2025 IEEE World Haptics Conference (WHC)
Suwon Convention Center, Suwon, Korea
July 8 ~ 11, 2025

Chameleon Touch: Enabling Configurable See-through Capability for Vision-based Tactile Sensors with Photochromic Elastomers

Zhiqiang Ren[1,2], Xiaobo Liu[2], Mingjun Dai[1], Liang Lin[2,3] and Yazhan Zhang[2,*]

Abstract— **Vision-based tactile sensors (VBTS) provide rich spatial data crucial for robotic manipulation, yet typically rely on static markers, limiting their adaptability. Inspired by biological systems like chameleon camouflage, we present a transparency-tunable tactile skin utilizing configurable photochromic elastomers. These materials enable tactile markers to be activated under UV light, and fade back to a semi-transparent state otherwise. We first synthesized photochromic elastomers exhibiting distinct UV-activated colors (e.g., blue, purple) and global/local activation behavior. Markers and tactile skins fabricated from these materials successfully demonstrated configurable see-through capability. Leveraging these capabilities, we propose novel schemes for enhancing VBTS, including adaptive spatial resolution (attentional focus) and multi-feature tracking via different color cues. This photochromic approach overcomes static marker limitations in VBTS, facilitating task-adaptable robotic sensing.**

I. INTRODUCTION

Dexterous robotic manipulation critically relies on high-resolution tactile feedback [1]. VBTS, such as GelSight variants, provide rich contact information by optically tracking markers [2]. However, a limitation arises from their inherent structure, where markers reside between the external contact surface and the internal camera. This configuration inherently creates blind spots: the contact object itself (especially in designs like FingerVision with significant constraints), can physically block the camera's view of certain markers. This inherent structural occlusion, unresolvable by static markers, leads to data loss and incomplete contact perception.

Inspired by the adaptive camouflage of organisms like chameleons. We introduce Chameleon Touch: a novel adaptive tactile skin employing photochromic elastomers. This approach draws inspiration from advancements in bioinspired stimuli-responsive materials for adaptive systems [3]. These smart materials enable markers that are normally translucent within the elastomer become vividly colored upon targeted light exposure (e.g., UV) undergoing a reversible light-induced photochemical process. This unique characteristic enables tactile markers that feature:

This work was supported by the Major Key Project of PCL (No. PCL2024A04), National Key R&D Program of China (2023YFE0126800), Natural Science Foundation of Xinjiang Uygur Autonomous Region (2023D01A60), and Natural Science Foundation of Guangdong (2024A1515010625).

[1]Zhiqiang Ren and Mingjun Dai are with College of Electronics and Information Engineering, Shenzhen University, Shenzhen 518060, China.

[2]Zhiqiang Ren, Xiaobo Liu, Liang Lin and Yazhan Zhang are with Research Institute of Multiple Agents and Embodied Intelligence, Peng Cheng Laboratory, Shenzhen 518000, China. email: {renzhq01, liuxb01, linl01, zhangyzh}@pcl.ac.cn

[3]Liang Lin is with School of Computer Science and Engineering, Sun Yat-sen University, Guangzhou 510006, China.

- **Controllable Visibility:** Markers transition between low-visibility (translucent) and high-visibility (opaque/colored) states on demand.

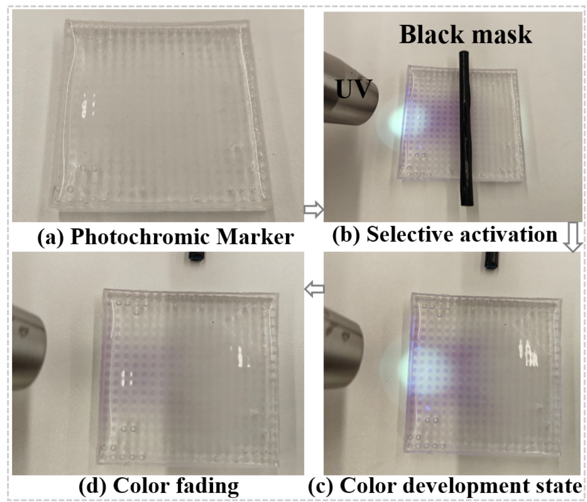

Fig. 1. Photochromic markers in PDMS: spatial selective activation & fading. (a) Skin with translucent photochromic. (b) UV activation, showing contrast between colored (left) and unactivated (right) markers. (c) Color development state of markers. (d) Marker color fading after UV removed.

- **Selective Activation:** UV light can be projected globally or, directed selectively to activate markers only in specific regions of interest (ROIs).
- **Color-Configurability:** The activated marker color can be tuned via the configurable mixture of photochromic agent and elastomer solution.

This work introduces the Chameleon Touch concept and presents its initial experimental validation. Our contributions include: (1) the fabrication and characterization of photochromic elastomer skins suitable for VBTS; (2) demonstration of the controllable (global/local) and reversible activation of high-contrast markers; and (3) validation that the markers, featuring controllable visibility allowing on-demand transitions between low-visibility and high-visibility states, are suitable for tracking algorithms.

II. CONFIGURABLE PHOTOCHROMIC SKIN PREPARATION

We developed photochromic elastomer skins using PDMS (Polydimethylsiloxane), chosen for its optical clarity and suitable mechanical properties. Different UV-activated colors were achieved by incorporating different photochromic agents into this base elastomer.

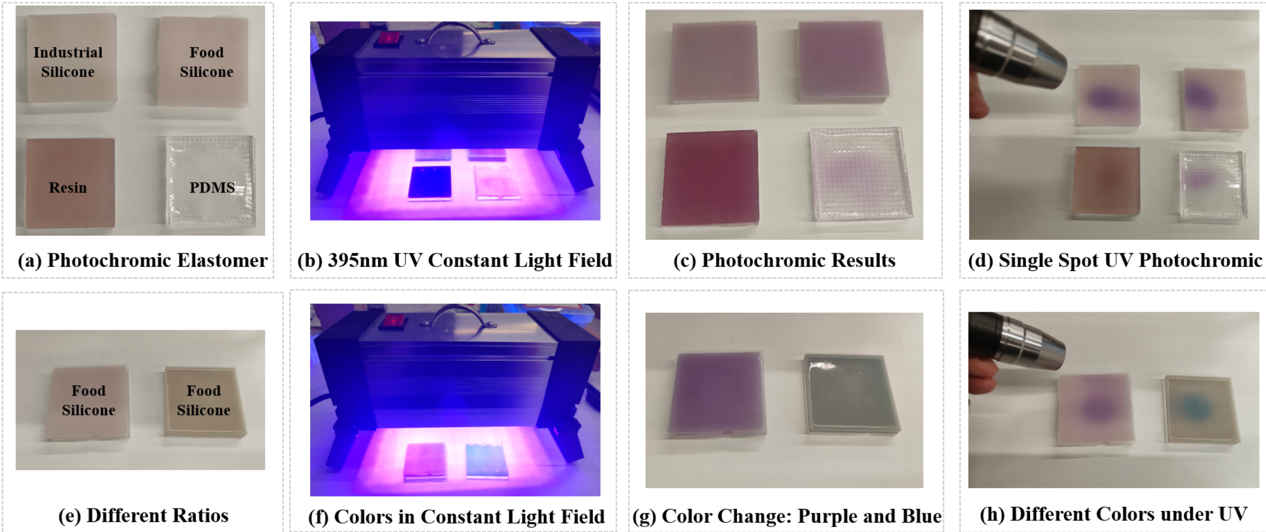

Fig. 2. Preparation and photochromic activation characterization of different elastomer skins. (a) Four distinct photochromic elastomer preparations. (b) Experimental setup for uniform UV irradiation process (e.g., 395 nm). (c) Resulting colors of the four preparations under uniform UV. (d) selectively activation patterns on the four preparations using focused UV. (e)-(h) Characterization of two specific color variants (e.g., purple and blue) based on silicone elastomer: (e) The two prepared skin samples (before activation). (f) Uniform UV irradiation process for these samples. (g) Distinct purple and blue colors activated under uniform UV. (h) Localized activation patterns using focused UV on the purple and blue samples.

- **Purple Color(Fig. 2g):** The base PDMS was mixed with a formulation including a Photochromic purple dye (at approximately 0.8 wt%), along with Styrene maleic anhydride monomethyl (SMA-Me), Polyoxymethylenemelamine (POMM), and 4-(1-phenylethyl)-o-xylene.
- **Blue Color(Fig. 2h):** A blue photochromic skin was prepared by mixing the base PDMS with 0.5 wt% of a spiropyran derivative selected for its UV-induced blue.

The photochromic agent was dispersed into the uncured PDMS precursor using mechanical stirring followed by ultrasonication for homogeneity. After thorough mixing and degassing under vacuum, the mixture was cured in a mold at 70°C for 45 minutes. This process yielded a flexible skin of approximately 1 mm thickness. The resulting skins are semi-transparent in ambient light and reveal their programmed color upon UV exposure (typically 395 nm).

III. ADAPTIVE MARKER ACTIVATION AND PROPERTIES

Experiments were conducted to characterize the key adaptive properties of the elastomers. The results demonstrate capabilities including color tunability, selective activation, reversibility, and suitability for visual tracking:

Selective Activation: Fig. 2c, 2g illustrates global activation, where uniform UV illumination activates the prepared purple and blue samples across their surfaces. In comparison, Fig. 2h shows local activation achieved using a focused UV source, rendering color visible only within targeted regions on these samples. This capability allows for the selective activation of markers in ROIs.

Reversibility and Transparency-tunable: The photochromic activation is fully reversible. Under UV light exposure, color activation occurs nearly instantaneously, on the millisecond (ms) timescale. Upon UV removal, the color fades within seconds(Fig. 1), restoring semi-transparency for potential visual pass-through. Adjusting the formulation's photochromic concentration tunes this relaxation time.

Suitability for Tracking: Crucially, the activated markers, either exposed to UV light globally or locally, exhibited high visual contrast against the transparent PDMS background in our experiments (Fig. 1). This observation confirms their suitability for use with established feature tracking algorithms fundamental to VBTS deformation analysis.

Configurable Color: As detailed in Section II, varying the photochromic composition enables color configurability. Under uniform UV illumination, elastomer samples reliably displayed distinct, stable colors based on their formulation, such as the purple and blue variants prepared (Fig. 2e-h).

IV. CONCLUSION AND FUTURE WORK

We introduced Chameleon Touch, validating adaptive VBTS markers via photochromic PDMS skins exhibiting tunable color, selective activation, rapid reversibility, and high tracking contrast (Section III). The material's photochromic mechanism and demostrates its function when integrated into a typical VBTS. Key future steps involve sensor integration and adaptive control development. The potential for advanced schemes (e.g., adaptive resolution) motivates this direction toward more versatile robotic touch.

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