Inkjet-Based Olfactory Displays: A Next-Generation Approach to Digital Scent

1. Adding Smell to the Digital World

Imagine watching a movie where you can smell the ocean breeze or playing a cooking VR game where spices fill the air. Our sense of smell is deeply tied to memory, emotions, and how we feel immersed in an environment. Virtual reality has mastered sight and sound — but ***smell*** remains a new frontier.

The sense of smell can trigger deep emotional responses, strengthen memory, and heighten realism. This is why olfactory displays are emerging as a vital part of immersive technologies in:

- Entertainment (VR movies, games)
- Training and safety simulations
- Cognitive and memory rehabilitation
- Therapeutic environments
- Marketing and multisensory interaction

Olfactory displays used today originated from **airflow-based scent modulation**, utilising technologies such as solenoid valves — an important and well-developed foundation in research from the Institute of Science, Tokyo, and others. These systems have enabled sophisticated scent blending and real-time odor activation. As the field advances, however, researchers aim for even **higher precision, faster modulation, miniaturisation**, and the capability to blend many scents at once, which naturally leads to **inkjet-based olfactory technology**.

2. From Airflow to Droplets: The Inkjet Concept

The inkjet-based olfactory system adopts the same principle as inkjet printing — but instead of ink droplets forming an image on paper, **odorant droplets evaporate into the air** to form a smell.

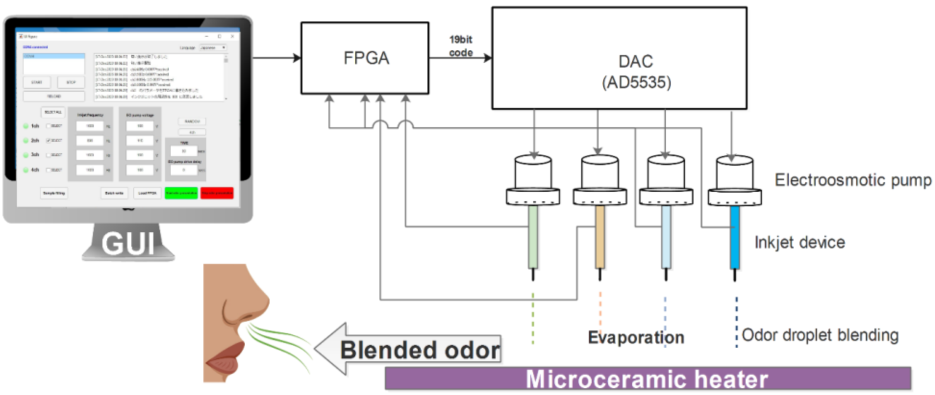

Figure 1: Block diagram of the olfactory display

Key device components

Component	Scientific Role
Electro-osmotic (EO) pump	Controls smooth liquid flow from the reservoir
Piezoelectric inkjet nozzle	Ejects controlled picoliter-scale droplets
Micro-ceramic heater	Vaporizes droplets rapidly into gas-phase odor
Airflow conditioning (DC fan)	Directs scent carefully toward the user

How inkjet olfaction works

- Scent liquid is stored in small reservoirs
- A tiny pump called an **electro-osmotic pump (EO pump)** pushes the scent gently
- A **piezoelectric-driven inkjet nozzle** releases exact volumes of odor liquid, often 160–300 picolitres (pL) per droplet.
- The droplet rate is controlled by frequency — a digital and linear parameter
- EO pump voltage adjusts backpressure, ensuring stable ejection without flooding or clogging
- **Droplets evaporate → scent molecules disperse → user smells it immediately**

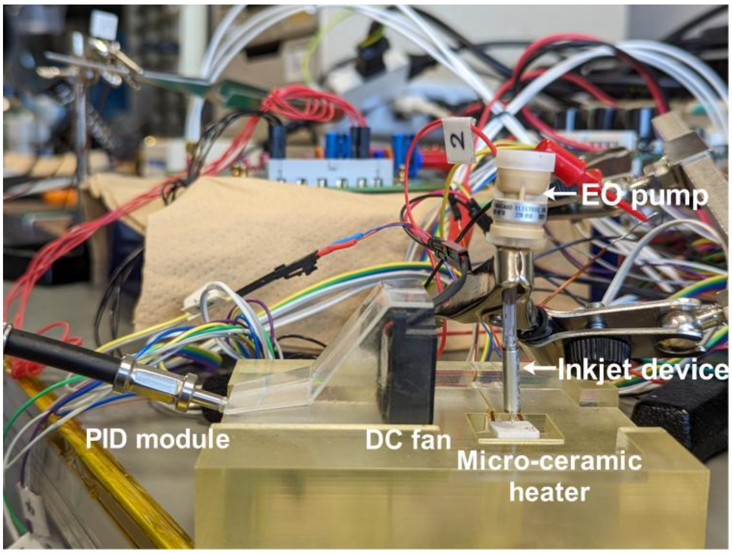

Figure 2: Experimental setup of the inkjet device placed above the microceramic heater with the 12 VDC fan placed

3. **Hardware–Software Architecture of the Inkjet-Based Olfactory Display**

The inkjet olfactory display employs an integrated hardware–software framework designed for precise spatiotemporal control of scent release. Liquid odorants are driven by an electro-osmotic (EO) pump, ensuring a stable microfluidic supply to a piezoelectric inkjet nozzle that ejects highly controlled picolitre droplets. System control is executed through an FPGA platform capable of high-speed pulse modulation, with EO pump backpressure tuned via a multi-channel DAC for independent channel regulation. A MATLAB-based GUI provides real-time parameter configuration—frequency, voltage, pulse duration, and channel activation—enabling dynamic and programmable odour presentation suitable for immersive multisensory environments.

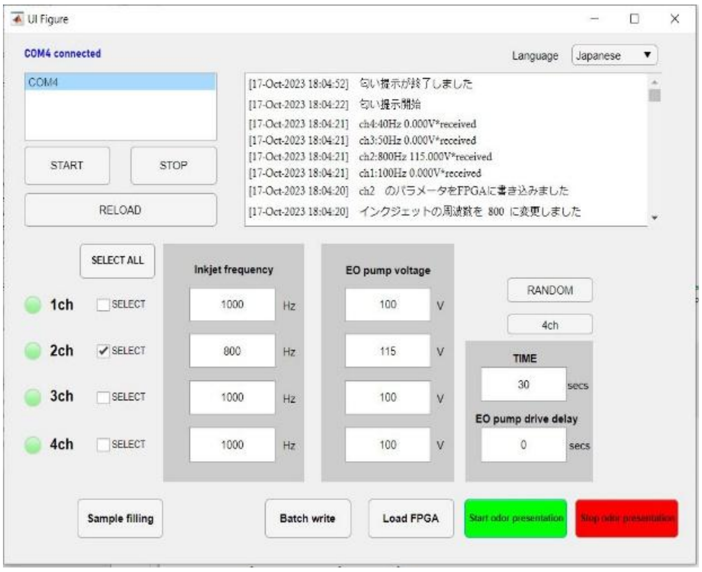

Figure 3: MATLAB GUI for controlling the inkjet device

Because each droplet is so tiny, the system can:
✓ Change smell intensity in tiny steps
✓ Mix multiple aroma components like blending colours
✓ Release scent fast and stop instantly
✓ Prevent odor from sticking inside tubes
✓ Allow compact and wearable form factors

4. Evaporation & Airflow: Making the Scent Travel

To fully transform droplets into airborne scent molecules, evaporation must be instantaneous — especially for low-volatility fragrance compounds.

A **micro-ceramic heater** placed under the droplet stream:

- Efficiently reaches temperatures from **68°C → 326°C** (depending on input voltage)
- Vaporises droplets within milliseconds
- Operates with a **simple, compact design** suitable for future miniaturisation

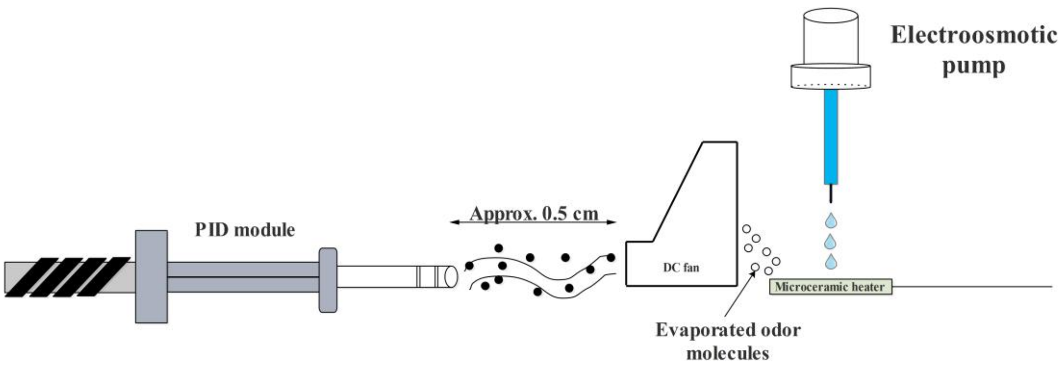

Figure 4: The block diagram of the measurement condition when the fan is placed in front of the micro-ceramic heater.

Airflow = Direction + Comfort

A precisely positioned **DC micro-fan** ensures the vapor moves:
→ directly toward the user's nose
→ without spreading to the surroundings

Results show that placing airflow **in front** of the heater gives:

- **Stable concentration profiles**
- **Consistent repeatability between trials**

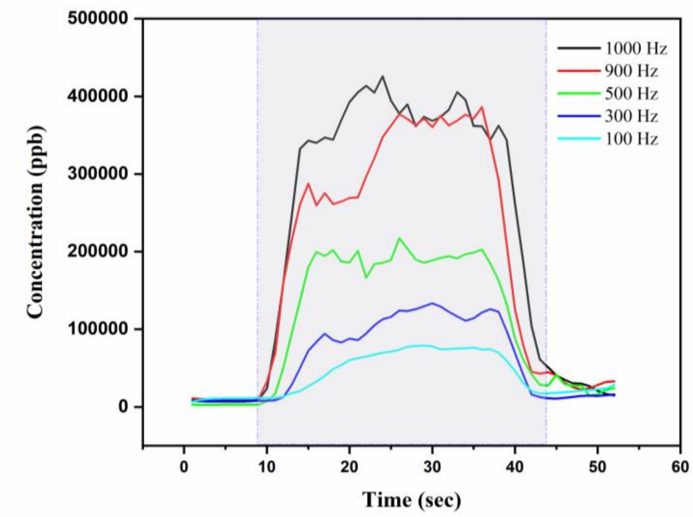

Figure 5. PID responses for inkjet devices with DC fan position (a) front operating at 1000, 900, 500, 300, and 100 Hz, respectively

5. Scalable Mixing — Toward "Smell Pixels"

One of the most exciting scientific outcomes is the ability to **mix odor components digitally**.

Each channel behaves like a **scent source**:

- The system can blend multiple droplets from different reservoirs
- Intensity is digitally programmable per channel
- Complex aroma profiles can be formed — similar to RGB mixing for colour.

6. What Makes Inkjet Olfaction Scientifically Interesting?

Instead of replacing prior systems, inkjet devices represent the **next step in the technology continuum**:

Research Evolution	Key Capability Added
Piezo elements releases droplets exactly	Consistent smell strength
Heater helps liquid transform to gas faster	Instant scent change
Fan shapes scent plume direction	Ensures only *you* smell it
Short scent pulses prevent “nose fatigue”	Better VR immersion
Frequency & voltage adjust output	Perfect for real-time gaming/movie sync

This evolution preserves valuable experience and infrastructure, while **expanding performance possibilities** in accuracy, form factor, and multisensory depth.