

# **Spiderbot: an example of synergy between University, Industry and Government to strengthen research and engineering education**

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## **ABSTRACT**

This paper summarizes the experience of creating a multidisciplinary research group on microelectronics and microsystems at Instituto Tecnológico de Costa Rica involving professors and undergraduate students with seed capital from industry and government to start the first microrobotics project of our Costa Rica, the Spiderbot Project, with the goal of creating a new field of high technology research at our university and introduce students to these fields in a multidisciplinary, participative and hands-on approach by involving them in the research as a complementary way of learning. Students learn through voluntary participation in research, outreach and training, in contrast with traditional approaches relying only in inclusion of new courses in the engineering curricula. With this approach, students develop both technical and soft skills, learn to research, and gain the ability to communicate technology to technical and non-technical audiences. The results of this approach to enhance the experience of studying engineering are discussed.

**Keywords:** microelectronics, microelectromechanical systems, engineering education, microrobotics

## **1. INTRODUCTION**

Undergraduate engineering curricula usually do not provide much freedom to introduce complementary topics. Most of the time cutting-edge engineering topics are left aside from the lectures, or included in the form of bibliographical research to the students. In many curricula, special topics are included in the form of elective lectures for advanced students and targeted to very specific engineering disciplines. This hinders interaction between students from different engineering majors, leading to a way of learning contrary to the global tendency of creating multidisciplinary research and development teams.

In complex and quickly varying knowledge fields such as microelectromechanical system design, undergraduate students hardly become a chance to participate in the knowledge generation process achieved by research. We are convinced that preparing the human resources of the future relies on the early finding of talented students and their opportunity to grow at the professional level by getting access to research in parallel to their engineering major and opening spaces to develop their soft skills. Involving students in research groups complements the activities carried out by professors and also provides the students adequate conditions this way of learning.

We present here our experience of integrating undergraduate students in teaching, research and outreach activities related to a research project on miniaturized robots. In contrast with traditional approaches relying only in inclusion of new courses in the engineering curricula, our experience demonstrates that with this new approach students gain technical knowledge, develop both technical and soft skills, learn to research, and gain the ability to communicate technology to technical and non-technical audiences.

## **2. RELATIONSHIP BETWEEN UNIVERSITY, INDUSTRY AND GOVERNMENT TAKEN TO THE NEXT LEVEL: SEED CAPITAL FOR RESEARCH**

Since its establishment in our country, Intel has supported and encouraged high tech research and development. The partnership between Intel and our university started with curricula consulting, donations and student internships. The financial support to research and development at our university is aiming to take the partnership to the next level: creation of intellectual property and creation of proprietary solutions for industry. To start this new level of cooperation, Intel has funded research projects at the Electronics Engineering School (EES). One successful example of cooperation was the design and fabrication of the first integrated circuit 100% designed by national engineers, where three of the four designers who participated in the design and tape out were lecturers of the EES at our university. After that successful experience, Intel was willing to increase the critical mass of researchers in micro and nanotechnologies, as well as microelectronics.

With that goal in mind, they sponsored our university with a seed capital to start a research project in the field of miniaturized autonomous robots, as a way to encourage high technology research at our university, which traditionally carried out most of its research in the fields of agriculture, forestry, chemistry and biology. In addition to that, they explicitly mentioned their interest of creating a critical mass of researchers at our university in the fields of microelectronics, micro and nanotechnology. This gave rise to the creation of the research project called “Spiderbot”, dealing with the design and implementation of a miniaturized robot for failure analysis of integrated circuits. After starting the project, the project proposal was submitted to the Ministry of Science and Technology (MICIT), where it obtained financial support from the government. Financial support from the project from Intel and MICIT permitted to obtain laboratory equipment, research scholarships for the students, consumables, chemicals, materials, components and software licenses for the project, setting the base for the research group.

## **3. IMPACT OF THE PROJECT AT THE UNIVERSITY**

The project contributed to the creation of a multidisciplinary group of faculty members with research interests in microelectronics and microsystems. Twelve faculty members from the Electronics Engineering, Physics, Computer Science and Materials Science and Engineering Schools have participated in the project. Furthermore, their research activities in the project are supported by students carrying out their graduation projects, directed projects, lab projects or as assistant students. Up to now, the research activities have included students from Electronics Engineering, Computer Science, Computer Engineering and Materials Science and Engineering.

From January 2008 up to now, undergraduate students have participated in the Spiderbot project carrying out 19 capstone projects and 3 lab course projects, representing a participation of 24 students. In addition to that, other 19 students have participated as research assistants.

The project has provided the students the opportunity of putting into practice their knowledge of integrated circuit design and microcontroller architecture, following the front to back design flow for digital and analog circuits at the Integrated Circuit Design Laboratory donated by Intel to the EES. Integrated circuit design was already incorporated in lectures and lab courses at the Electronics Engineering School taking advantage of this laboratory. Moreover, students they have been introduced to MEMS (microelectromechanical systems) by carrying out

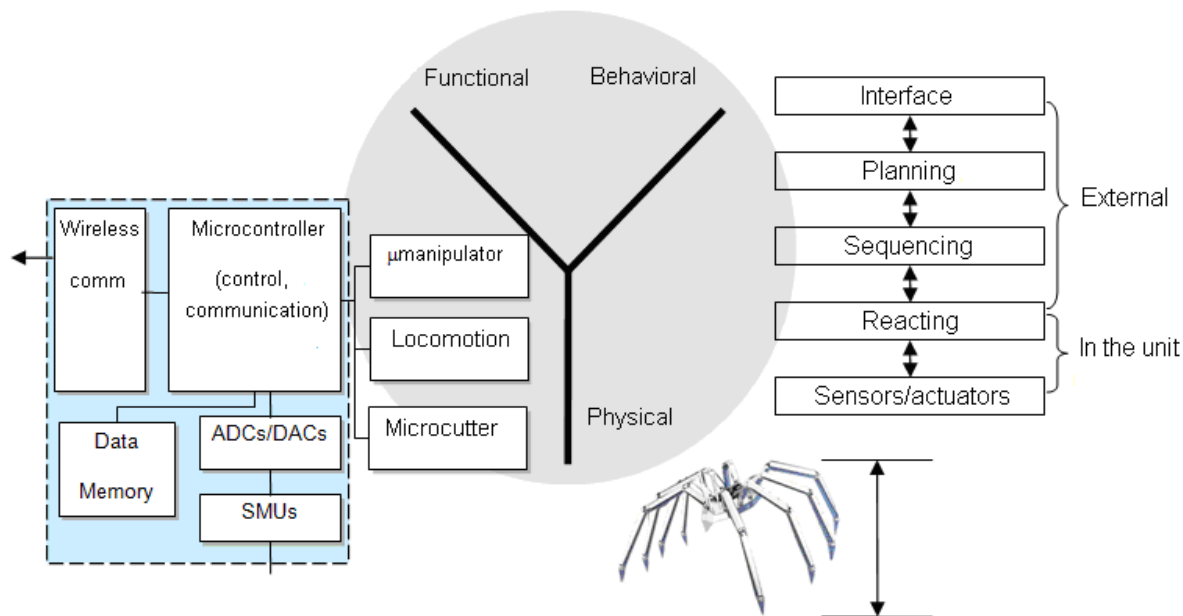
MEMS evaluation and design, exercising their knowledge in physics and numerical methods at the Modelling and Simulation Lab donated by Intel to the Materials Science and Engineering School.

This experience, the demand of industry and the creation of a Nanotechnology Research Program for micro and nanotechnologies at our university set the basis to propose three majors of the Master's Program in Electronics: Microelectromechanical Systems, VLSI Design and Embedded Systems, to start in 2012.

The Spiderbot Project is the first project on microrobotics in the country. The project is part of the Nanotechnology Research Program, the only research program in the country devoted to nanotechnology. Other universities have carried isolated initiatives in nanoscience.

#### 4. ENHANCING THE CURRICULA THROUGH RESEARCH ASSISTANTS STUDENTS

The implementation of Spiderbot requires knowledge in hardware, software, MEMS and materials, since the functional, behavioral and physical architecture of the robot must be considered, as illustrated in figure 1. Students have participated in specific tasks of the project at different architectural levels according to their major, either in the form of capstone projects required to graduate or as research assistants.



**Figure 1: Architectural domains of Spiderbot [1]**

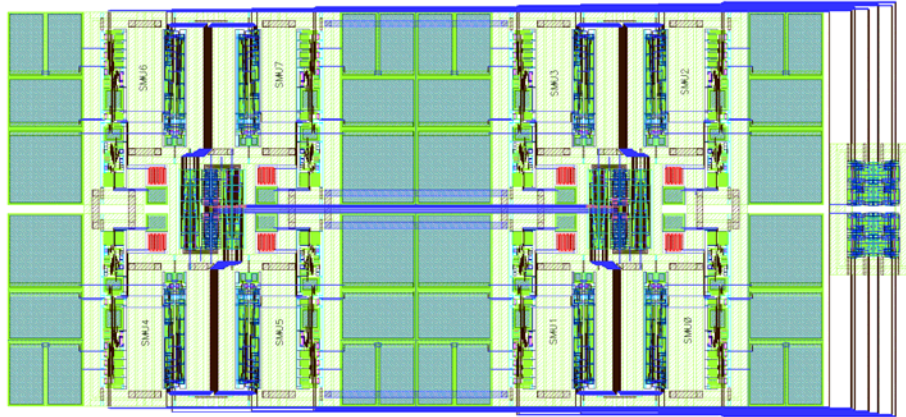
The following sections will address the technical and soft skills developed by our students during their participation in the project.

##### 4.1 DEVELOPMENT OF TECHNICAL SKILLS

Regarding hardware, Electronics Engineering students have participated building proof of concepts and prototypes at different levels.

Students were trained in analog and mixed signal integrated circuit front to back design flow, using Mentor Graphics® and Cadence Design Framework II®. Examples of these including data converters, amplifiers,

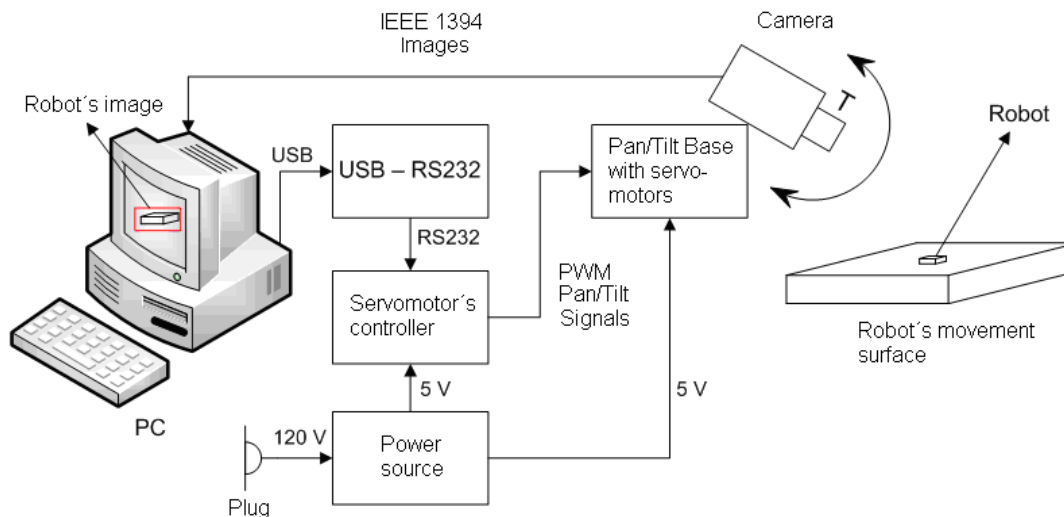
switched-capacitor systems, among others. They also learn and apply the digital integrated circuit front to back design flow, using Mentor Graphics®, Cadence Design Framework II®, Synopsys® and Verilog®. Starting from an open source Verilog® code for a microcontroller design, students simulated, tested and corrected the code, synthesized and followed all the digital flow down to the layout. With the design tasks assigned for the Spiderbot project students learn to design integrated circuits from its conception to its physical implementation in layout. Figure 2 presents an example of a layout of circuits designed by our students, after one year of training working in the project.



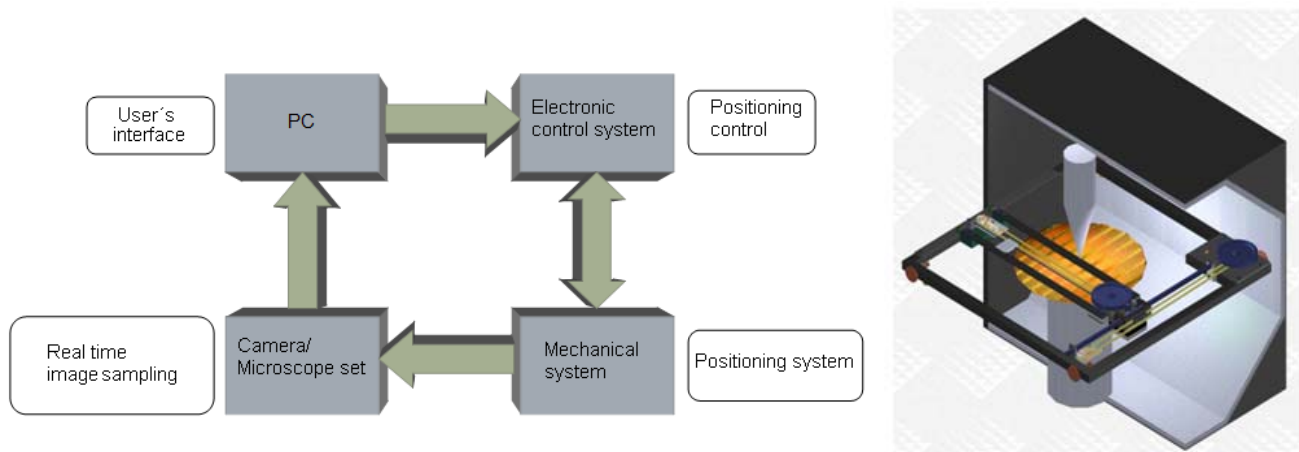
**Figure 2: Example of a layout created by our students as part of the Spiderbot project [2]**

In the field of image capture and processing systems to follow the minirobot, one of our students implemented the systems presented in the block diagram in figure 3. The system is based on color probability maps and the Mean Shift Tracker (MST) algorithm.

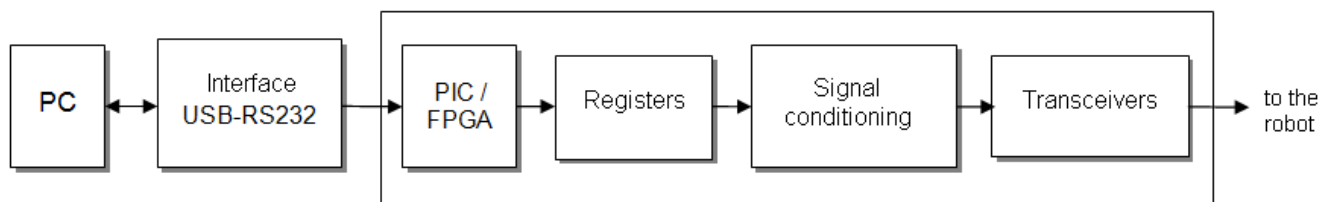
In addition to that, students developed hands-on in design, implementation and programming microcontroller-based systems, positioning systems, both self made x-y electromechanical positioning systems and programming piezoelectric-based precision positioning systems, and infrared communication. Figures 4 and 5 present block diagrams of the coarse positioning system of the robot and the infrared communication system.



**Figure 3: Block diagram of the image capture and processing system to follow the minirobot [3]**



**Figure 4: a) Block diagram of the coarse positioning system of the robot, b) conception of the positioning system inside the operating environment of the robot [4]**



**Figure 5: Block diagram of the infrared communication system designed for the robot [5]**

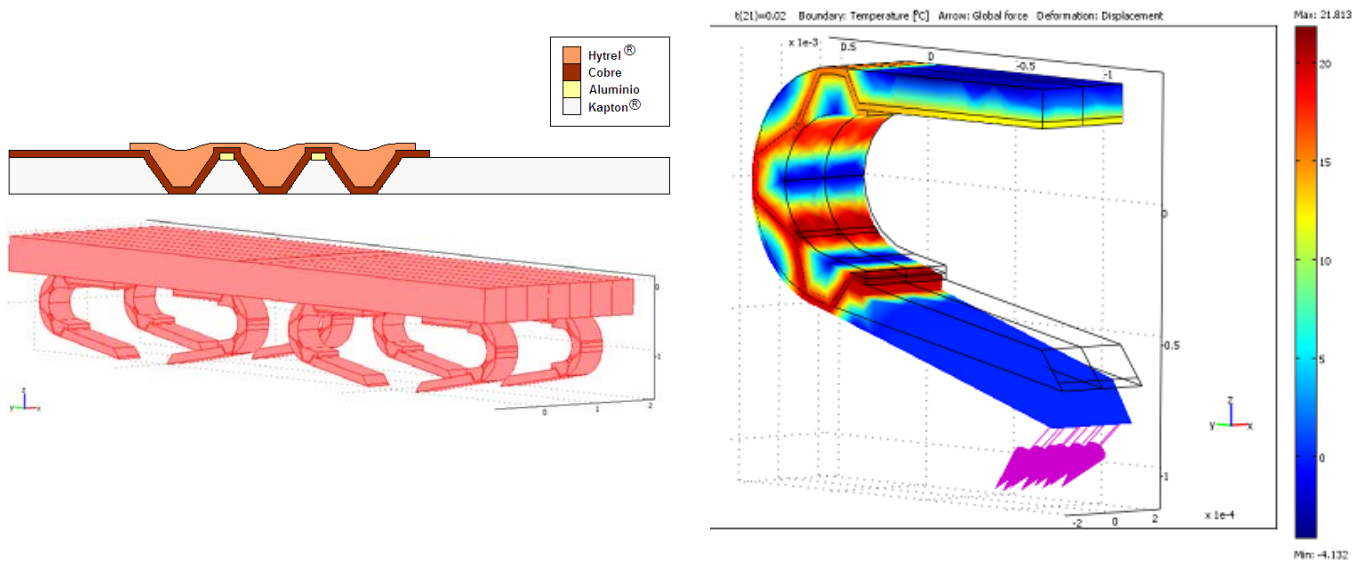
Spiderbot must be capable of autonomous locomotion, positioning and manipulation of objects. To expand its range of uses, the design of a microgripper is also considered. To perform these tasks, microelectromechanical actuators are required. In addition to provide functionality and small dimensions, the actuators must operate under low power, low voltage conditions, and a vacuum environment inside a scanning electron microscope (SEM) chamber, which imposes an additional constraint regarding the materials that can be used to fabricate the actuators, for instance, those requiring humid environments. Although literature documents many different approaches for MEMS locomotion and manipulation, low power and low voltage greatly restricts the applicability of the described actuators. For example, power consumption in the Watt range for most thermal actuators, or hundreds or thousands of Volts for piezoelectric actuators, whereas the highest operation voltage in Spiderbot is 3V, and the power consumption must be in the milliwatt range or less. With all these considerations in mind, MEMS design for Spiderbot is quite challenging.

Under the guidance of tutor professors from the Physics, Materials Science and Electronics Schools, students carried out their graduation projects in the field of MEMS design and simulation. With this, they gained knowledge of materials, numerical methods, finite element analysis, scaling of physical effects and multiphysics simulation using COMSOL Multiphysics®. Thermal, piezoelectric, electric and mechanical effects were taken into account in the simulations.

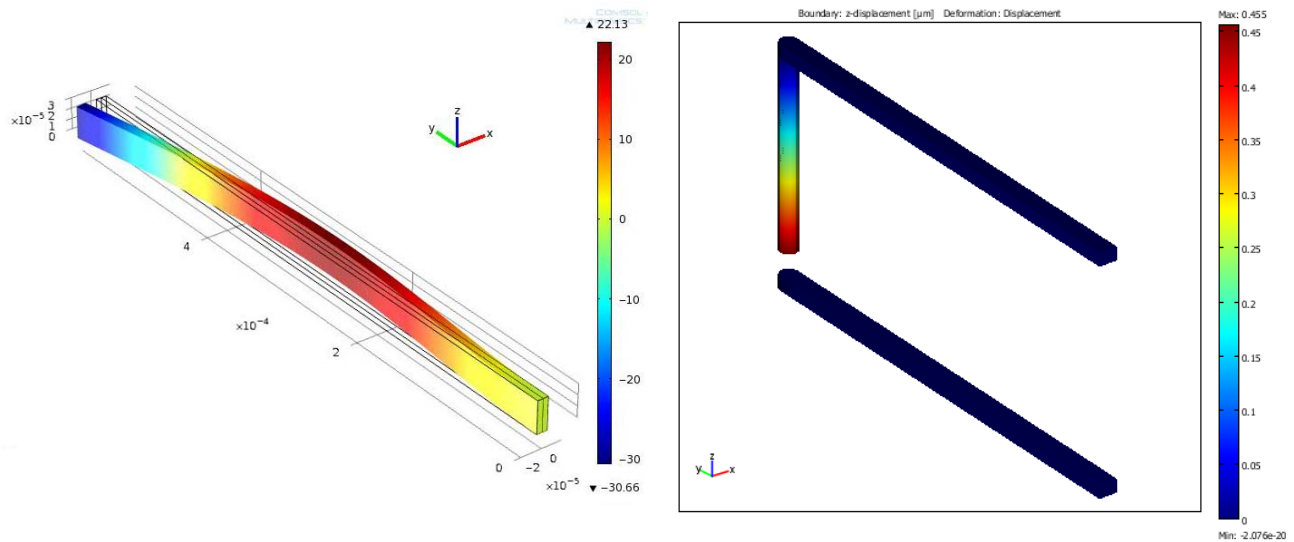
Among the most important results, a thermal based actuator for locomotion [6] was optimized to simplify its fabrication and decrease the cost [7]. Figure 6 presents a schematic cross section of the optimized actuator and the simulation for its function as extremity of the locomotion system of the robot.

Several actuators were also designed and simulated to achieve mechanical tasks for positioning and grasping objects. Bimorph, stack and Meander piezoelectric microactuators were studied to obtain operation parameters

such as deformation, force, power consumption mechanical stress and its behavior in resonance. Figures 7 and 8 present examples of the microactuators simulated by our students.



**Figure 6: Schematic cross section of the optimized actuator and the simulation for its function as extremity of the locomotion system of the robot [7]**



**Figure 7: a) Laminar bimorph piezoelectric microactuator operating in the second resonant frequency [8], b) piezoelectric stack in a microgripper [9].**

Students received also training and signed agreements on intellectual property and confidentiality, use of trademarks, copyright and intellectual property legislation at the university and national level.

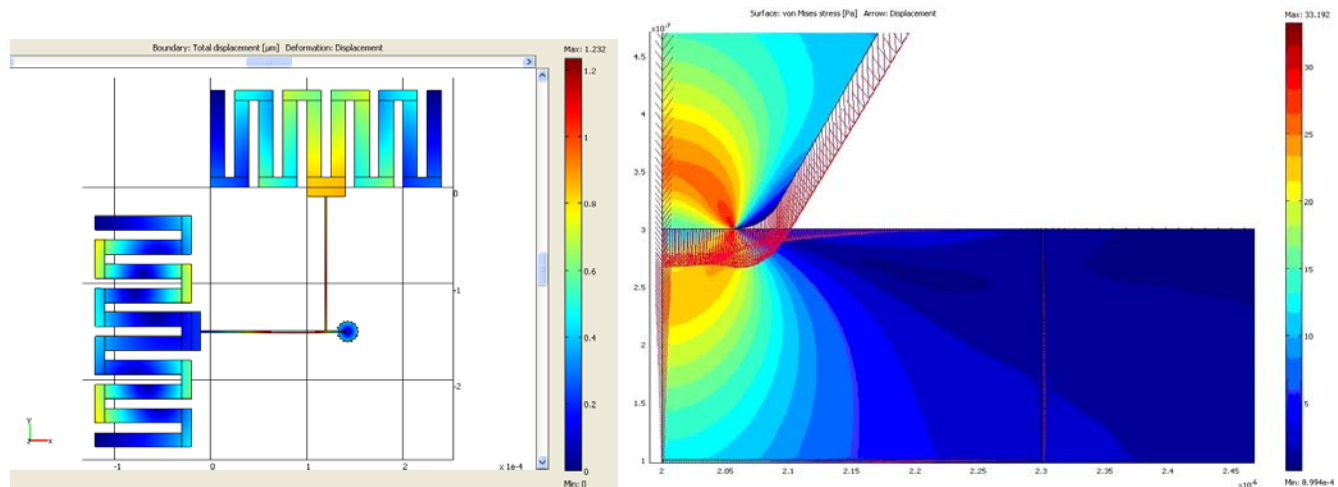
## 4.2 DEVELOPMENT OF SOFT SKILLS

In our experience, one of the most valuable soft skills students have learned from participating in the Spiderbot project is working in multidisciplinary environment. We found out that they were not used to discuss any technical topic with students from other careers. Before their experience in this project, students had only



worked in groups with students of the same career in the lab courses. Becoming part of a multidisciplinary design team helped them to build a common vocabulary, increased their sensitivity and ability to communicate with people out of their field of expertise, and learned basic concepts from other disciplines involved.

As part of the divulgation activities of the project, we organized exhibitions for students and professors, but also for the general public at a career fair and the open door day at the university, where also the press was invited. This interaction with technical and non-technical public greatly improved their communication skills. They developed a sense of explaining in simple, yet technically correct words, the purpose and implementation of their work and their role in the project.



**Figure 8: a) Two Meander actuators operating together to rotate a disc [10], b) von Mises stress and displacement of a microactuator pressing a surface [11]**

As professors, we tried to make students understand that their work was an important part of the Spiderbot project, and that we relied both in their work and ours to design the minirobot according to schedule. After these activities they were highly motivated to continue working in the project and learning more in the lectures. Some of them even expressed working on Spiderbot and being part of a larger team with a common goal and an interesting, advanced application, helped them getting back their motivation for studying engineering and helped them to confirm they chose the right career, even if they sometimes feel it's a hard field of study. They strengthen their compromise with the project and their studies, and felt highly motivated by training junior students, transmitting the status of their work and the use of software and hardware tools.

Students also were highly motivated by the culture of divulgation of research results by publications. When possible, intermediate research results were published when no intellectual property is compromised. They enriched their technical vocabulary in the topics related to the project and improved their technical writing skills by means of project proposals submitted for the capstone project, capstone project final reports, documents for reporting advances in the project, designing project posters and coauthoring publications. Students helped writing drafts of the main ideas of their part of the publication. Professors made content and style correction for the publications and determined the format, giving shape to the final version of the article and including the technical discussion. In this way, students learned to deal with publication formats and their corresponding writing styles.

In addition to this, as part of the research group, students have the following benefits:

- An undergraduate research assistant scholarship
- Laboratory training
- Certified research experience at the time of graduation
- Visibility at the university and the media

- Training in intellectual property, theoretical and practical
- Possibility to protect their own intellectual property authoring rights, according to the intellectual property regulations of the university
- Participation in seminars and conferences related to the research
- Contact with software tools for professional design and simulation

## 5. POSSIBLE APPLICATIONS OF SPIDERBOT

Spiderbot is an ambitious project, with a wide spectrum of potential applications in different disciplines. With the upcoming of microelectronics, nanotechnology and biotechnology, it became necessary to study and manipulate specimens with very small dimensions. In this sense, minirobots find industrial and scientific applications such as:

- Operations in dangerous environments
- Very high precision operations (micrometric and nanometric precision)
- Automatic micromanipulation, that is, automated obtaining and manipulating small sized samples
- Microassembly, that is, assembly of very small systems, such as MEMS assembly

By modifying or adding other type of actuators, Spiderbot as a whole or some of its parts can be useful in the fields of nanotechnology, biotechnology, microbiology, materials science and engineering, biomedical applications, microsurgery, microelectronics and MEMS.

Examples of tasks that could be implemented in future research projects after Spiderbot are cell manipulation, fluid injection and extraction, chemical and biological sensing applications in very small volumes, carbon nanotube characterization and manipulation, endoscopy for industrial inspection and minimally invasive surgery, in vitro fertilization for genetic research, among many others.

## 6. CONCLUSIONS

The fabrication methods, MEMS and IC design developed during the project established a platform for further research. More than a research project, the Spiderbot Project is the beginning of a long term vision for IC and MEMS design at our university. The experience generated in the project opens the possibility of national and international cooperation with universities, industry and government for medical, biotechnological among other possible application fields.

The students who participated in the project expressed their wish to work in these engineering fields, get research positions and continue studying towards a master or doctoral degree, which is not the case for many of the regular students graduating from our bachelor's program. They became part of the research team and worked together with classmates and professors for a common goal, instead of the traditional professor-student relationship. They felt more comfortable in communicating with the professor and learning from and with them. Students became more confident and their self-esteem improved, developed a sense of leadership and responsibility beyond passing a lecture. They took attitudes of self-learning, put into practice problem-solving skills, learning how to face a problem and think to solve it, improved their written and oral communication abilities. In addition to that, they obtained knowledge on intellectual property, electronics, mechanics, materials and programming in a multidisciplinary work environment. The experience gained in the Spiderbot Project was definitely of great value for the students and professors, providing a new way of interaction with the undergraduate students and an excellent complement to the traditional engineering education at the classroom. The results obtained so far in the research itself and the participating students set the basis to establish a permanent Student Branch for the Nanotechnology Research Program, to give opportunity to more students to become part of this experience.

At the research level, the project contributed to establish a MEMS design flow at our university, further develop



integrated circuit design, and create a multidisciplinary research team in microrobotics.

Future work for this project involves the establishment of a microfabrication flow in order to start the fabrication of the microelectromechanical actuators of the robot and implement the designed microactuators at smaller scale than the current prototypes, as a basis for implementation of other projects of the Nanotechnology Research Program.

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