Butterfly Haptics: A High-Tech Start-Up

Ralph L. Hollis, Butterfly Haptics, LLC, http://butterflyhaptics.com

There are many ways to contribute to the exciting and growing field of robotics. We all try to publish good papers and participate in conferences. A few of us also see a way to contribute by offering state-of-the-art products, which can be used as platforms for continuing research by the community. Our company, Butterfly Haptics, LLC, is one such company. We produce and sell high-performance haptic systems based on a magnetic levitation principle. The systems can be interfaced to virtual environments and remote real environments to provide high-fidelity touch interaction.

The Technology

Researchers have experimented with haptic devices for several decades. Fred Brooks and students at the University of North Carolina were early pioneers. Ken Salisbury and his student at the Massachusetts Institute of Technology (MIT) developed a haptic device that was commercialized as the Sensable Technologies PHANToM. This and its follow-up products are likely the most widely used haptic devices. In recent years, half-dozen companies have jumped into the haptic arena. All of these companies' devices are essentially lightweight back-driven robot arms, with either serial or parallel kinematics, ranging from two to six degrees of freedom (DOFs). Because they are robot mechanisms, they have links, joints, transmission elements, motors, and encoders. These elements are subject to wear and tear, link flexing, cable stretching, joint friction, backlash, and motor cogging effects, which together can interfere with the fidelity of haptic interaction.

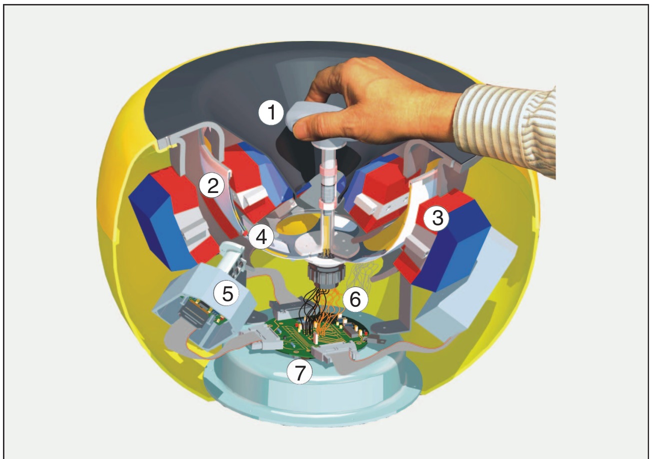

Figure 1. *Cutaway view of the Butterfly Haptics Maglev 200 device: 1) handle, 2) levitated flotor, 3) magnet assemblies, 4) LED beacons, 5) optical sensors, 6) flexible wires, and 7) interface.*

Digital Object Identifier 10.1109/MRA.2010.938835

We have taken a different approach based on principles of magnetic levitation. The user interacts with a handle rigidly connected to a hemispherical structure called a flotor that is freely levitated in magnetic fields. The handle with its flotor can be translated and rotated by the user in six DOFs within the work space. Optical sensors measure the position and orientation of the handle, providing input to the user's computer, while six coils embedded in the flotor interact with the fields of stationary permanent magnets through the Lorentz force to provide a force-torque wrench at the handle. The result is more than an order of magnitude improvement in performance compared with current electromechanical haptic devices.

How We Got There

Magnetic levitation haptic devices (Figure 1) seem pretty straightforward to us now, but looking back at their origins some 26 years ago, it was not quite so obvious. I was a researcher at the IBM Thomas J. Watson Research Center and had invented several two- and three-DOF robotic fine motion devices for use in automated assembly and testing. I wanted to create a full six-DOF device with reasonable motion range but was baffled by how to design the appropriate linkages. It occurred to me one evening that by combining recently introduced high-strength magnetic materials with position sensing optical diodes and the latest digital signal processing, one could eliminate all the mechanics and precisely control a freely floating body having but a single moving part.

Several years later with help from Peter Allan, a Duke University summer student intern, and controller design by Tim Salcudean, a new Ph.D. hire from Berkeley, we had a crude version working on the bench top using a collection of surplus power amplifiers and a US$9,000 digital signal processor plugged into an IBM PC/XT. In subsequent years, a refined version that could be attached to the terminal link of a robot was built and replicated as the IBM Magic Wrist. We were able to synthesize a number of compliant mechanisms for parts insertions and demonstrate its viability in coarse-fine robotic applications. We also interfaced it to an early scanning tunneling microscope to enable feeling of atomic-scale surface features in real time.

We soon began to realize that the operating principle of our devices, which we dubbed Lorentz levitation, could be applied to several other domains, including vibration isolation (particularly in space), haptic interaction with virtual environments, and teleoperation. Tim moved on to the University of British Columbia, where he continued to work with Lorentz levitation, and a few years later, I joined Carnegie Mellon University in Pittsburgh. Tim and his students built a system demonstrating teleoperation mediated by magnetic levitation, and working with the Canadian Space Agency and astronaut Bjarni Tryggvason helped to develop Lorentz levitation vibration isolation systems that were successfully operated for three years on the Russian Mir space station, and on the STS-85 shuttle mission.

At Carnegie Mellon, I was fortunate to receive National Science Foundation (NSF) funding to develop a large motion range haptic device for virtual environments. With Ph.D. student Peter Berkelman, a hemispherical design was completed and demonstrated in the late 1990s. We used this system for many years for psychophysical studies of haptic interaction with virtual textures, deformable objects, and in teleoperation experiments, again supported by NSF. These efforts were conducted with psychology professor Roberta Klatzy, Ph.D. student Bertram Unger, and master's student Vinithra Varadharajan.

Although we were able to demonstrate remarkably high performance attainable with magnetic levitation haptics, a major hindrance was the inability of other researchers to replicate and build upon our work since our's was the only system available. We set out to rectify this state of affairs when I received an NSF Major Research Instrumentation grant in 2005, allowing us to take our prototype's design, improve upon both the hardware and software, and make it manufacturable at a reasonable cost. We created ten of these systems, five of which were distributed to other researchers in the United States and

Calling all Entrepreneurs

The chasm between research prototype and released product is not easy to cross. While the first 90% of the work is hard, it's the second 90% that really gets you down. Those people who make it across, or even come close, provide case studies for *IEEE Robotics & Automation Magazine* readers considering the leap to the world of business.

Do you have a unique story that would enlighten other potential entrepreneurs? We're seeking not only entrepreneurs from the United States, where starting a small business is relatively easy, but also from other parts of the world where kitchen-table companies may be quite uncommon. Send a précis to admin@ram.ieee-ras.org

—Jeanne Dietsch, Adept and Mobile Robots, Inc.
RAS Industrial Activities Board

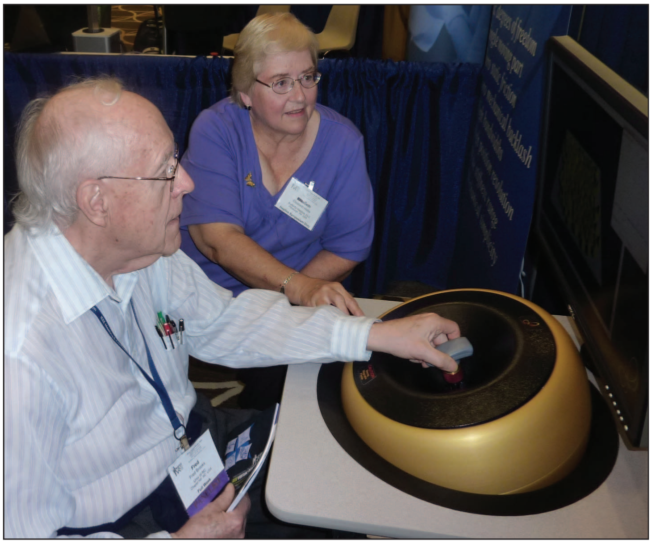

Figure 2. Butterfly Haptics President Beth Hollis demonstrating the system to Prof. Fred Brooks.

Canada. We were actually surprised at our proposal's reviews, which were highly supportive, but strongly suggested the results be commercialized.

Setting Up and Running Our Business

In 2007, I began to think seriously about creating a business around the technology. My main interest was, and continues to be, in getting the technology out into the world and into use. But, surely, I also did not want to lose money. I read many articles on starting high-tech businesses, consulted people in start-ups, talked with faculty in our business school, and even advised a team of students taking an entrepreneurial class. There seemed to be two main routes to go, which can be loosely described as going big and trying to raise money or going small and bootstrapping our way up. Since I wanted to continue doing robotics research as a professor, but still wanted to retain control, we decided to start small. My wife Beth has administrative experience in several small businesses and organizations and agreed to become president (Figure 2). She handles all financial and manufacturing oversight, while I act as a technical consultant. We have kept the company small by relying on a network of highly qualified contractors and service providers. From the beginning, Carnegie Mellon University was very helpful. We secured an exclusive license to the technology and received some start-up funding and help in getting additional funding from a local economic development organization. We also took out a sizeable bank loan, which we were able to repay in a short time.

Was it worth it? We worked very hard, especially during the first year which required another round of engineering enhancements, but currently things are running smoothly enough that it is a lot of fun and not so much effort. One of the keys to our efficiency is to have very complete documentation and specifications for everything we do. For example, our product relies on quite a few manufacturing processes, such as spin forming, vacuum forming, carbon fiber molding, plastic casting, chemical machining, five-axis milling and water jet cutting, and laser cutting, as well as more standard CNC milling and lathe operations, and circuit board and cable assembly. For nearly all of these operations, we are able to go directly from computer design to fabrication equipment via the Internet to minimize errors and keep the cost low.

Haptic interaction must be experienced first hand to understand its potential. Because of this, we have found it necessary to exhibit our systems at conferences. The logistics of doing this has been a bit frustrating at times, but on the other hand, we have very much enjoyed demonstrating maglev haptics and meeting many researchers. We are mindful that no matter how good the technology is, a good company must treat its customers fairly and provide a high level of service and support.

Outlook

Our product is positioned as a high-quality laboratory instrument that can be readily interfaced to other equipment or simulation software, which could benefit from having haptic interaction. Applications include haptic control of remote robot arms and vehicles, visualization of complex multidimensional data sets, medical and dental training, and micro- and nanomanipulation. Like other haptic devices, it is the classic solution looking for a problem. We believe there is no singular haptic technology that is appropriate for all applications, and there is ample room in the market for several different approaches. By virtue of its outstanding performance, it seems likely that turnkey applications will be developed for maglev haptics satisfying important needs. For example, my group at the Carnegie Mellon University Robotics Institute is pursuing applications in robotic bomb disposal, dental probing and drilling, and simulation of needle insertion. As for any radically new technology such as ours, it takes a community of users for it to be successfully adopted. To that end, Carnegie Mellon sponsors the Magnetic Levitation Haptic Consortium, which helps to support and provide a communication medium for a growing number of researchers. We are optimistic about the future of maglev haptics and hope this short article will provide some inspiration to others contemplating starting a high-tech business.