Revealing Texture: A smart material approach towards dynamic, adaptable and scalable free-form tactility in devices using Azo Sol-Gel Hydrogels

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Abstract

Tactility can augment and enhance many physical interactions, however digital devices such as smartphones typically feature minimal tactile feedback. Texture is a fundamental type of tactile feedback, playing a crucial role in object identification and discovery for non-digital objects. Implementation of dynamic texture opens the potential for programmable non-invasive output enhancing fundamental interactions with phones, tablets and smartwatches. However, the current body of work towards dynamic texture still leaves a significant space for improvement on matters of shape agnosticism, tactile adaptability and control granularity. We propose a material solution to actuation and revealing of varying levels of texture. Using photoresponsive Azo Sol-Gels we control the reveal of textured surfaces including the depth and width between tactile stimuli as well as having high and dynamic granular control over the surface. This method promises scalable and adaptable methods of creating virtually any type of textured surfaces.

I. INTRODUCTION

The sense of touch is one of our fundamental human senses, allowing us to perceive, explore, and engage with the world around us. The tactility of an object is the principal contributor to a multitude of perceptual functions: assessment, verification, monitoring, and building mental models [1]. What we feel under our tactile receptors has the power to alter the perception of our surrounding world. Haptic feedback is used as an encompassing term to describe feedback which stimulates the mechanoreceptors present within both muscles and nerve endings [2]. In devices, this is generated through physical aspects of computing to create tactile stimulation, and has been associated with: improved learning in children [3]; improved performance during professional training tasks [4]; possibility of adding affective context to interactions [1]; increased input speed, accuracy and less frustration during interaction [5];

Regardless of the numerous ways that tactile feedback can enhance physical interactions, the mainstream devices we use daily (such as smartphones, tablets, and smartwatches) typically offer minimal tactile features, usually limited to simple vibrations.

Humans are able to feel a plethora of tactile sensations when touching and exploring an object through its core physical properties [6]: texture, temperature, hardness/softness, elasticity, pressure, vibration, density, sharpness, friction.

II. RELATED WORK

Texture is an object's discoverable surface level tactile information; this is one of the first noticeable tactile traits when exploring objects through the sense of touch. Texture can aid the interactive devices we engage with daily by stimulating a new sense in a deeper way. Specifically, texture has been defined and shown to be one of the tactile details that is perceived first when we touch an object, as well as used towards our identification and understanding of the object [6]. What distinguishes texture from other methods of haptic feedback —I.e linear force output, stiffness change - is the high levels of granularity required while maintaining very small sizes. We parameterise texture implementations as either static or dynamic depending on its possibility of facilitating assisted or non-assisted changes in output.

Static Texture

The general practice of studying and implementing texture either in interface systems of psychophysical study systems is by manually swapping out surfaces with different tactile feelings. This is a robust method, successful in creating varied surface level stimuli, however, it is a 'static' way of doing so [7], [8]. This implies the need of multiple materials, constant manual labour and generally extensive external input to reconfigure tactility.

Dynamic Texture

On the contrary side to the above mentioned methods, there exists research done into dynamic texture reconfigurability. This involves a system which can change its presented tactile feedback without requiring any external input.

Vibro-tactile feedback is at the forefront of methods that are used to create 'texture' in devices. Kim et al. [9] create varying surface tactility through alternating the frequency of vibrations. Similarly, another popular approach is making use or micro-scale linear actuators that extrude out of an interface to create uneven surfaces under a user's fingers [10]. Jansen, Karrer, and Borchers [11], Simonelli et al. [12] built dynamically adaptable texture on their surfaces through changes of the applied magnetic field to chambers of magnetorheological fluids. The variation in magnetism causes magnetic particles to suspend and align in response, leading to changes in the surface textures displayed. Craig Shultz and Chris Harrison[13] showcase a method of creating tactility using electro-osmotic excitation of liquids, moving a dielectric carrier fluid between chambers exposed or not to a user - therefore, facilitating surface level tactility.

Lastly, there have been methods developed to simulate texture without an actual physical device needing to facilitate it. Reference [14] provides a review of these types of processes which revolve around the precise excitation of nerve endings in your body, thus simulating touching texture. These, however, are usually invasive even if minimally and still require the use of specific devices to stimulate peripheral nerves.

The previous methods may illustrate a potential for digitalization and integration of texture feedback into interactive devices, but there is still a large opportunity present for further research and development in effectively creating meaningful textures.

III. IMPLEMENTATION

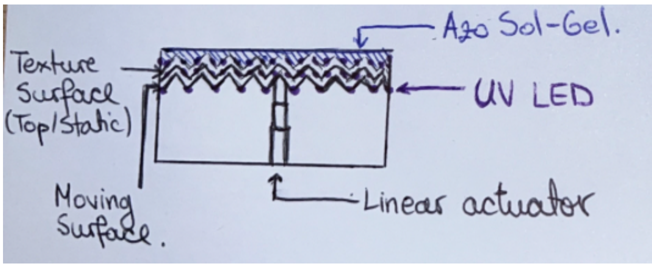
Previous approaches have demonstrated how we can change textures, however creating prototypes of varying sizes and form factors while simultaneously allowing a wide range of dynamic tactile sensations is not possible/difficult because each has its own dependencies and constraints which cannot yet co-exist within one system. To address this, we propose a hydrogel-based prototype that can take any form factor and which facilitates dynamic and multi-localized tactility. Furthermore, the material centric approach promises high reconfigurability and adaptability of the device - size, tactile output - while requiring lower power and having minimal waste. Our prototype is an implementation that facilitates texture by revealing it using outer mechanisms to be able to facilitate higher dynamic control and surface variation using Sol-Gels.

A. *Azo Sol-Gel*

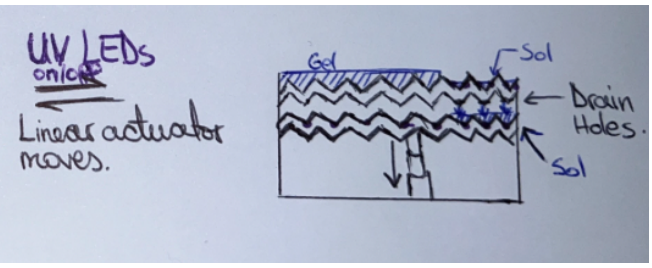
The Most materials used are either easily fabricated - ie. 3D design-able and printable surfaces - or bought - i.e off-the-shelf linear actuator, acrylic encasing, UV LEDs. However, the main functionality of the system is carried by what was referred to as “Sol-Gel” throughout the paper. A Sol-Gel is a material which exhibits a Solution - Gel state fully reversible transition under highly specific circumstances and stimuli. The proposed sol-gel material is established in [15] and can be adapted and manufactured in a variety of form factors and sizes accordingly. Other sol-gel materials can be used towards different characteristics - transparency, plasticity, etc. The proposed material becomes a solution under UV light and resumes gel-state under visible light. The proposed Azo Sol-Gel is biocompatible, making it a suitable material to enable tactility in interactive device.

B. *Sketch/Design*

Default state Sketch:



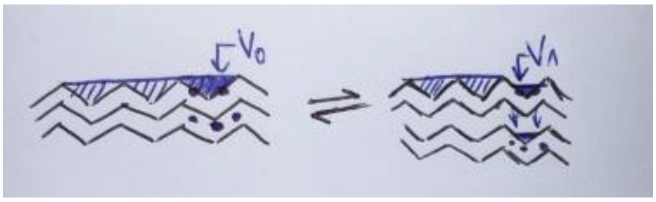
Example of actuation to reveal the texture under the gel layer when specific UV LEDs turn on and the actuator moves to enable the transitioned liquid to sink through gaps in the top surface:



As presented in the picture, our system will consist of a linear actuator, a textured surface on top of which UV LEDs are placed as well as small drain holes. The tactile surface is topped with a photoresponsive sol-gel which covers it wholly and seeps through its gaps, resting on top of the LEDs. This means that the system’s texture and tactility is fully covered and enclosed in default state. The UV LEDs are controlled by a micro-computer; when they turn on, the sol-gel area above them will begin transitioning from a gel to a solution. The supporting linear actuator will lower allowing the formed solution to sink below the textured surface. The amount of volume that can sink is controlled by the linear actuator. Afterwards, the UV LEDs on top turn off allowing the lower volume of the remaining solution to return to its previous gel state. By lowering the volume of the smart material we therefore are able to reveal controlled amounts of the textured surface. In order to hide the texture, the solution gets pushed back to the top by the linear actuator closing the gap between itself and the texture surface forcing the solution back above it through minimal holes in the top surface.

C. *Dynamic Control*

Further example of actuation:



Our system enables dynamic and reversible control over the height and distance left between tactile stimuli on a surface. The surface and type of tactile stimuli - ie. granularity, depth, distance[19] - can be adapted and changed while maintaining the same drainage of material mechanism and use of UV-VIS sol-gel transitions.

The amount of volume change can be controlled by temporally modulating the LEDs. Depending on what type of LEDs, their emitted UV spectra (<400nm) the time of sol-gel transition will vary. The general t = time of actuation per ml can be calculated by repeated actuations and precise averaged timing.

t = time of actuation per millilitre given 1 LED

$\mathcal{V}$ = volume of texture depth between two tactile stimuli as presented in the sketch

$$t \times \mathcal{V} \tag{1}$$

Equation (1) is the time of actuation per volume of texture depth given 1 LED

$$\frac{t\times\mathcal{V}}{x} \tag{2}$$

Equation (2) is the time of actuation per volume of texture depth given x LEDs

$$\frac{t\times(\mathcal{V}0-\mathcal{V}1)}{x} \tag{3}$$

Equation (3) is the time of actuation knowing the desired height and volume of the end state V1.

Furthermore, due to the moving/sinking area being inherently a negative of the texture surface this allows for high accuracy of control and multi-point actuation. The mentioned time-based control also allows for varying levels of actuation to occur at the same time.

IV. RESPONSIBLE INNOVATION

There are certain design considerations and implications that need to be kept in mind when taking this project further.

1. Materials: The material centric aspect of the project allows for the tactile components and static components to be adjusted and changed at will meaning you don't need a wholly new prototype each time. The use of Sol - Gels also means they are compatible with virtually any type of texture, once again reducing environmental waste and increasing re-usability. They are also, in most cases, self-healable materials resulting in higher re-usability and less general waste. However, if one may want to change the used smart material, they need to be careful regarding safety of the material and what precautions that may need - such as a cover or encapsulation.

2. Control: The general complexity of the control used for the device is not high, given the use of only LEDs and an actuator, but it is to be kept in mind when upscaling: the bigger the size of the interactive surface or the faster the required actuation, the more LEDs needed therefore control and consumption needed.

3. Scalability: The project was developed with scalability in mind - the process of applying a fabrication method to bigger or smaller sized systems. Due to the mentioned material centric approach and its applicability to varying systems its general size dependencies have minimal component limitations.

4. Form: Similarly to the above, the proposed concept of facilitating dynamic texture has minimal shape/form dependencies. The functionality can be applied to any surface shape meaning it can be fully free-form.

5. Waste: Mentioned in the previous points, lesser environmental and general waste of resources and materials is another promising factor to our proposed method. The Sol-Gel, or smart material of choice, can be easily adapted from one prototype to another and re-used. Furthermore, there are other sustainable smart materials that can be used or directly developed to be fully biodegradable such as hydrogels based on water and algae or sugar polymers[16]. The texture surfaces can also be changed depending on the study, meaning there is no need for a new prototype each time and instead one can work with one system and adapt it according to circumstance.

V. AUTHOR BIO(S) / EXPERIENCES

I am a PhD student in Computer Science with a focus on developing novel ways of building devices using smart materials. My main aspiration is creating the methodology of achieving a fully and multi tactile engrossing device that co-locates high visual aspects - screen/display - and the aforementioned levels of tactility. The type of smart materials I primarily work with are programmable, responsive hydrogels.

My technical expertise includes hardware/micro-computer systems, interactive device building, signal processing programming, interface programming, algorithmic approaches to systems, novel sensing and display building, tactile systems, 3D modelling and printing.

My work, however, spans past computer science into applied chemistry, chemical engineering, polymer and material science. I have implemented and developed my own novel materials for hardware development and characterised them using advanced analytical methods - SEM, Spectroscopy, NMR, GPC, DSC, TGA, etc. I have developed, synthesized and implemented tactile materials, metal-based catechol materials, various types of polymers and polymerisation processes, multi-fluorescent and electroluminescent materials. Furthermore, I have worked with upscaling micro-scale materials for the sake of implementing them within working hardware systems.

I am adept in several programming languages including C/C++, Java, Python, MatLab and have worked on developing interfaces for user studies as well as running them[17][18].

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