Skin Properties Actuation Techniques and Remote Clinical Palpation: A Review

Lana N. Joharji[1], Aljohara A. Alsharif[1], Haneen M. Alamoudi[1], Wedyan H. Babatain[2], Thangam Palaniswamy[1], and Muhammad M. Hussain[3]
[1] Department of Electrical and Computer Engineering, King Abdulaziz University (KAU), Jeddah, Saudi Arabia
[2] Computer Electrical Mathematical Science and Engineering Division, King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia
[3] Electrical Engineering and Computer Sciences (EECS), University of California Berkeley, California, United States
Email: {joharjilana, Aljohara.a.alsharif, Haneenmoalamoudi}@gmail.com, wedyan.babatain@kaust.edu.sa, tswamy@kau.edu.sa, mmhussain@berkeley.edu

***Abstract*—Actuators are the main components of any machine due to their responsibility in providing the desired action of control. As recent studies have been developing new actuation methodologies and remote clinical palpation tools that provide more complex and enhanced functionalities, this review paper aims to provide researchers interested in the actuation techniques and remote clinical palpation technologies with a reference guide about the recent actuation techniques including, shape deformation, moisture, and temperature actuators along with remote clinical palpation mechanisms. In addition, this review paper outlines comprehensive comparisons between their characteristics.**

***Index Terms*—shape deformation actuator, moisture actuator, temperature actuator, remote palpation**

I. Introduction

Actuators are the process of producing useful actions through energy transformation [1]. These machine components provide several types and functionalities according to their particular features, including Hydraulic, Pneumatic, Electric, Magnetic, and Mechanical actuators. Most actuators are commercially available, whereas others are still in the testing phase in which this review paper aims to discuss [2], [3].

Palpation, which is the process of touching, sensing, and pressing on the patients' body for general examination. Also, is one of the essential steps healthcare professionals perform despite their specialization in the medical field. Recently, there was a significant rise of interest in developing remote palpation techniques that can be used in the medical field. Remote palpation can be done through a robotic-assisted minimally invasive procedure. The development of such a method is challenging and difficult to achieve [4].

This review paper studies multiple actuation techniques, including shape deformation actuator, moisture actuator, and temperature actuator. Moreover, it reviews the different remote palpation techniques to understand the optimum methodology of palpation recreation.

Manuscript received April 16, 2021; revised August 22, 2021.

II. Skin Properties Actuation Techniques

A. Shape Deformation

Stanley *et al.* presented Haptic Jamming Deformable Surface with closed-loop shape control to accommodate actuation as shown in Fig. 1. Amid soft robotics and shape changing interfaces, the Haptic Jamming device showcases one column of cells and nodes for contributing to Jamming, Pinning and Pressurization. The hardware and mechanical design of closed loop shape control complements accuracy and design of generated shape for revamping actuation practices. The role of Haptic Jamming Deformable will contribute to re-creation of 3D objects with enhanced sensing and control features to facilitate the actuation process. Also, to determine the shape accuracy and quality features [5].

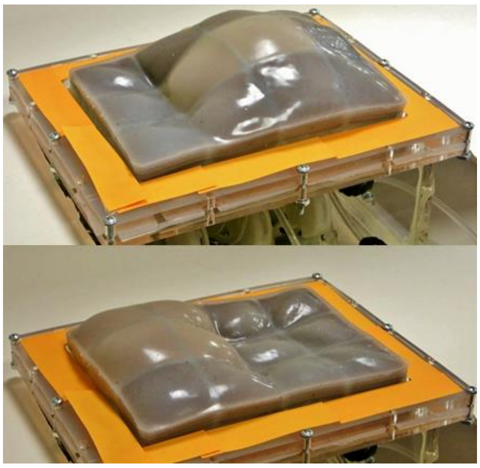

Figure 1. Closed-loop shape control of a haptic jamming deformable surfaces [5].

Modern advancement in technology brought visual reality nearer to a visually fascinating experience. Haptic feedback technology is not advanced enough for users to be able to manipulate and touch. Encountered type haptic systems are which change shape and move when a user

doi: 10.18178/ijeee.9.3.70-77

creates a contact with virtual objects as seen in Fig. 2. Encountered type haptic devices are handheld and wearable also allows the examination of objects through complete hands. The small display size, low resolution, and low pin speed are some of the limitations. The study of the conflict between the sense of touch and vision is Visuo-Haptic Illusions. When used as a type of haptic device with its three limitations, it improves the perception of shape display [6].

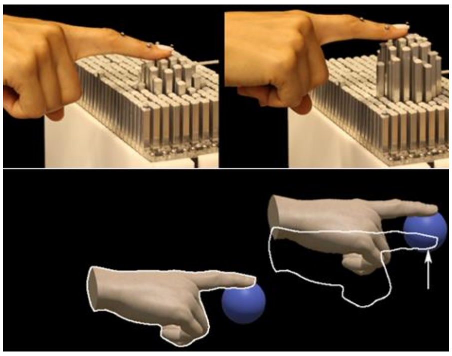

Figure 2. Visuo-Haptic illusions for improving the perceived performance of shape displays [6].

Tahouni *et al.* asserted NURBSforms for elaborating shape changing interfaces for modeling curved surfaces as shown in Fig. 3. The prioritization of NURBSforms enable designers to construct a surface ascertaining self-contained and controllable modules. The role of NURBSform constructs curvature by embedding Shape Memory Alloy (SMA) wire. The NURBSforms facilitate actuation mechanism for accomplishing curvature quickly by accommodating hardware. This can be done through fabricating a NURBSform module whereas the software part also features SMA wire adjustments to form relevant curvature. The NURBSform is considered as complementary to bridge the virtual (software) and physical (hardware) modelling. Also, to improve the actuation process and supplementing the prototyping for appreciation [7].

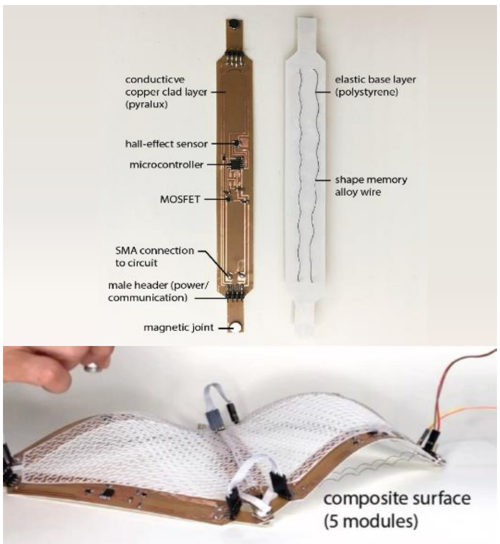

Figure 3. NURBSforms modular shape-changing interface for prototyping curved surfaces [7].

B. Moisture Actuator

Sweating plays an essential role in the human thermoregulation process. Nearly all aspects of sweating have been investigated experimentally to recreate the structure of sweat glands and the process of perspiration. However, previous studies focused on the human thermoregulation revealed that the recreation of sweating process is more complicated than they appear to be at first sight [8]. A limited number of studies recreated the human sweat secretion process, validating their approach reliability.

Andrew *et al.* [9] proposed an entirely automated, computer-controlled fluid mixing and dispensing system shown in Fig. 4. The system uses electronic relays as an actuation technique to allow the control of fluid with different salt concentrations. Moreover, the system dispenses the fluid through tubes embedded in an arm structure to represent skin pores. Dragon skin, a specific type of silicone material is used to design and implement the arm structure. This research succeeded in implementing a device that can provide sweat rates within the range of 1 µL/min to 500 µL/min. Similarly, the device repeatedly produced salt concentrations within the range of 10 mM up to 200 mM. The system showed a robust performance impervious to the system factors' interactions, including salt concentration, flow rate, relative humidity, and temperature, thus validating its reliability.

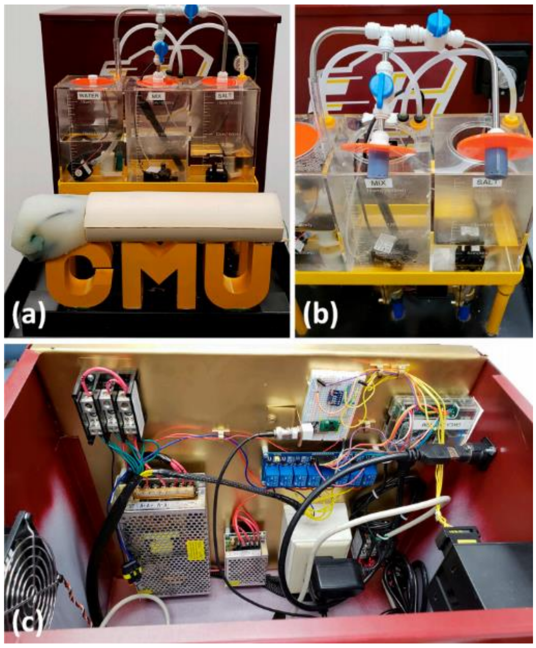

Figure 4. Sweating arm prototype, (a) Whole system implementation, (b) Zoomed view of the tanks, pumps, and flush valves; and (c) A metal board contains the system's electronic components [9].

Similarly, another paper proposed an artificial microfluidic skin developed to simulate the human skin perspiration process shown in Fig. 5. The research implemented a fabricated bi-layer membrane using simple lamination and laser milling techniques. An acrylic holder was used to hold the fabricated layer, proposing a gravity-fed mechanism as an actuation technique to simulate the human skin sweat drops. The artificial microfluidic skin showed consistent sweat rate results among the fabricated sweat pores. The research also proved the achievability of lower sweat rate densities by reducing the sweat pores' sizes. The artificial microfluidic skin model performance was aligned with researchers' theoretical model that predicts sweat rate densities based on microfluidic geometries [10].

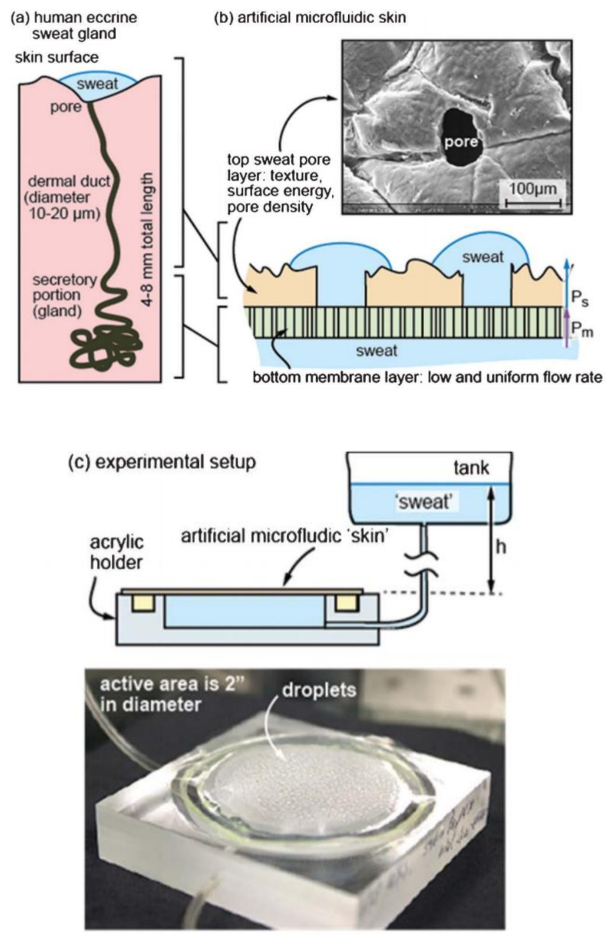

Figure 5. (a) Representation of a human sweat gland, (b) The fabricated bi-layer membrane design and an SEM photo; and (c) The experimental setup and a snapshot of the sweat droplets [10].

Another research proposed a soft hydrogel-based actuator that thermoregulates biological and engineered systems shown in Fig. 6. A 3D finger-like design was printed using Poly-N-Isopropylacrylamide (PNIPAm) as the primary body material and microporous (~200 μm) Polyacrylamide (PAAm) as the dorsal layer. Using this multi-material design provided a chemomechanical response, allowing pores to change their size dynamically based on the system temperature. Mainly, the pores are closed at low temperatures (< 30°C), and they dynamically maximize their size at high temperatures (> 30°C), allowing the liquid secretion process. The soft hydrogel-based actuator improved the cooling rate up to 600% (i.e., 39.1°C minute−1). Similarly, increasing the number of soft hydrogel-based actuators in a single device, such as robotic grippers, allows various manipulation of heated objects [11].

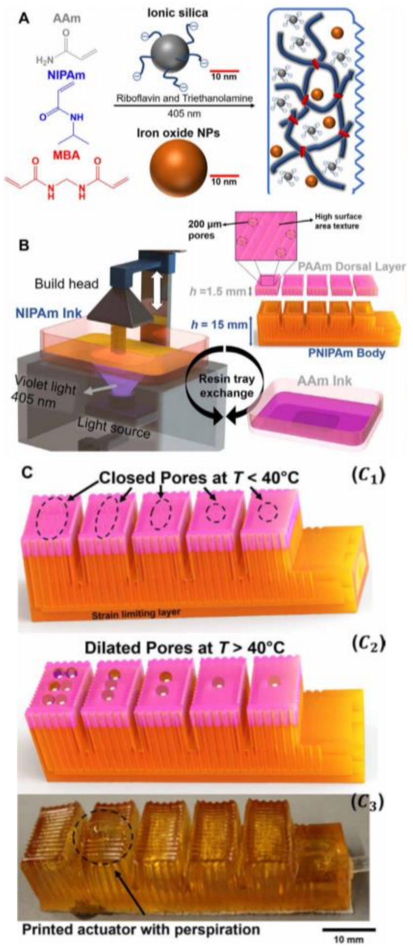

Figure 6. Actuator materials and the 3D printing technique, (A) The chemical aspects of materials used (B) A simplified explanation of the 3D printed actuator (C) simulation of the actuator design and the actual 3D-printed actuator (C1) Actuator pores simulation under temperatures below 40°C; (C2) Actuator pores simulation under temperatures greater than 40°C (C3) the actual 3D-printed actuator [11].

C. Temperature Actuator

Temperature actuation is any method that converts supplied electric energy into thermal energy [12]. In this section, two common types of actuators are discussed, and the state-of-the-art flexible temperature actuators is presented.

1) Joule heating

Joule heating is the process of producing heat due to an electric current flowing through a conductor. This method follows Joule's law, which states that the amount of heat produce (power) is directly proportional to the resistance and the current square. The resistor's power dissipates in heat; the heat is caused by the collision between the electrons and the conductor's atomic ions. The electric field in an electric circuit causes the electrons to accelerate and have electrostatic potential energy. As the electrons collide with ions in the conductor, the electrons are dispersed with random motion through the conductor. This movement of electrons through the circuit causes the temperature to increase [12].

2) Thermoelectric Cooler / Heater

Thermoelectric cooler/heater uses the Peltier effect to produce heat. Peltier effect works when a DC current flows through a circuit with two different conductors or semiconductors connected through two connections. The DC current flow will cause the warmth to transfer from one side to another. Semiconductors are more preferred when using the Peltier effect as p-type semiconductors lack electrons, and n-type semiconductors supply electrons. The thermal effect is produces by the junction made by taking one from each type of semiconductors [13]. Two ceramic plates with alternating p-type and n-type semiconductors are the building block of a standard thermoelectric device as shown in Fig. 7. The semiconductors are connected electrically in series and thermally in parallel arranged between them. Depending on the supplied current direction, one plate is hot while the other is cooled, and if the direction changes, the heat flow will change also [14].

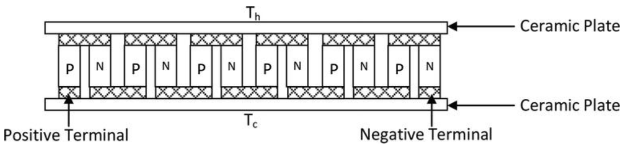

Figure 7. Thermoelectric cooler / heater [14].

3) *Physically Flexible Temperature Actuation*

Flexible temperature actuators are fabricated using flexible material and metals. Usually, flexible temperature actuators implement Joule heating and are manufactured using a substrate, for example, polyimide and a thin resistive film such as copper. Aftab *et al.* present a smart thermotherapy patch that is ultra-stretchable and flexible. The thermotherapy patch design is shown in Fig. 8. This design with stretchable lateral spring allows the patch to be 800% stretchable, making it compatible with the human body. The patch was fabricated using a thin film copper and polyimide as the substrate, making the patch affordable with a cost of $2-3 [15].

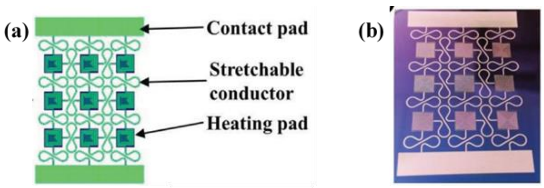

Figure 8. Thermal Patch, (a) The design and (b) Optical images of the patch [15].

However, flexible temperature actuation can also use the Peltier effect, thermoelectric cooler/heater. Recently, TEGway a company in Japan, presented the first flexible Thermoelectric Device (TED) shown in Fig. 9. The device is implemented using a BiTe-based material, and the structure of the device is modified, making it consume less energy than a typical TED. An experiment of bending a flexible TED 10,000 times was done, and the bending did not cause any degradation of the TE performance. TEGway used the flexible TED to build Thermoreal, a virtual reality application that allows gamers to feel instant heat, chill, or feel pain [16].

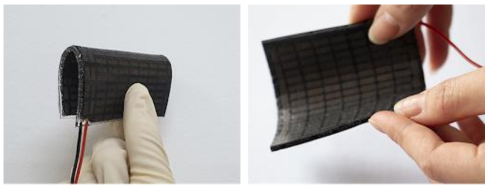

Figure 9. TEGway flexible thermoelectric device (TED) [16].

TABLE I. COMPARISON BETWEEN THE DIFFERENT ACTUATION TECHNIQUES

Type	Technique	Advantages	Disadvantages
Shape deformation	Haptic jamming deformable surfaces [5]	• The pressure of the chamber under the surfaces in each control loop increases	• The current implementation stems from the controller's limited loop rate.
	Visuo-Haptic Illusions [6]	• Improving the perceived display resolution of the shape • Increasing the perceived display size • Increasing the perceived speed of the pins	• limited by single finger interactions
	NURBSforms [7]	• Exploring various versions of a shape in a single integrated design process	• Realizing a new shape involves repeating the manufacturing procedure
Moisture actuator	Automated, systems using electronic relays [9]	• Insensitive to different factors • Reliable system • Wide range of sweat rates (1 μL/min to 500 μL/min)	• Extremely low concentrations have an error of 10%
	Fabricated membrane using gravity-fed mechanism [10]	• Uniform sweat rates among fabricated sweat • Ability to achieve low-rate densities	• Testing was held in vitro under fixed conditions
	3D-printed hydrogel with dynamic pores [11]	• Dynamic pores change dimensions based on temperature values	• The work was not tested for multifunctional systems
Temperature actuator	Joule heating [17]	• Fast temperature response • Uniform heats distribution • Low maintenance cost • Efficient in high energy conversion • No moving parts • Lightweight and thin structure • Environmentally friendly	• Absence of information • Controlling and monitoring of heat is challenging • Limited frequency band
Temperature actuator	Thermoelectric Cooler / Heater [18]	• Reliable • Lightweight • Noiseless operation • No moving parts • No working fluid • No chemical reactions • Uses DC power supply	• Balky • Low efficiency

III. Remote Clinical Palpation

Palpation can be done with light or deep pressure. It is performed lightly to detect abdominal tenderness, muscle tension, stiffness, and to assess abnormal lesions. Deep palpation, on the other hand, can be used to measure the liver, spleen, or kidneys and detect abnormal masses. Some solid tumors are harder than the surrounding tissue, so their presence, size, and location can be ascertained. Therefore, palpation is effective for medical diagnosis such as detection of breast and prostate tumors.

Technological advances in healthcare and telecommunications have dramatically improved people's access to clinical health care services. These improvements offered remote access to people in rural areas. Clinical diagnosis in the Western medical system has traditionally involved face-to-face and practical interactions. Therefore, one of the key aspects of telemedicine is the reproduction of human perception as well as vision, thereby improving the interaction between patient and medical personnel. Tactile feedback represents the feel of the human hand, and because tactile sensation is the brain's primary channel, it provides valuable information to healthcare professionals. In telemedicine, haptic feedback attempts to truly simulate the sensation of direct contact between a healthcare professional and a patient in a remote environment. Tactile feedback is generally divided into two different types: force (kinesthetic) and tactile (dermal). By integrating tactile and kinesthetic feedback into the tactile device, you can achieve the reality and transparency of tactile interactions. In telemedicine, virtual reality, and remote control, this has always been a long-term goal.

Relying on the research industry, a recent study presented a remote clinical palpation examination prototype design that is low-cost teletaction as shown in Fig. 10. It consists of a haptic sensor that measures a two-dimensional stiffness map. On the other side, it provides humanoid palpation sensitivity on the physician's pad using a haptic feedback display to recreate shape profiles and provides force and tactile feedback [19]. However, there are multiple limitations of this publication. First, there is no implemented prototype that provides real-time testing of the design. Second, the study only developed a shape deformation feedback using haptic which is not reliable at various aspects.

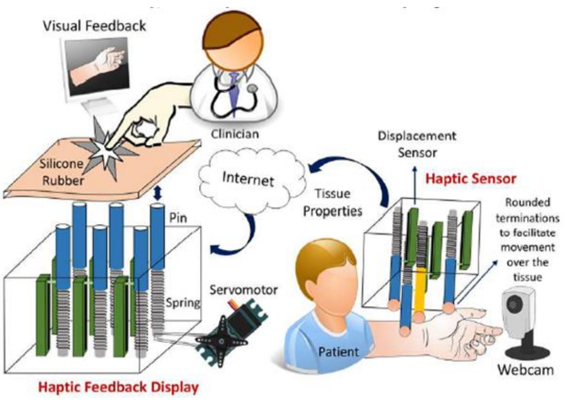

Figure 10. Teletaction system diagram [19].

Hernandez-Ossa *et al.* aims to define a surgical method that will act as an extension of the surgeon's fingers as shown in Fig. 11. A piezoelectric sensor array connected to the instrument's end effector can provide tactile information that is sent to the surgeon's fingertips through a tactile display. Also, to provide a sense of the shape and hardness of the tissue [20]. This will provide a broader sensing area for the surgeon by increasing the size of the design. Also, to count the motor revolution and provide position feedback, an optical position sensor to the motors can be added.

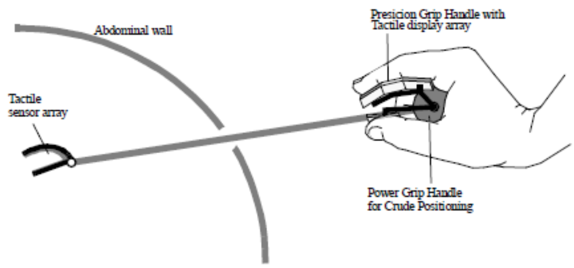

Figure 11. A tactile sensor and display sketch of the instrument [20].

The creation of a wearable Fingertip Haptic Device (FHD) that can provide cutaneous feedback via a Variable Compliance Platform (VCP) is presented in this paper as shown in Fig. 12. The FHD consists of an inertial measuring unit which monitors the user's finger movement, while its haptic functionality is focused on two parameters: the pressure in the VCP and the linear displacement of the fingertip. It will also be part of future work to re-design the FHD to make it even more compact and portable, and to replace its tracking system with other hand-held tracking devices [21].

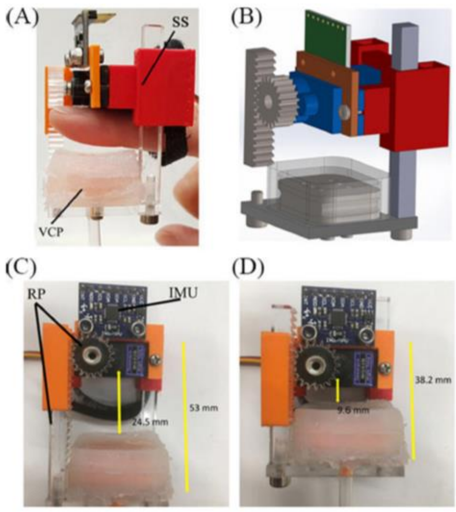

Figure 12. The FHD's side and front view [21].

Pacchierotti *et al.* presents a new cutaneous method for providing haptic feedback for palpation in robot-assisted surgery as shown in Fig. 13. The haptic system consists of a BioTac tactile sensor that registers deformations and vibrations in the surgeon's fingertip at the operating table, and a custom cutaneous feedback device that applies those deformations and vibrations to the surgeon's fingertip. Using a model-free algorithm based on data obtained while the BioTac is inside the cutaneous device, contact deformations and vibrations sensed by the BioTac are directly mapped to input commands for the cutaneous device's motors [22].

Figure 13. System setup [22].

Myers *et al.* present a novel health technology using a smartphone with its built-in accelerometers. The patient's own hands operate as remote replacements for the physicians. The system starts by taking the physician`s palpation motion set, as seen in Fig. 14. Then, the system directs the patient to match the action accurately by the physician. As a result, 81% of tested patients match a physician curve after six tries and less than 20% error. The system helps in abdominal pain evaluation to decide if a patient needs emergency intervention or some less severe cause [23].

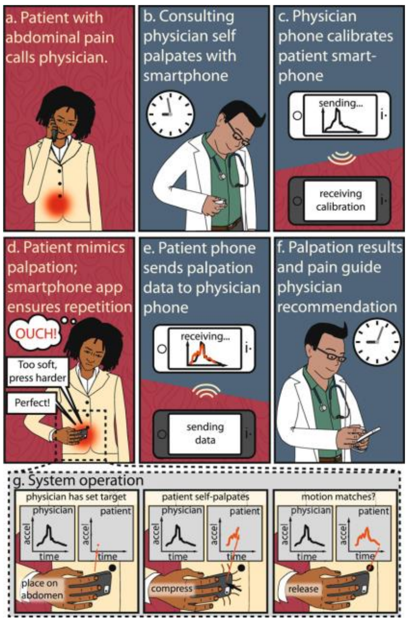

Figure 14. Smartphones with accelerometers enable physicians to remotely screen patients with abdominal pain and refer them to the appropriate medical facilities [23].

Schneider *et al.* presented a 3D elastography images through remote ultrasound imaging palpation technique as shown in Fig. 15. The system's freehand ultrasound scanning procedure utilized intraoperative tools, including 2D ultrasound transducer and da Vinci Surgical robot that eased the access to the elastic values of tissue. Experimental results of the freehand scanning were compared with a mechanical 3D probe and a magnetic resonance scanning. Tests were made using in vivo and phantom models, were both accuracy and feasibility were examined, respectively. Reported results showed repeatable elastography process with low values of standard deviations for elastic properties measurements. Similarly, in vivo kidney imaging showed clear internal collecting system and approximately defined its outlines [24].

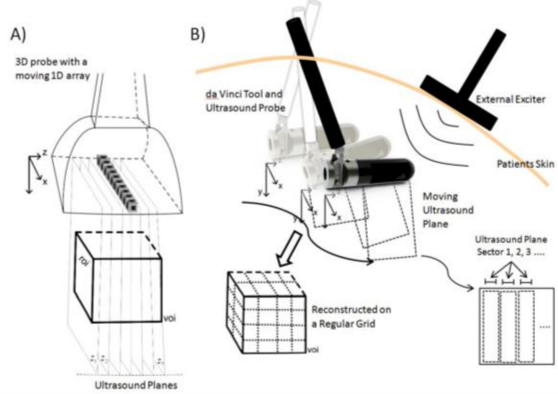

Figure 15. (A) The setup of 3D probe technique; (B) The setup of the 2D transducer and the da Vinci robot for the freehand imaging process [24].

TABLE II. COMPARISON BETWEEN THE DIFFERENT PALPATION TECHNIQUES

Technique	Advantages	Disadvantages
Haptic Feedback Display [19]	• The pressure of the chamber under the surfaces in each control loop increases	• The haptic sensor position control can be lost during the exploration of the remote environment
Tactile Sensor Array [20]	• Small and inexpensive design • The pin-based actuator provides measurements with high resolution	• The Minimally Invasive Surgery (MIS) lacks sensory input through the tactile sensation
Fingertip Haptic Device [21]	• The system improves the performance provided by the FHD • FHD, depending on the task, allows both "pressing" and "tapping" on the user's fingertip	• The system needs to be more compact and portable
Haptic Feedback [22]	• Enhanced task efficiency radically in terms of absolute error	• In its present state, it cannot be used during surgery due to its large size
Smartphone with Its Accelerometers [23]	• No additional hardware or devices other than a smartphone are needed	• The system accuracy and error should be improved
Remote Ultrasound Palpation [24]	• Eased the process of recording elasticity values in clinical setting • Independent and less influenced by boundary restrictions	• Synchronization of the external exciter and the scanning

IV. CONCLUSION

This review paper presented different types of actuation techniques, including shape deformation, moisture, and temperature actuators. It also reviewed the different remote clinical palpation techniques and designs. To understand the optimum actuator and remote clinical palpation techniques, a summarization of the advantages and disadvantages was provided.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Lana N. Joharji, Aljohara A. Alsharif, and Haneen M. Alamoudi conducted the review paper while Professor Muhammhad M. Hussain, Doctor Thangam Palaniswamy, and Wedyan H. Babatain supervised the process adding technical inputs.

ACKNOWLEDGMENT

The authors acknowledge generous support of the King Abdullah University of Science and Technology (KAUST) and King Abdulaziz University (KAU).

REFERENCES

[1] "Actuator principles and classification," in *Design Rules for Actuators in Active Mechanical Systems*, Springer, 2010, pp. 3-28, 2010.

[2] K. Suzumori, "New actuators and their applications -- from nano actuators to mega actuators," in *Proc. Micro-Nanomechatronics and Human Science, 2004 and the Fourth Symposium Micro-Nanomechatronics for Information-Based Society*, 2004.

[3] V. O. Cura, F. L. Cunha, M. L. Aguiar, and A. Cliquet, "Study of the different types of actuators and mechanisms for upper limb prostheses," *Artificial Organs*, vol. 27, no. 6, pp. 507-516, 2003.

[4] A. M. Okamura, "Haptic feedback in robot-assisted minimally invasive surgery," *Current Opinion in Urology*, vol. 19, no. 1, pp. 102-107, 2009.

[5] A. A. Stanley, K. Hata and A. M. Okamura, "Closed-Loop shape control of a haptic jamming deformable surface," in *Proc. IEEE International Conference on Robotics and Automation*, Stockholm, 2016, pp. 2718-2724.

[6] P. Abtahi and S. Follmer, "Visuo-Haptic illusions for improving the perceived performance of shape displays," in *Proc. CHI Conference on Human Factors in Computing Systems*, 2018, pp. 1-13.

[7] Y. Tahouni, I. P. S. Qamar, and S. Mueller, "NURBSforms: A modular shape-changing interface for prototyping curved surfaces," in *Proc. Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction*, 2020, pp. 403-409.

[8] A. Brueck, *et al.*, "An artificial sweating system for sweat sensor testing applications," *MDPI. Electronics*, vol. 8, no. 6, p. 606, May 2019.

[9] L. Hou, J. Hagen, X. Wang, I. Papautsky, R. Naik, N. Kelley-Loughnane, and J. Heikenfeld, "Artificial microfluidic skin for in vitro perspiration simulation and testing," *Lab on a Chip*, vol. 13, no. 10, p. 1868, March 2013.

[10] A. K. Mishra, *et al.*, "Autonomic perspiration in 3D-printed hydrogel actuators," *Science Robotics*, vol. 5, no. 38, p. eaaz3918, Jan. 2020.

[11] Y. T. Shah, *Thermal Energy: Sources, Recovery, and Applications*, FL: CRC Press, 2018, pp. 71-72.

[12] TEC modules. *Advanced Thermal Solutions, Inc.* [Online]. Available: https://www.qats.com/Products/TEC/TEC-Modules

[13] R. M. Atta, "Thermoelectric cooling," in *Bringing Thermoelectricity into Reality*, London: Intechopen, 2018, pp. 219-220.

[14] A. M. Hussain, E. B. Lizardo, G. A. T. Sevilla, J. M. Nassar, and M. M. Hussain, "Thermal patches: Ultrastretchable and flexible copper interconnect-based smart patch for adaptive thermotherapy," *Advanced Healthcare Materials*, vol. 4, no. 5, pp. 664-664, 2015.

[15] TEGway flexible thermoelectric device. *Tegway.co.* [Online]. Available: http://tegway.co/tegway/

[16] M. Sakr and S. Liu, "A comprehensive review on applications of Ohmic Heating (OH)," *Renewable and Sustainable Energy Reviews*, vol. 39, pp. 262-269, 2014.

[17] R. A. Kishore, A. Nozariasbmarz, B. Poudel, M. Sanghadasa, and S. Priya, "Ultra-High performance wearable thermoelectric coolers with less materials," *Nature Communications*, vol. 10, no. 1, 2019.

[18] K. Hernandez-Ossa, A. Leal-Junior, A. Frizera-Neto, T. Bastos-Filho, K. Adams, and M. Ferguson-Pell, "Haptic feedback for remote clinical palpation examination," in *Proc. 2nd International Workshop on Assistive Technology*, 2019.

[19] M. V. Ottermo, O. Stavdahl, and T. A. Johansen, "Palpation instrument for augmented minimally invasive surgery," in *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems*, Sendai, 2004, pp. 3960-3964.

[20] A. Tzemanaki, G. A. Al, C. Melhuish, and S. Dogramadzi, "Design of a wearable fingertip haptic device for remote palpation: Characterisation and interface with a virtual environment," *Frontiers in Robotics and AI*, vol. 5, p. 62, June 2018.

[21] C. Pacchierotti, D. Prattichizzo, and K. J. Kuchenbecker, "Cutaneous feedback of fingertip deformation and vibration for palpation in robotic surgery," *IEEE Transactions on Biomedical Engineering*, vol. 63, pp. 278-287, February 2016.

[22] C. Pacchierotti, D. Prattichizzo, and K. J. Kuchenbecker, "Cutaneous feedback of fingertip deformation and vibration for palpation in robotic surgery," *IEEE Transactions on Biomedical Engineering*, vol. 63, pp. 278-287, 2016.

[23] D. R. Myers, A. Weiss, M. R. Rollins, and W. A. Lam. (October 2017). Towards remote assessment and screening of acute abdominal pain using only a smartphone with native accelerometers. *NatureResearch. Sci Rep.* [Online]. 7(1). Available: https://www.nature.com/articles/s41598-017-13076-x

[24] C. Schneider, A. Baghani, R. Rohling, and S. Salcudean, "Remote ultrasound palpation for robotic interventions using absolute elastography," in *Proc. Conf. Medical Image Computing and Computer-Assisted Intervention*, Berlin, Heidelberg, 2012, pp. 42-49.

Lana N. Joharji is currently an undergraduate senior student majoring in electrical and computer engineering at King Abdulaziz University (KAU), Saudi Arabia. She is also a visiting student conducting research under the supervision of Prof. Muhammad M. Hussain at the MMH Labs, King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia. Her research interests include robotics, cost-efficient MEMS devices, and soft actuation.

Aljohara A. Alsharif is currently pursuing her B.Sc. degree in electrical and computer engineering at King Abdulaziz University (KAU), Saudi Arabia. She is also a visiting student at the MMH Labs at King Abdullah University of Science and Technology (KAUST), Saudi Arabia. Her research interests include humanoid and flexible robotics developments along with analog and digital electronic circuits analysis, design, and implementation.

Haneen M. Alamoudi is a senior undergraduate student majoring in electrical and computer engineering at King Abdulaziz University (KAU), Saudi Arabia. Currently, she is a visiting student at the MMH Labs at King Abdullah University of Science and Technology (KAUST), Saudi Arabia. Her research interests include robotics, machine learning, and deep learning.

Wedyan H. Babatain received her bachelor's degree in Biomedical Engineering from the University of Delaware, USA, in 2017, her master's degree in Electrical Engineering from King Abdullah University of Science and Technology (KAUST), KSA, in 2019. Currently, she is pursuing her Ph.D. degree under the supervision of Professor Muhammad Mustafa Hussain at the MMH labs at KAUST. Her research area of interest is in the fields of sensors, actuators, microfluidics devices, and flexible futuristic electronics.

Thangam Palaniswamy received her Ph.D. in Information and Communication Engineering from Anna University at India in 2013. Currently, she is serving as Associate Professor in the Department of

Electrical and Computer Engineering of King Abdulaziz University, Saudi Arabia. Her research interests include Databases, Data Processing & Mining, Medical Image Analysis, Image Processing, Cryptography, Embedded Systems, and Internet of Things. Her contributions in Professional Societies include IEEE, International Association of Engineers, Indian Society for Technical Education and the International Association of Computer Science and Information Technology. She serves as editorial board member in international journals like International Journal of Engineering Research and Science, Asian Engineering Review and as reviewer in many international journals and conferences.

Muhammad M. Hussain received his Ph.D. in electrical and computer engineering from the University of Texas at Austin in 2005. Currently, he is a professor of Electrical Engineering at King Abdullah University of Science and Technology (KAUST) and a professor of EECS of University of California, Berkeley. Before joining KAUST, Prof. Hussain was Program Manager of Emerging Technology Program in SEMATECH, Inc. Austin, Texas. He is the Fellow of IEEE, American Physical Society (APS), Institute of Physics, UK and Institute of Nanotechnology, UK. His research interest is to expand the horizon of complementary metal–oxide–semiconductor (CMOS) electronics and technology for futuristic applications.