Applications of Smart Materials to Haptics

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Index Terms—Smart materials, electroactive polymers, shape memory polymers, magnetorheological actuators, tactile displays

1 Introduction

Technological advances in Augmented and Virtual Reality systems have mainly focused on visual and auditory aspects of the user experience to the point that mass produced headsets for AR/VR can be bought at local electronic stores with high-resolution displays and audio systems. In all cases, these commercially available headsets are accompanied by a hand-controller with a vibrating motor inside, mainly used to provide confirmation feedback. We are, to this date, still using electro-mechanical actuators to provide haptic feedback, at least in commercially available products. As presented in [1], devices that have emerged in academia and young startups to provide haptic feedback for the hand and fingertip still use some form of actuator based on coils and magnets; this is the same haptic technology used almost two decades ago [2].

A problem with these haptic solutions is that they result in apparatus that are big, consume large amounts of power, are heavy, and also produce sounds that hinder its usability for long periods of time. There are, however, other types of actuation systems capable of producing large forces, with low power, that are thin and flexible, and light weight [3]. These are actuators made from electroactive polymers, which in turn are a subclass of materials better known as smart materials capable of sensing critical aspects of their environment and optimally responding/adapting to them [4], [5]. The properties of smart materials can be changed or altered significantly by applying some external stimuli like stress, temperature, moisture, magnetic and electric fields, change in pH, light, etc. Smart materials are highly responsive and have a great capacity to sense and respond to any environmental change.

Recently, haptic devices have been built using actuators and sensors made with smart materials, targeting force/position sensing, and haptic feedback for the fingertip and hand [6]. Specifically, the authors used dielectric elastomer actuators to provide vibrotactile feedback to a user wearing a haptic glove. The device contained the electronics to drive the actuator, used low power compared to conventional vibrotactile actuators, and it was light weight. This is just one example where smart materials produced a compact and silent wearable haptic device. Despite the many benefits of the device, it was driven with very high voltage (4 kV), something that could increase its size and cost.

Computer devices have also benefited from the development of smart materials. LG has produced a phone with self-healing capabilities [7] and Samsung has indicated that it is working on a flexible/bendable phone [8] to be released this or next year. This type of handheld device will require new actuation capabilities that follow the tendency of the phones: thin, flexible, and low power. Without a doubt, smart material actuators will be the best candidates to provide haptic feedback in these new types of devices, especially if the actuators are transparent and located on the visual display or surface to display haptic textures.

2 Contents of the Special Section

This special section presents recent results in research related to the application of Smart Materials to Haptics. Smart Materials have been used in other areas like robotics, aeronautics, and medicine to mention a few. The articles selected for publication in this special section target tactile displays to be explored with the hand or fingers, tactile displays made of thin films to be worn by the users, and novel force feedback devices for the finger tips.

In "A Multi-Finger Interface with MR Actuators for Haptic Applications," Huanhuan Qin, Aiguo Song, Zhan Gao, Yuqing Liu, and Guohua Jiang designed a novel resistive actuator based on magnetorheological fluids with a small footprint, large dynamic range, and a large workspace when compared to previous designs. Three of these actuators were used in a 6-DOF force feedback device to provide passive forces to the thumb, index, and middle fingers. The application of the actuators highlights the need for small and safe actuation systems for the fingers to allow users to experience grasping of virtual objects as opposed to the traditional point-based interactions. The paper shows that it is possible to create smaller actuators to convey force information to the fingers in a safe and realistic manner.

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Actuators made of electroactive polymers for wearable devices are presented in "Electro-Active Polymer Based Soft Tactile Interface for Wearable Devices" by Seongcheol Mun, Sungryul Yun, Saekwang Nam, Seung Koo Park, Suntak Park, Bong Je Park, Jeong Mook Lim and Ki-Uk Kyung.[1] The authors describe a soft and flexible actuator fabricated using electroactive polymers. The paper demonstrates that it is possible to use multilayers of dielectric elastomers to produce actuators that can directly stimulate the skin. They also describe the materials, procedures, and techniques to create the flexible electrodes and actuator. A user study suggests that these actuators configured in a tactile display can stimulate the fingertip and the forearm. More importantly, the actuators generate low (1 Hz) and high frequency vibrations making them candidates for a wide range of applications, especially for wearable devices due to their very low power consumption. The authors clearly detail the "recipe" to fabricate such actuators, allowing the haptics community to experiment with this novel technology, and perhaps create new applications, the same way 20 years ago they experimented with DC motors, and hydraulic and pneumatic actuators.

Using a different approach, in "An Enhanced Soft Vibrotactile Actuator Based on ePVC Gel with Silicon Dioxide Nanoparticles," Won-Hyeong Park, Eun-Jae Shin, Sungryul Yun, and Sang-Youn Kim present a novel electroactive polymer vibrotactile actuator built with a recently re-discovered material (PVC) composite. The advantage of the actuator is that it does not require compliant electrode layers as traditional dielectric elastomer actuators do. They show that making a composite actuator with silicon dioxide and PVC, a high performance haptic actuator is created. Since the actuator can be fabricated in the form of a flexible thin film, it is expected that the actuator technology in this paper might be applied to wearable haptic interfaces and flexible or bendable devices.

In "Understanding Graphics on a Scalable Latching Assistive Haptic Display Using a Shape Memory Polymer Membrane," Nadine Besse, Samuel Rosset, Juan José Zárate, Elisabetta Ferrari, Luca Brayda, and Herbert Shea*, present a tactile display based on shape memory polymer actuators that can be individually addressable to draw tactile shapes or symbols. Using this type of technology, tactile effects can be created with sustained forces that are perceivable by human touch. The psychophysical studies showed that visually impaired users can recognize symbols with little help and training. The tactile display represents a new type of device that is portable, low power, and with the right resolution not only for people with visual disabilities, but for sighted people as well.

The four papers in this special section highlight recent developments of light weight, soft, and flexible actuation systems not only for wearable devices but for haptic devices in general. It is hoped that the methods presented in these papers will stimulate other researchers in the haptic community to investigate and experiment with new materials and create new applications.

1. The review process for papers on which one of the authors was a Guest Editor was handled by the journal's Editorial Board.

REFERENCES

[1] C. Pacchierotti, S. Sinclair, M. Solazzi, A. Frisoli, V. Hayward, and D. Prattichizzo, "Wearable haptic systems for the fingertip and the hand: Taxonomy, review, and perspectives," *IEEE Trans. Haptics*, vol. 10, no. 4, pp. 580–600, Oct.-Dec. 2017.

[2] R. Azuma, Y. Baillot, R. Behringer, S. Feiner, S. Julier, and B. Macintyre, "Recent advances in augmented reality," *IEEE Comput. Graph. Appl.*, vol. 21, no. 6, pp 34–47, Dec. 2001.

[3] J. D. W. Madden, N. A. Vandesteeg, P. A. Anquetil, P. G .A. Madden, A. Takshi, R. Z. Pytel, S. R. Lafontaine, P. A. Wieringa, and I. W. Hunter, "Artificial muscle technology: Physical principles and naval prospects," *IEEE J. Oceanic Eng.*, vol. 29, no. 3, pp. 706–728, Jul. 2004.

[4] H. N. G. Wadley, "Characteristics and processing of smart materials," Paper 1, AGARD LS-205, 1996.

[5] W. Cao, H. Cudney, and R. Waser, "Smart materials and structures," *Proc. National Acad. Sci. United States America*, vol. 96, pp. 8330–8331

[6] D. De Rossi, F. Carpi, N. Carbonaro, A. Tognetti, and E. P. Scilingo, "Electroactive polymer patches for wearable haptic interfaces," presented at the *33rd Annu. Int. Conf. IEEE*, Boston, MA, USA, Aug. 30/Sep. 3, 2011.

[7] A. Souppouris, "Watch LG's new flexible phone heal itself after a knife scratch," 2013. [Online]. Available: https://www.theverge.com/2013/11/20/5125194/lg-g-flex-knife-scratch-heal-video

[8] J. Rogerson, "Samsung Galaxy X: The story of samsung's foldable phone so far," 2018. [Online]. Available: http://www.techradar.com/news/samsung-galaxy-x-the-story-of-samsungs-foldable-phone-so-far

Manuel Cruz received the PhD degree in electrical engineering from McGill University in 1998 and was a postdoc at the same university in 1999. In 2000, he joined Haptic Technologies Inc., later acquired by Immersion Corp., where he has held positions as a control systems scientist, research scientist, senior research scientist, and research manager. Currently, he is the research director responsible for laying the groundwork for all next-generation technology explorations. He has served as an associate editor for the *IEEE Transactions on Haptics*, and volunteers his time organizing major international Haptic Conferences. In 2004, he developed the first haptic controllers for mobile devices, now widely used in the cellphone industry. He has been named an inventor on more than 200 US granted and pending patents and has published refereed scientific papers. His mission is to understand the science of touch and its applications to enhance human communication. He is a member of the IEEE and ACM.

Ki-Uk Kyung received the bachelor's degree in mechanical engineering from the Korea Advanced Institute of Science and Technology (KAIST), in 1999 and the PhD degree from KAIST. He is an associate professor in the Korea Advanced Institute of Science and Technology (KAIST), Korea. He joined the POST-PC Research Group at ETRI in 2006 and was a director of the Smart UI/UX Device Research Section. The main objectives of his lab at KAIST are to discover soft and transparent materials for flexible sensors/actuators and to apply them to future devices such as flexible display, wearable device, and soft robots.

Herbert Shea received the PhD degree from Harvard University, in 1997. He is a full professor at EPFL in Switzerland, leading a group developing elastomer-based actuators and sensors for applications in haptic displays, soft robotics, and as tools for mechanobiology. After a PhD degree in 1997 from Harvard University, he spent two years as a post-doc with IBM Research, then joined Lucent Technologies' Bell Labs, becoming the technical manager of the Microsystems Technology Group. In 2004, he joined the EPFL as a faculty member.

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Ingrid Graz received the PhD degree in physics from Johannes Kepler University. She is an associate professor with Johannes Kepler University (JKU) Linz in Austria working on stretchable electronics and soft robotics. After receiving the PhD (2006) degree in physics from JKU researching flexible polymer sensors, she spent three years in the Department of Engineering, University of Cambridge, United Kingdom. There, she developed stretchable transistors and sensors. In 2011, she returned to JKU as an assistant professor and completed her habilitation on skin-inspired electronics, in 2015. She has authored and co-authored more than 39 peer-reviewed papers and is establishing her own group on Soft Smart Materials.