JDLED: Towards Visio-Tactile Displays Based on Electrochemical Locomotion of Liquid-Metal Janus Droplets

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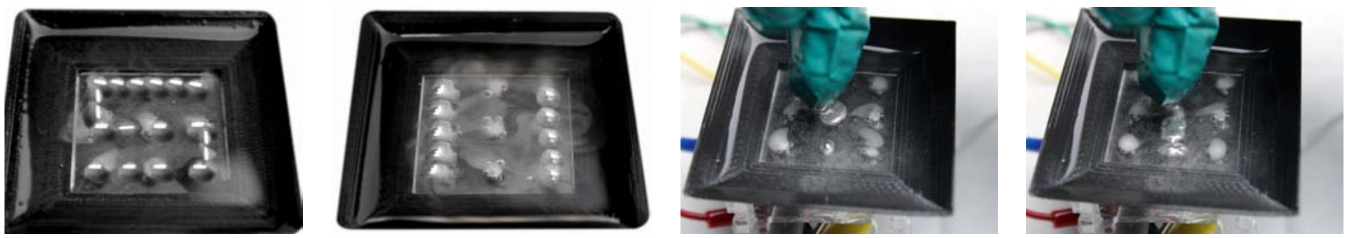

(a) (b) (c) (d)

Figure 1. Applications of JDLED. In (a), a pixel is moving on flat surface to show the alphabet "S". In (b), two pixels are moving to show an "equalizer" widget. In (c) and (d), the pixel is moving back and forth under the finger to provide tactile sensation.

ABSTRACT

An actuated shape-changing interface with fast response and small pixel size using a liquid material can provide real time tangible interaction with the digital world in physical space. To this end, we demonstrate an interface that displays user-defined patterns dynamically using liquid metal droplets as programmable micro robots on a flat surface. We built a prototype using an array of embedded electrodes and a switching circuit to control the jump of the droplets from electrode to electrode. The actuation and dynamics of the droplets under the finger provides mild tactile feedback to the user. Our demo is the first to show a planar visio-tactile display using liquid metal, and is a first step to make shape-changing physical ephemeral widgets on a tabletop interface.

Author Keywords

Shape-changing Interface; Tactile Display; Liquid-metal; Gallium Indium Eutectic; Bipolar Electrochemistry; Electric-field Control; Janus Particle; Micro Robot.

ACM Classification Keywords

H.5.2. Information Interfaces and Presentation (e.g. HCI): User Interfaces, Haptic I/O, Prototyping

INTRODUCTION

Shape changing visual and tactile displays can provide tangible interactions with the digital world by giving it physical form [7]. Devices based on actuated rods are used to probe this interaction space [3, 4, 14]. Various actuators, e.g. shape memory alloy [2], pneumatic [5], electromagentic [13], electrostatic [15], and deformable materials such as rubber and fabric are used as the tactile interface [9, 15]. PixieDust and JOLED used moving polystyrene beads to show visual information [12, 16]. Programmable blobs used slow moving large magnetic fluid blobs to present computer graphics in physical visual form on a flat surface [17]. Ferrofluid has been used for haptic feedback on a tabletop [6, 8]. LIME used liquid metal blobs constrained in cells to make small tangible visual and tactile widgets [11]. We propose JDLED (Janus Droplet Locomotion in Electric-field Display), a visio-tactile display that uses liquid metal droplets on a large flat surface, and a mechanism to move droplets fast and with smaller size using embedded electrode array. The novelty of JDLED and its unique applications are presented next.

WORKING PRINCIPLE

JDLED relies on locomotion of liquid-metal droplets from electrode to electrode. It is based on the bipolar electrochemistry phenomena and formation of Janus droplets in an electrolytic solution [10]. In an external electric field, a potential difference is created across the two ends of the droplet which results in different oxidation and reduction reactions at the two ends. It creates different electrons and ions, and forms a Janus droplet with asymmetric electrical charge distributions at the two ends [18]. The droplets, as a result, feel a force in the external electric field and move along its direction towards the anode. JDLED controls the droplets by modulating and distributing the electric field.

LIME (cf. [11]) used another mechanism in which the liquid metal blob in contact with anode spreads towards the cathode without jumping due to surface oxidation. Prior work of liquid metal uses it in channels which is not suitable to make a tactile display. Manipulation of liquid droplets using open

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electrode arrays uses electrowetting on dielectric (EWOD) [1]. Metallic liquid droplets are not suitable for this approach.

IMPLEMENTATION

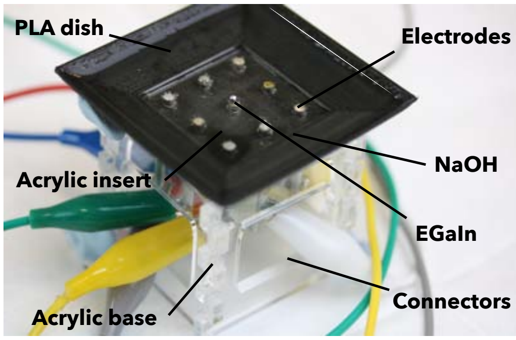


Figure 2. An early prototype of JDLED is shown. EGaIn droplets jumping from electrode to electrode in NaOH solution show different programmed patterns to the users which can be touched wearing finger cots.

Figure 2 shows an early implementation of JDLED. Gallium Indium eutectic (EGaIn) and Sodium Hydroxide (NaOH) are used as the liquid metal and the electrolyte which pose low risk hazard. An acrylic sheet is used at the base which allows the droplets to move freely without adhesion. Steel rods with 2.34 mm diameter are used as the electrodes on which the EGaIn droplets move freely without adhesion. A 3×3 array of electrodes with 10 mm separation is embedded in the acrylic surface and are exposed to the NaOH solution. A 3D printed dish houses the electrolyte, EGaIn droplets and the electrodes. The electrodes are connected to an 3×3 array of H-bridge switches made from L293 dual-channel H-bridge motor drivers and controlled using an Arduino Mega microcontroller. A desktop power supply provides 10 V voltage with 1 A current limit to the driver circuit.

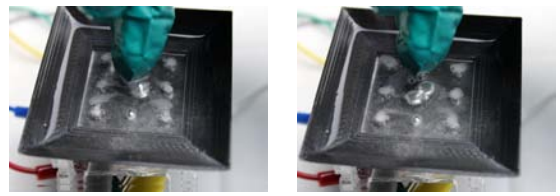
VISUAL APPLICATIONS

We present the unique applications of JDLED. In Figure 1(a) and (b), the initial demonstration of visual effects of JDLED are shown. In Figure 1(a), a millimeter size liquid metal droplet is moving like a micro robot on a flat surface to show the letter “S”. The unique capability of this display is the *fast* controlled-locomotion of a deformable pixel on a flat surface. For example, the programmable blobs are significantly slower in comparison [17]. Games, toys or physical placement and movement of pointers for data navigation could benefit from JDLED-like displays.

In Figure 1(b), two liquid metal droplets are moving to show a widget with two slider knobs. The unique capability of this deformable widget is its higher resolution, i.e., smaller pixel size and spacing between nodes, and ephemeral implementation without liquid metal operating in a channel or cell like in LIME [11]. JDLED widgets such as slider, dial and switch knobs could be combined with a JDLED or projected tabletop display for tangible interaction.

TACTILE SENSATION

LIME explored the static force feedback while pressing liquid metal covered with a film in an enclosed cell [11]. JDLED provides tactile sensation using the dynamic forces from the liquid metal droplets on a flat surface under the finger using two mechanisms. Under the first mechanism, the droplets are moved under the finger by switching the electrode voltages like in the visual mode (see Figure 1(c) and (d)). Under the second mechanism, a DC voltage is applied. At a suitable lower voltage the droplets start deforming between spherical and flat shapes (see Figure 3 (a) and (b)). Further lowering the voltage switches off the deformation and the tactile feedback. Due to 6.25 times higher density, liquid metal can provide better tactile sensation than water droplets moving under the finger. The JDLED tactile display using the second mechanism is used to demonstrate braille alphabets (see Figure 4). The tactile sensation is mild. A user study is being investigated to explore the tactile sensations that JDLED can elicit.



(a) (b)

Figure 3. A JDLED pixel is deforming between spherical and flat shapes in response to an appropriate DC voltage to provide tactile sensation.

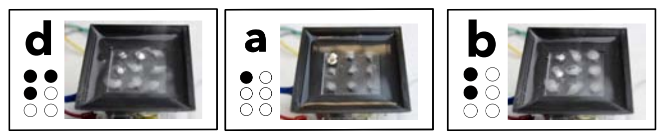


Figure 4. Braille letters ‘d’, ‘a’ and ‘b’ are created in a JDLED tactile display.

LIMITATIONS

JDLED needs to be on a flat surface. Gloves or finger cots are required to touch JDLED pixels as EGaIn and NaOH can cause minor skin irritation. A thin film covering the NaOH solution with provision for venting the oxygen and hydrogen gases from electrolysis could be used. The 3×3 electrode JDLED prototype drew 400 mA current at 10 V DC voltage consuming 4 W power. The power consumption could be reduced using pulse width modulation (PWM) and shaping input voltage signals. To avoid interference and related instability in operation, the anode needs to be surrounded by cathodes. The droplet size and electrode size, separation and voltage dictate the potential difference across the droplet which needs to be high enough for asymmetric electrochemical reactions to create the Janus droplet. These parameters need to be tuned for desired speed and resolution of JDLED.

CONCLUSION

JDLED is a novel display offering both visual and tactile information to the user. We present the first demonstration of locomotion of liquid metal droplets on a flat surface. Two novel mechanisms providing tactile sensation using liquid metal are presented. Despite limitations in force, range and resolution, JDLED shows the possibility to use liquid metal droplets as an ephemeral display for physical visualization and tangible interaction. Our vision is that JDLED will lead to compelling applications to provide real time usable physical interaction with the digital world.

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