electrostatic micro-grippers for assembly of MEMS, and nano-assembly of macro-molecules using electrostatics.