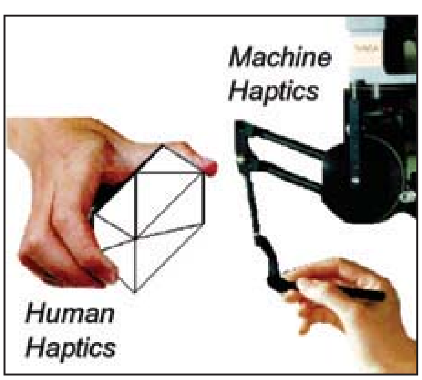
Haptics: Sense of Touch

The research activities in Robotics and Mechatronics Laboratory (RML) are mainly focused on investigating multi-modal sensory interactions between humans and machines. In particular, we are interested in human and machine haptics for real, virtual, and teleoperated worlds.

Çağatay Başdoğan

Although the other sensory modalities such as vision and audition have been investigated in detail, our most intimate sense, touch, has been somehow neglected until the last decade. However, the sense of touch (haptics) is a modality that we use so often in our daily lives. Can you image a day pass in your life without touching, exploring, or manipulating something using your hands? What strategies do you follow when you search for your office or car keys in your pocket using your fingers? Is it really possible to communicate with others without using hand gestures? When you purchase a fabric, why do feel a need to touch its surface? Can a surgeon operate on you without the sense of touch? Have you tempted to touch a Van Gogh painting to deeply understand how he created those sharp edges and contours?

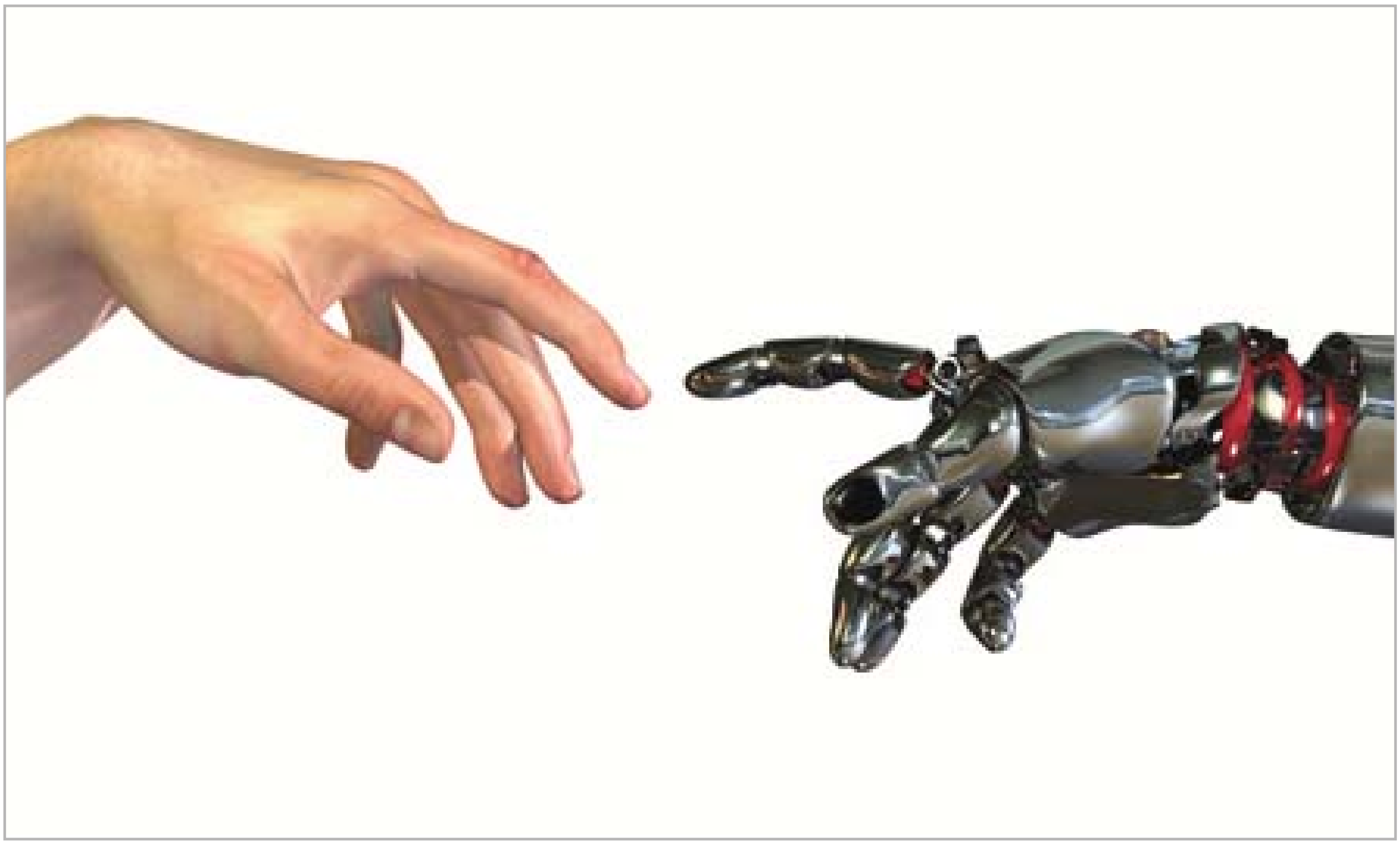
With the recent advances in hardware and software technologies in haptics, it is now possible to find better answers to some of these questions. The number of research studies on haptics has grown exponentially over the last decade. As a result, there are now three major conferences on haptics in the world: IEEE Haptics Symposium, EuroHaptics, and World Haptics (this is the largest haptics conference in the world and will be held in Istanbul in 2011). There is also a new journal, published by IEEE, dedicated to haptics only.



Robotics and Mechatronics Laboratory (RML) at Koç University is focused on investigating haptic (touch) interactions between humans and machines.

The group picture showing the members of RML (April 2009). The current graduate students are Bilal Orun (M.S.), Sina Ocal (M.S.), Umut Ozcan (M.S.), Gulay Ergul (M.S.), Selman Cebeci (M.S.), Can Gokgol (M.S), Yunus Emre Has (M.S), Baybora Bektas (Ph.D.), and Ayse Kucukyilmaz (Ph.D.). The alumni (not shown in the picture) are Mert Sedef (at UNC), Aydin Varol (at EPFL Lausanne), Nesra Yannier (at Stanford), Evren Samur (at EPFL Lausanne), Erk Subasi (at ETH Zurich), Ihsan Gunev (at Ford Motor Company R&D Division), Ibrahim Bukusoglu (at Ford Motor Company R&D Division), Ali Sengul (at ETH Zurich), A. Cengiz Oztireli (at ETH Zurich), Sertac Karaman (at MIT).

The research activities in Robotics and Mechatronics Laboratory (RML) are mainly focused on investigating multi-modal sensory interactions between humans and machines. In particular, we are interested in human and machine haptics for real, virtual, and teleoperated worlds. For this purpose, we conduct highly interdisciplinary research at the intersection of mechanical engineering and computer science with applications to different fields. The students working in the RML accumulate knowledge and hands-on experience in the areas of electro-mechanical systems, control engineering, mechanical design, biomechanics, robotics, physics-based modeling and simulation, computer graphics, and virtual environments technology.



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Below are the short summaries of the ongoing research projects at RML.

Research Projects at RML

A) Biomedical Robotics and Simulation

A1) Virtual Surgery: Visual and Haptic Simulation of Soft Organ Tissue Behavior: Surgical training has been based traditionally on the "apprenticeship" model, in which the novice surgeon is trained with small groups of peers and superiors, over time, in the course of patient care. However, it is known that this approach has several shortcomings. As an alternative to this traditional approach, we are currently developing a laparoscopic surgical simulator to train medical personnel in virtual environments. Our laparoscopic surgical trainer displays 3D graphical models of virtual organs on the computer screen as well as the interaction forces between the surgical instruments and organs to the user through the force-reflecting haptic devices.

A2) Haptic Recording and Characterization of Soft Tissue Properties: The lack of experimental data in current literature on material properties of soft organ tissues in living condition has been a significant obstacle in the development of realistic soft tissue models for virtual reality based surgical simulators used in medical training. However, collecting data from live organ tissues in situ is a highly challenging task for several reasons. We developed a robotic indenter to measure soft tissue properties in abdominal region during a laparoscopic surgery. Using the robotic indenter, force versus displacement and force versus time responses of pig liver under static and dynamic loading conditions were successfully measured in collaboration with medical staff from Istanbul University Medical School to characterize its material properties.

Robotics and Mechatronics Laboratory (RML) at Koç University develops a surgical simulator to be used in medical training. a) First, a robotic indenter is developed to record and characterize mechanical properties of soft organ tissues. b) These properties are then integrated into our surgical simulator to display deformation and force response of the organs to a trainee through a visual and haptic display (force reflecting robotic arm) respectively.

PUBLICATIONS:

1. Sedef, M., Samur, E., Basdogan, C., 2006. "Visual and Haptic Simulation of Linear Viscoelastic Tissue Behavior Based on Experimental Data", Proceedings of the 14 th IEEE Symposium on Haptic Interfaces for Virtual Environments and Teleoperator Systems, pp. 201-208, March 25-27, Washington D.C (nominated to the best paper award).

2. Sedef, M., Samur, E., Basdogan, C., 2006, "Real-time Finite-Element Simulation of Linear Viscoelastic Tissue Behavior Based on Experimental Data", IEEE Computer Graphics and Applications, Vol. 26, No. 5, pp. 58-68.

3. Basdogan, C., Sedef, M., Harders, M., Wesarg, S., 2007, "Virtual Reality Supported Simulators for Training in Minimally Invasive Surgery", IEEE Computer Graphics and Applications, Vol. 27, No.2, pp. 54-66.

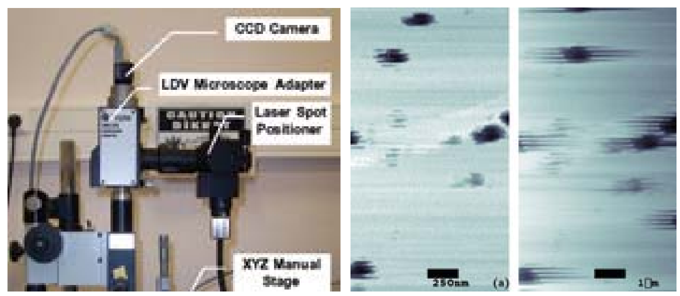
4. Samur, E., Sedef, M., Basdogan, C., Avtan, L., Duzgun, O., 2005. "A Robotic Indenter for Minimally Invasive Characterization of Soft Tissues". Proceedings of the 19th International Conference on Computer Assisted Radiology and Surgery, Vol. 1281, pp. 713-718, June, Berlin.

5. Samur, E., Sedef, M., Basdogan, C., Avtan, L., Duzgun, O., 2006, "A Robotic Indenter for Minimally Invasive Measurement and Characterization of Soft Tissue Response", Medical Image Analysis, Vol. 11, No.4, pp. 361-373.

B) Micro/Nano-Mechatronics and Robotics

B1) Manipulation of Nano Particles Using Haptic Feedback: Nano-manipulation refers to controlled movement of nano-scale objects with high precision. Fully automated nano-manipulation systems have not been realized yet due to the lack of online visual feedback during manipulations and the uncertainties during the contact interactions at nano scale. However one can better appreciate the potential role that the fully automated nano manipulation systems will play in the future if we consider the fact that fully automated robotic systems and assembly lines have started a new industrial revolution in 1980's. We have developed an Atomic Force Microscopy (AFM) set-up and a virtual reality tool-kit for tele-manipulating nano-scale particles with haptic feedback to the user to provide better guidance and control. The set-up includes a self-actuated piezoelectric probe for pushing nano-scale particles, a Laser Doppler Vibrometer (LDV) for sensing the deflection of the probe, a piezo-actuated nano-stage for Z-positioning of the particles with respect to the probe, and a haptic device for displaying the contact forces between the probe and the particles to the user. Using the proposed set-up, gold nano-particles, 200 nm in diameter (approximately, one-thousandth the diameter of human hair) were manipulated successfully.

B2) Nano Scanning Using a Piezo-actuated Bimorph Probe: To be able to manipulate nano-scale objects lying on a surface, their location and shape must be determined accurately via scanning. For this purpose, a new scanning approach, called Adaptive Q-control, for tapping-mode AFM is introduced and implemented on the experimental set-up discussed above. In the standard Q-control, the effective Q-factor of the scanning probe is adjusted prior to the scanning nano-scale surfaces. However, there is a trade-off in setting the effective Q-factor of an AFM probe: the Q-factor is either increased to reduce the tapping forces or decreased to increase the maximum achievable scan speed. Realizing these two benefits simultaneously using the standard Q-control is not possible. In adaptive Q-control, the Q-factor of the probe is set to an initial value as in standard Q-control, but then modified on the fly during scanning when necessary to achieve those two benefits at the same time.

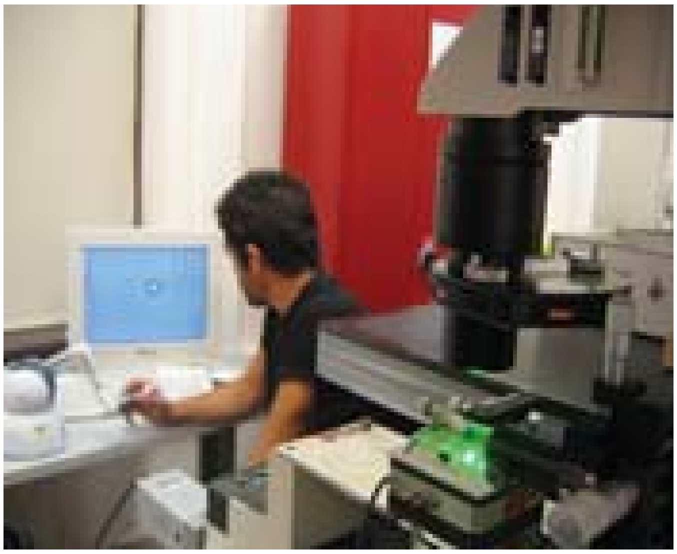


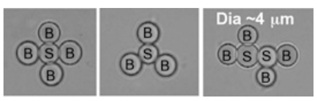
a) b)

Robotics and Mechatronics Laboratory (RML) at Koc University develops hardware and software solutions for better nano scanning and nano-manipulation: **a)** New control algorithms are developed to scan nano-size particles and surfaces faster and more accurately. **b)** Gold particles having 200 nm diameter (approximately, one-thousandth the diameter of human hair) are manipulated using the tip of an AFM probe and a haptic device providing force feedback to the user during manipulations.

B3) Micro Manipulation Using Optical Tweezers and Haptic Feedback: In collaboration with Prof. Kiraz at Physics Department of Koç University, we tele-manipulated microspheres having diameters of 3-4 μm and floating in a fluid solution using optical tweezers and a haptic device to form various patterns of coupled optical microsphere resonators. For this purpose, biotin-coated microspheres (labeled as "B" in the figure) trapped by a laser beam are steered and chemically bound to a streptavidin-coated sphere (labeled as "S" in the figure) one by one using a XYZ piezo scanner controlled by the haptic device. Initially, the positions of all spheres in the scene are detected using a CCD camera. A collision-free path for the manipulated sphere is then generated by the artificial potential field approach used for path planning in robotics. During manipulations, the forces acting on the sphere due to the viscosity of the fluid and the artificial potential field are scaled and displayed to the user through the haptic device for better guidance and control.

We are currently developing a laparoscopic surgical simulator to train medical personnel in virtual environments





We successfully manipulated micro-spheres in a fluid solution using a haptic device connected to an optical tweezers to form patterns of coupled optical micro-resonators. To our knowledge, this is one of the first studies showing the benefits of haptic feedback in optical manipulation

PUBLICATIONS:

1. Gunev, I., Varol, A., Karaman, S., Basdogan, C., 2007, "Adaptive Q-control for Tapping-mode Nano-scanning Using a Piezo-actuated Bimorph Probe", Review of Scientific Instruments, Vol. 78, No. 4.

2. Varol, A., Gunev, I., Orun, B., Basdogan, C., 2008, "Numerical Simulation of Nano-Scanning in Intermittent Contact-mode AFM under Q-control", Nanotechnology, 19, 075503.

3. Varol, A., Gunev, I., Basdogan, C., 2006. "A Virtual Reality Toolkit for Path Planning and Manipulation at Nano-Scale", Proceedings of the 14th IEEE Symposium on Haptic Interfaces for Virtual Environments and Teleoperator Systems, pp. 485-489, March 25-27, Washington D.C.

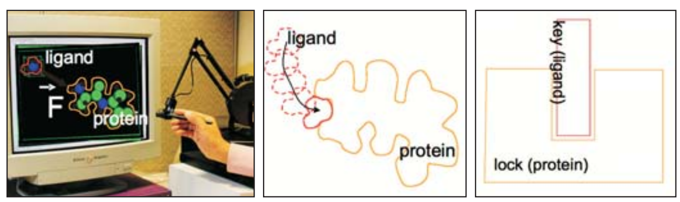
4. Bukusoglu, I., Basdogan, C., Kiraz, A., Kurt, A., 2006. "Haptic Manipulation of Microspheres with Optical Tweezers", Proceedings of the 14th IEEE Symposium on Haptic Interfaces for Virtual Environments and Teleoperator Systems, pp. 361-365, March 25-27, Washington D.C.

5. Bukusoglu, I., Basdogan, C., Kiraz, A., Kurt, A., 2008. "Haptic Manipulation of Microspheres Using Optical Tweezers Under the Guidance of Artificial Force Fields", Presence: Teleoperators and Virtual Environments, MIT Press, Vol. 17, No. 4, pp. 344-364.

6. Basdogan, C., Kiraz, A., Bukusoglu, I., Varol, A., Doganay, S., 2007, "Haptic Guidance for Improved Task Performance in Steering Microparticles with Optical Tweezers", Optics Express, Vol. 15, No. 18, pp. 11616-11621.

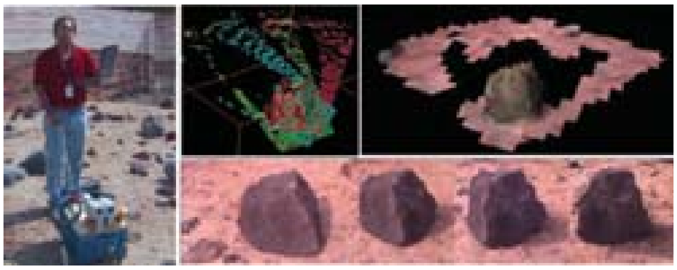
C) Graphical and Haptic Visualization

C1) A New Haptic Interaction and Visualization Approach for Rigid Molecular Docking in Virtual Environments: Many biological activities take place through the physicochemical interaction of two molecules. This interaction occurs when one of the molecules finds a suitable location on the surface of the other for binding. This process is known as molecular docking and has applications to drug design. If we can determine which molecule binds to a particular protein molecule and how the protein interacts with the bonded molecule, we can possibly enhance or inhibit its activities. This information, in turn, can be used to develop new drugs that are more effective against diseases. We propose a new approach for the solution of rigid-body molecular docking problem based on haptic interaction. In our approach, a drug molecule is manipulated by the user in virtual environments and inserted into the cavities of a rigid protein molecule one by one to search for true binding cavity while the molecular interaction forces between the drug and protein atoms are scaled and conveyed to the user via a haptic device for guidance.



The visual and haptic interactions between a ligand and a protein molecule are simulated in virtual environments to help the user discover the binding site and binding configuration more intuitively in molecular docking.

C2) Graphical and Haptic Rendering of 3D Virtual Objects and Point Clouds: We have developed computationally efficient methods for reconstruction of 3D graphical models of an object from multiple range images acquired by stereo cameras from different angles. These models can then be transmitted to a remote site progressively over the internet for graphical and haptic visualization. This technology has applications to cell phones, remote sensing, mobile robotics, medical imaging,



Using a mobile platform, we acquired 2D stereo images of a rock from different angles. Multi-resolution and three-dimensional models of the rock are reconstructed from these images using the 3D reconstruction and registration techniques. These models are then transmitted to a remote site progressively over the internet for graphical and haptic visualization.

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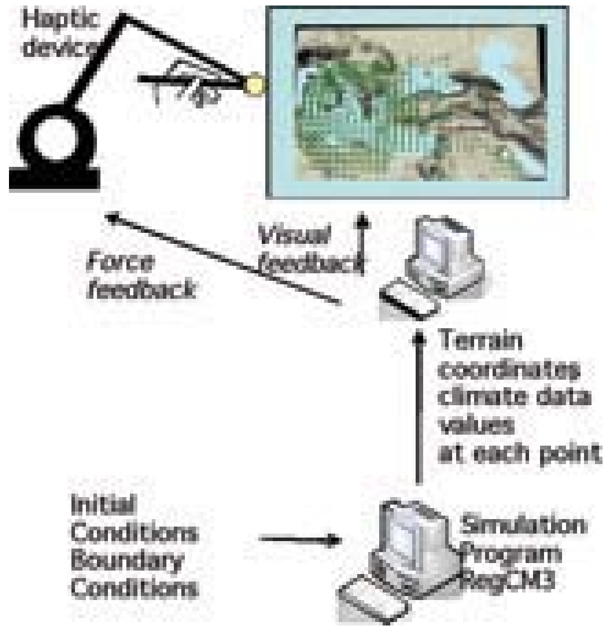
architectural reconstruction, and many more. Our approach involves four main steps: a) data acquisition: point clouds (PCs) are generated from stereo images captured by the cameras, b) registration: the PCs are correctly positioned and oriented with respect to each other and fused to construct a 3D volumetric representation of the object being reconstructed, c) transmission: the volumetric data is encoded and progressively transmitted to the remote site over the internet, d) visualization: a surface model is reconstructed from the transmitted data at the remote site and displayed to a user.

C3) Using Haptics to Convey Cause and Effect Relations in Climate Visualization In collaboration with Prof. Serdar Taşıran of Koç University and Prof Ömer Şen of Istanbul Technical University, we investigated the potential role of haptics in climate visualization. In existing approaches to climate visualization, different dimensions of climate data such as temperature, humidity, wind, precipitation, and cloud water are typically represented using different visual markers and dimensions such as color, size, intensity, and orientation. However, since the number of dimensions in climate data is large and climate data needs to be represented in connection with the topography, purely visual representations overwhelm users. Rather than overloading the visual channel, we propose an alternative approach in which some of the climate information is displayed through the haptic channel in order to alleviate the perceptual and cognitive load of the user. In this approach, haptic feedback is further used to provide guidance while exploring climate data in order to enable natural and intuitive learning of cause and effect relationships between climate variables. Our experiments with 33 human subjects showed that haptic feedback significantly improves the understanding of climate data and the cause and effect relations between climate variables as well as the interpretation of the variations in climate due to changes in topography.



Using haptic devices, we investigated the cause and effect relations between the variables in climate visualization in virtual environments. To our knowledge, this is one of the first studies showing the benefits of haptics in climate visualization. The news about our work appeared in popular science magazine New-Scientist Tech, several internet-based news portals, and also in local newspapers and TV channels.

C4) Visual and Haptic Perception of Object Softness in Virtual Environments: For virtual environments (VEs) to be interactive and immersive, sensory modalities have to be integrated into virtual reality (VR) systems in an effective and efficient manner. One of the goals of our research is to augment the effectiveness of a VE by displaying these sensory modalities in an ordered or altered manner to a human operator. To achieve this goal, we need a better understanding of human perceptual, cognitive, and motor control skills in a multimodal VE. With this goal in our mind, we designed and conducted human experiments to investigate the influence of visual and haptic information on perception of object softness in a multimodal VE. The results of our experiments show that visual position information is preferred over haptic hand position information in the perception of object softness and a single variable named Apparent Stiffness Difference can predict the pattern of human

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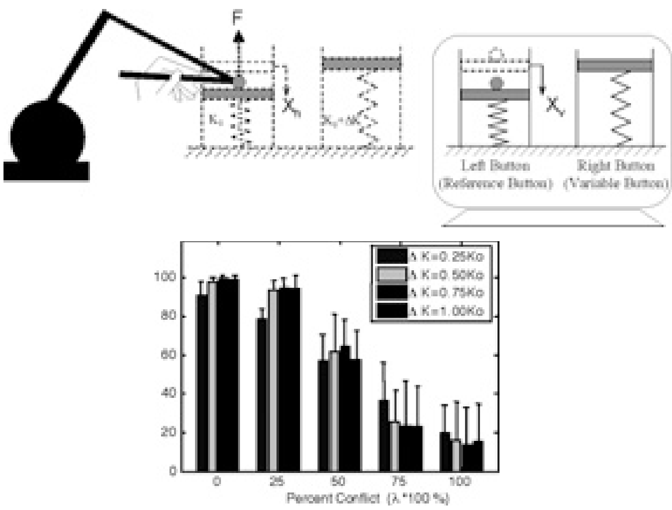
stiffness perception under manipulated conflict. The results also show that perspective cues are important in human softness perception and our perceptual system compensates for the deficiencies of each modality such that the sensory information coming from visual and haptic channels is fused in an optimal manner.



We designed and conducted human experiments to investigate the influence of visual and haptic information on perception of object softness in a multimodal VE: a) A pair of soft virtual buttons was displayed to the subjects during the experiments. Subjects could view the visual deformation of each button on a computer monitor and/or feel its stiffness through a stylus connected to the end-effector of a haptic interface device when it is pressed. b) The results of the experiments show that visual position information is preferred over haptic hand position information in the perception of object stiffness under manipulated conflict.

PUBLICATIONS:

1. Subasi, E., Basdogan, C., 2006, "A New Approach to Molecular Docking in Virtual Environments with Haptic Feedback", Proceedings of EuroHaptics Conference, pp. 141-145, July 3-6, Paris.

2. Subasi, E., Basdogan, C., 2008, "A New Haptic Interaction and Visualization Approach for Rigid Molecular Docking in Virtual Environments", Presence: Teleoperators and Virtual Environments, MIT Press, Vol. 17, No.1, pp. 73-90.

3. Basdogan, C., 2007, "From 2D images to 3D Tangible Models: Autostereoscopic and Haptic Visualization of Martian Rocks in Virtual Environments", Presence: Teleoperators and Virtual Environments, MIT Press, Vol. 16, No. 1, pp. 1-15 (some pictures from the paper appeared in the front cover of the journal and the paper is listed 5th in the top 25 most-downloaded articles of the journal for all times).

4. Oztireli, C., Basdogan C., 2008. "A New Feature-Based Registration Method for Robust and Efficient Rigid-Body Registration of Point Clouds", Visual Computer, Vol. 24, pp. 679-688.

5. Yannier, N., Basdogan, C., Tasiran, S., Sen, O.L., 2008, "Using Haptics to Convey Cause and Effect Relations in Climate Visualization", "Using Haptics to Convey Cause and Effect Relations in Climate Visualization", IEEE Transactions on Haptics, Vol. 1, No. 2, pp. 130-141.

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