Overview of the Delta Haptic Device

Sébastien Grange, François Conti, Patrice Rouiller, Patrick Helmer, Dr. Charles Baur
Institut de Systèmes Robotiques
Ecole Polytechnique Fédérale de Lausanne
1015 Lausanne, Switzerland

Computing and machines keep getting more versatile, powerful and complex. This trend opens the door to a new level of interactivity between humans and computers. New applications bring together the human intelligence and the machine ability to carry complex tasks. The benefits of such symbiosis are safer, faster and more productive applications. However, fluent collaboration between man and machine require new tools that allow for a wider range of information to be exchanged. This encourages the development of force-feedback devices, which exploit the often under-estimated human sense of touch. This paper describes an overview of the Delta Haptic Device developed at the EPFL, which offers 6 active degree-of-freedom together with an outstanding mechanical behavior.

INTRODUCTION

The increasing need for enhanced human-computer interaction (HCI) is pushing for new interfaces that allow humans and machines to exchange a wider range of information. As a consequence, applications involving new interaction modalities such as machine vision and virtual reality are being developed. Among these new interfaces, haptic devices are promised a place of choice. Not only does haptic make difficult manipulation tasks possible or easier, it also opens the door to a wide range of new applications in the fields of simulation and assistance to human operators.

Numerous applications can benefit from haptic technology, ranging from teleoperation [2],[13] to nanomanipulation [6], as well as medical simulators and surgical aids [1]. Moreover, force-feedback devices are moving to the consumer market, and are invading the gaming industry as well as unexpected other areas such as automobile industry (BMW's new Z9 for instance).

The Virtual Reality and Active Interfaces (VRAI) Group at the Swiss Federal Institute of Technology (EPFL) is working on innovative haptic solutions combining state-of-the-art parallel mechanics with dedicated control electronics, which can be coupled with any application through a simple API.

RELATED RESEARCH

A significant research effort has been conducted towards the use of haptics in HCI ([5], [8], [11], [13]), or more specifically on what are the mechanical and control constraints that come into play when developing haptic devices ([7], [9], [10], [11], [14], [15]). A non exhaustive list that summarize some of the most important criterions in haptics is given below:

- the *mechanical system* should have low inertia, high stiffness with low friction (force threshold) and no backlash (mechanically induced force discontinuity).
- the force *actuators* should enable back-drivability, offer a high dynamic range, a sufficient maximum force, a sufficient force output resolution and a sufficient force and torque precision.
- the *position sensors* need to have a good position sensing resolution (depending on control loop refresh rate).
- *force sensors* should be added as close as possible to the human user. When well tuned, they greatly improve the overall system performance.
- the *local control loop* must have a high frequency (typically > 1kHz) to ensure (1) that vibrations are kept under a sensable level and (2) that control stability is achieved at the desired contact stiffness.
- the *global force interaction* low-frequency loop, typically linked to a graphical environment, needs to be as high as possible.

DEVICE DESCRIPTION

Our innovative high-end force-feedback system called the Delta Haptic Device meets the high standards required for industrial applications by combining high strength, high stiffness and high sensitivity. It is shown on Figure 1. This system is based on the patented Delta robotic structure [3], which provides three translational degree-of-freedom (DOFs). A dedicated mechanical wrist plug-in provides 3 rotational DOFs (shown in figure 1) and is based on the Paramat structure (figure 3). All of the DOFs are fully active and generate forces and torques that are way beyond the ability of currently available devices on the market. Dedicated electronics and signal processing provide the high-quality control required for credible force rendering. Figure 2 shows an overview of the control system.

Figure 1: Delta Haptic Device

The overall performance of such a haptic system is closely related to how convincingly the human sense of touch can be tricked. There are many functional components in a generic haptic device, which contribute to the overall system quality. They can be split in two main groups: the mechanical elements as shown in figure 2, and the control elements, shown in figure 4.

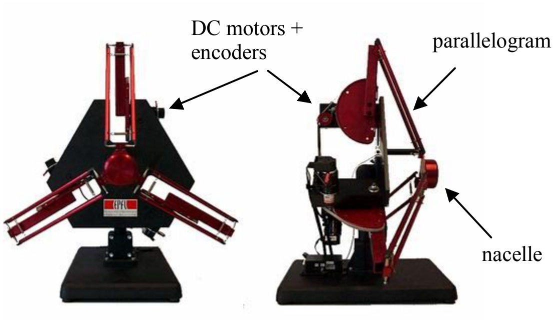

Figure 2: the DELTA structure

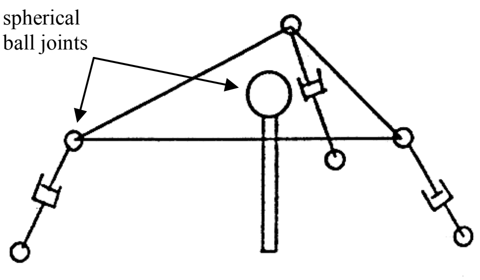

Figure 3 – the PARAMAT structure

The mechanical system displays very interesting properties, thanks to its parallel structure and robust components. The main advantages are:

- low inertia / light weight of the mobile parts
- high stiffness
- high force/torque
- large workspace
- no backlash

The design of our 6 DOFs system addresses most of the issues described above (see "Related Research"). The system specs are summarized in the following table:

TABLE I : system specs

Property	Value
workspace	cylinder Ø360mm x 200mm +/- 20° for each rotation
force	25N
torque	0.2 Nm
resolution	< 0.1 mm (translation) < 0.04° (rotation)

The controller described in figure 4 is responsible for two tasks: communication with the PC, and low-level safety. Its main purpose is to command the motor amplifiers and transmit the device position back to the PC. However, since the forces generated by the Maxon motors can be significant, low-level security features have been introduced, namely:

- *check speed velocity* of the nacelle. If the speed goes beyond a given threshold, the controller cuts the power to the device motors and electromagnetic brakes are applied
- *check structure position limits*. If the nacelle is set to an extreme position nearing the structure limits, power to the motors is cut to avoid shocks

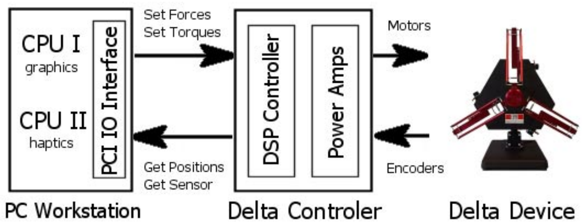

Figure 4: DHD control architecture overview

FUTURE WORK

We are currently working on integrating a force sensor into the nacelle of the Delta Haptic Device. The consequences of this modification are:

- lower friction/force
- lower inertia of the system

Preliminary results show a dramatic improvement of these characteristics.

Our research effort for the near future will lead to the development of plug-in haptic tools that will enhance the application range of the device. At the same time, the haptic device will be integrated in a generic human-computer interaction solution involving virtual reality and environment sensing in real-time. Several partnerships are being conducted, and a spin-off company (www.forcedimension.com) is currently being created that will deal with the commercialization of the Delta Haptic Device.

CONCLUSION

We have developed an innovative haptic device called the Delta Haptic Device that combines a parallel mechanic structure with dedicated electronic and software. Our device has 6 degrees-of-freedom and its technical specifications are beyond currently available haptic devices, in particular as far as workspace, force and torques are concerned.

Our research effort for the near future will lead to the development of plug-in haptic tools that will enhance the application range of the device. At the same time, the haptic device will be integrated in a generic human-computer interaction solution involving virtual reality and environment sensing in real-time.

Several partnerships are being conducted, and a spin-off company is currently being created that will deal with the commercialization of the Delta Haptic Device.

ACKNOWLEDGEMENT

We wish to thank the following people for their contribution to the system design, as well as their helpful expertise in the domain. R. Clavel, inventor of the Delta structure, L. Flückiger for developing and adapting the Delta Haptic Device at NASA Ames, and M. Frossard for writing control software for the Delta Haptic Device.

REFERENCES

[1] Baur C., Guzzoni D., and Georg O., "VIRGY, A Virtual Reality Force Feedback Based Endoscopic Surgery Simulator", *Proc. Medicine Meets Virtual Reality 6*, San Diego, CA, January 28-31, 1998 pp 110-116.

[2] Fong, T., Conti, F., Grange, S., and Baur, C., "Novel Intefaces for Remote Driving: Gesture, Haptic and PDA", SPIE 4195-33, *SPIE Telemanipulator and Telepresence Technologies VII*, Boston, MA, November 2000

[3] Clavel R., "Conception d'un robot parallèle rapide à 4 degrés de liberté " Thèse EPFL n°925, EPFL, 1991.

[5] Ruspini D., Kolarov K., Khatib O., "The Haptic Display of Complex Graphical Environments." *SIGGRAPH 97 Proceedings*, pp. 345-352, August 1997.

[6] Kulik A., "Nanomanipulation of carbon nanotubes", CTI Projet n°4941.1, 1999.

[7] Adelstein B. D., Rosen M. J., "Design and Implementation of a Force Reflecting Manipulandum for Manual Control Research", in Kazerooni H. (Ed.), *Advances in Robotics*, ASME, DSC-42, pp. 1-12, 1992.

[8] Srinivasan M. A., Chen J., "Human Performance in Controlling Normal Forces of Contact With Rigid Objects", in Kazerooni H., Colgate J. E., Adelstein B. D. (Eds.), *Advances in Robotics*, Mechatronics, and Haptic Interfaces, ASME, DSC-49, pp. 119-125, 1993.

[9] Rosenberg L. B., "How to Assess the Quality of Force-Feedback Systems", in Morgan K., Satava R., Sieburg H. B., Mattheus R., Christensen J. P. (Eds.), *Medicine Meets Virtual Reality - Interactive Technology and the New Paradigm for Healthcare*, IOS Press, Amsterdam, 1995.

[10] Tan H. Z., N. I. Durlach, Y. Shao, M. Wei, "Manual Resolution of Compliance When Work and Force Cues Are Minimized", in Kazerooni H., Colgate J. E., Adelstein B. D. (Eds.), *Advances in Robotics, Mechatronics, and Haptic Interfaces*, ASME, DSC-49, pp. 99-104, 1993.

[11] Jandura L., M. A. Srinivasan, "Experiments on Human Performance in Torque Discrimination and Control", in Radcliffe C. J. (Ed.), *Dynamic Systems and Control*, ASME, DSC-55, Vol.1, pp. 369-375, 1994.

[12] Tan H. Z., Pang X. D., Durlach N. I., "Manual Resolution of Length, Force, and Compliance", *Advances in Robotics*, ASME, Vol. 42, pp. 13-18, 1992.

[13] Tan H. Z., Srinivasan M. A., Eberman B., Cheng B., "Human Factors for the Design of Force Reflecting Haptic Interfaces", in Radcliffe C. J. (Ed.), *Dynamic Systems Control*, ASME, DSC-55, Vol. 1, pp. 353-359, 1994.

[14] Brooks T. L., "Telerobotic Response Requirements", *Proceedings IEEE International Conference on Systems, Man, and Cybernetics*, pp. 113-120, Los Angeles, CA, 1990.

[15] Shimoga K., "Finger Force and Touch Feedback Issues in Dexterous Telemanipulation", *Proceedings NASA-CIRSSE International Conference on Intelligent Robotic Systems for Space Exploration*, pp. 159-178, Greenbelt, MD, 1992.

[16] Shimoga K., "A Survey of Perceptual Feedback Issues in Dexterous Telemanipulation: Part I: Finger Touch Feedback", *Proceedings IEEE Virtual Reality Annual International Symposium*, pp. 263-270, Seattle, WA, 1993.