

M13 Bacteriophage-Based Colorimetric Electronic Noses for Complex VOC Discrimination toward Humanoid Olfactory Display

Yujin Lee¹ and Jin-Woo Oh^{1,2,*}

¹ Humanoid Olfactory Display Innovation Research Center, Pusan National University, Republic of Korea

² School of Transdisciplinary Engineering, Pusan National University, Republic of Korea

*ojw@pusan.ac.kr

Mammalian olfaction discriminates subtle differences among complex volatile compounds through the collective responses of cross-reactive receptors and neural processing of the resulting response patterns. Inspired by this mechanism, M13 bacteriophages provide a versatile building block for artificial olfactory sensing: their surface chemistry can be programmed through genetic engineering, while their self-assembled nanostructures generate structural color. Each phage carries approximately 2,700 copies of the major coat protein pVIII, on which diverse peptide motifs can be displayed as artificial receptor elements. When volatile organic compounds (VOCs) interact with these receptors, swelling and structural modulation of the self-assembled phage bundles produce rapid, reversible optical responses quantifiable as RGB color changes [1,2]. This invited talk presents the development of an M13 bacteriophage-based colorimetric electronic nose for detecting and discriminating complex VOCs.

The sensing characteristics of the phage-based electronic nose can be tailored through both chemical and physical programming of the phage films. Computational screening and density functional theory calculations combined with genetic engineering identified peptide receptors with distinct molecular affinities, enabling sensitive discrimination of chemically related VOCs, including explosive and hazardous compounds [3]. Beyond receptor design, neural pattern separation and sensor-array optimization were introduced to extract discriminative information from cross-reactive response patterns: for structurally similar polycyclic aromatic hydrocarbons, selective sensor combinations increased the classification success rate from 85% with the full array to 97.5% [4]. The same bio-inspired concept was extended to human breath, where optimized receptor combinations discriminated lung cancer patients from healthy subjects [5].

The platform has subsequently been applied across diverse chemical and biological environments, distinguishing endocrine-disrupting chemicals and structurally related vapors, and monitoring peach and banana freshness and ripening. In apples, a 20-receptor array with sensor-combination optimization simultaneously classified four standard aroma compounds, apple cultivars, and aging-related odor changes, resolving multiple attributes within a single complex VOC mixture [6]. The approach was further extended to non-intrusive assessment of cardiovascular cell differentiation through volatile signatures of cellular respiration [7]. Together, these studies show that M13-based electronic noses translate diverse, overlapping chemical information into characteristic optical fingerprints rather than relying on a single analyte-specific response. Building on these advances, current research at the Humanoid Olfactory Display Innovation Research Center is extending the platform toward intelligent olfactory sensing through expanded receptor libraries, standardized sensor-array fabrication and optical measurement, and AI-assisted pattern analysis for real-world environments.

Keywords: M13 bacteriophage; Colorimetric electronic nose; Structural color; VOC discrimination; Sensor array; Humanoid olfactory display

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