# Puppeteered Rain: Interactive Illusion of Levitating Water Drops by Position-Dependent Strobe Projection


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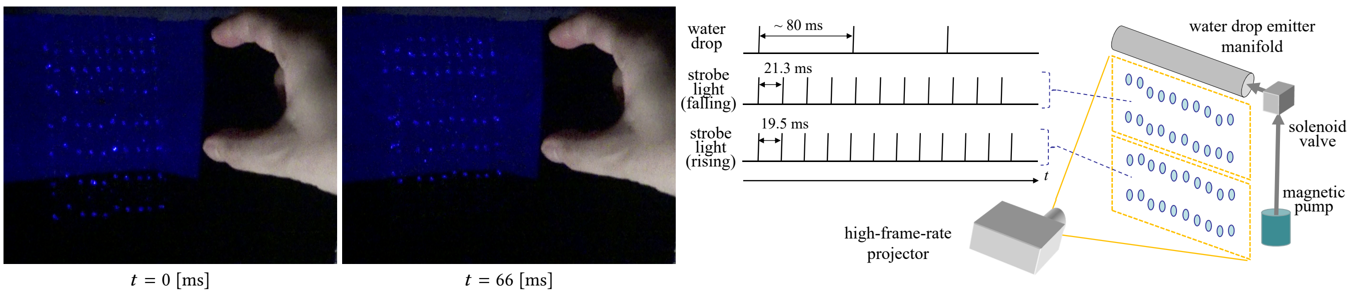


**Figure 1: (Left) Snapshots of illusion by which water drops appear to be absorbed slowly into a horizontal line determined by the hand gesture. (Right) Schematic diagram of the system and an example arrangement of strobe periods.**

## CCS CONCEPTS

• **Human-centered computing** → **Interaction devices**;


## KEYWORDS

high-speed projection, optical illusion

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## 1 INTRODUCTION

Light projection onto falling water produces distinct and impressive experience which is suitable for entertainment and advertising installations in public spaces [Barnum et al. 2010; Eitoku et al. 2006]. One of popular and classical techniques used in illuminating water for such purposes is strobe lighting, which presents optical illusion of levitating — or slowly falling or rising — water drops depending on the relation between water dropping and strobe lighting frequencies (e.g. [Pevnick 1981; Rosenthal 1984]).

The use of a single strobe light limits the capability of spatial control of drops. Consider the case that we have a horizontal 1D array of water drop emitters to produce a 2D wall of apparent water drops. To render different rise and fall motions of drops for different positions, we at least need to control water emitting frequencies for individual water drop emitters, which however is not sufficient to flexibly control the 2D pattern of the drop motions, because the apparent motions of the drops in a single vertical line is ruled by the operation of the corresponding single drop emitter.

Instead of using a single strobe light, we propose to use a high-frame-rate projector such that light rays with slightly different strobe frequencies can be produced in a position-dependent manner. Even with a simple water emitter array controlled by a single valve, it is possible to individually control the rise and fall motion of each apparent drop in the water wall. In this paper, we describe a pilot implementation of such a system, in which a user can interact with the formation of the drop motions.

## 2 PROJECTION-BASED WATER LEVITATION ILLUSION

Let us assume that a water emitter discharges water drops at frequency $f$. With a strobe light at frequency $Nf$ where $N$ is an integer, the apparent motions of the drops caused by the strobe effect become still. When the falling velocity of a water drop at a position is $v$, the spacing between the apparent drops around that position is $v/Nf$. The strobe frequency $Nf$ should be high enough to exceed the critical flicker fusion frequency of human vision so that the persistence of vision is effective.

With the implementation setup described in Section 3, we had $f$ = 12.5 [Hz], and $v$ in the projection area ranged approximately from 1 to 3 m/s depending on the height because the display size is not large enough for the water drops to reach the terminal velocity. With $N$ = 4, i.e., the strobe frequency at 50 Hz, the persistence of vision enables perception of still water drops with inter-drop spacing approximately from 20 to 60 mm depending on the height.

When the strobe period is $1/(Nf)$, a series of water drops successively reaches the same height at every $N$ strobe instant. With a slightly longer strobe period $1/(Nf) + \Delta t$, the water drop coming



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next to the one that visits a height $y_0$ at time $t = 0$ will visit the height $y_0 + vN\Delta t$ at time $t = N\{1/(Nf) + \Delta t\}$. This renders the apparent water drop velocity $vN\Delta t/(1/f + N\Delta t)$ downward. Similarly, an apparent motion of slowly rising water drops is rendered with a shorter strobe period, say, $1/(Nf) - \Delta t$.

An important condition here is that $\Delta t$ should be small. For example, with $f = 12.5$ [Hz], $N = 4$ and $v = 2.0$ [m/s], setting $\Delta t = 0.001$ [s] renders the apparent velocity of 0.095 [m/s]. However, setting $\Delta t = 0.05$ [s] gives 1.4 [m/s], which is on the same order of the native water drop velocity and severely limits the usefulness of the strobe effect. Whereas controlling the strobe period at millisecond granularity is easy for a single strobe light, it is not straightforward to achieve this fine granularity of timing control in position-dependent manners using a standard video projector. When larger $f$ and $N$ are employed to present apparently denser water drops, the requirement on $\Delta t$ becomes tighter.

In contrast, a Digital Micromirror Device (DMD), which is a spatial light modulator used in Digital Light Processing (DLP) projectors, is able to display up to tens of thousands of binary frames per second if dedicated controllers for high frame rate purposes are incorporated. Next Section describes our implementation using a DMD projector for position-dependent strobe lighting.

## 3 IMPLEMENTATION AND FUTURE WORK

Our prototype, shown in Figure 2, is equipped with a water drop emitter array made of a polyvinyl chloride pipe with 3-mm diameter holes spaced at 17-mm intervals. The input flow to the pipe is pulsed by a single solenoid valve to generate 12.5-Hz water drops. The dropped water is stored in a tank located under the projection area, from which the water is taken up to the valve again by a magnetic pump.

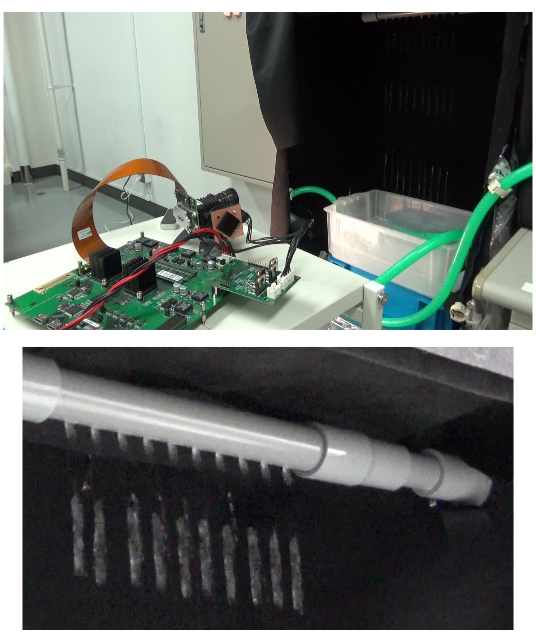

**Figure 2: (Top) Overview of the implementation. (Bottom) Water emitter array.**

We use a high frame rate projector consisting of a Texas Instruments DLP7000BFLP DMD and a custom controller [Kagami and Hashimoto 2018], which is able to display up to 2,470 binary frames per second. With this controller, one is able to repeatedly project a sequence of binary patterns stored in a within-projector memory. By designing the pre-stored pattern sequence, we are able to generate a position-dependent strobe pattern of which the period in each pixel can be designed at the granularity of $1/2470$ [s] $\simeq 0.405$ [$\mu$s] at minimum.

With the binary frame time set to 453 $\mu$s, a strobe period of 45 frames was confirmed to make the water drops appear to be almost still. Therefore, slightly shorter strobe periods (e.g. 44 or 43 frames) render rising motions and longer periods render falling ones. An example configuration is shown in Figure 1. With this configuration, the top half of the projection area renders slowly falling water drops while the bottom half shows slowly rising ones, which therefore gives an illusion of the water drops being absorbed into the boundary line between the top and bottom areas. By interchanging the projection patterns in the two areas, an illusion of the water drops fountaining from the mid air is presented.

Our controller is also equipped with the functionality of warping the stored binary frames according to homography warp parameters provided through a USB interface on the fly. Using this functionality, interactive manipulation of the location, size, and shape of the projected patterns — and therefore the apparent motion pattern of the water drops — is achieved. We implemented hand gesture based control of projected patterns using a Leap Motion controller such that, for example, the position of the apparent water absorption sink or the fountain source can be interactively moved and switching between water absorption and fountaining can be instructed through the palm direction.

Current implementation is limited by insufficient brightness of the projector light source. This is why the supplemental video had to be taken with a high camera gain, resulting in noisy pictures. In future work, we will improve the light source for better visibility. Future work will also include increasing the number of drop emitters to enable more flexible contents design.

## ACKNOWLEDGMENTS

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## REFERENCES

Peter C. Barnum, Srinivasa G. Narasimhan, and Takeo Kanade. 2010. A Multi-Layered Display with Water Drops. In *SIGGRAPH 2010*.

Shin'ichiro Eitoku, Tomohiro Tanikawa, Yasuhiro Suzuki, Koichi Hirota, Toshio Iwai, and Michitaka Hirose. 2006. Display Composed of Water Drops for Filling Space with Materialized Virtual Three-dimensional Objects. In *IEEE VR 2006*.

Shingo Kagami and Koichi Hashimoto. 2018. A Full-Color Single-Chip-DLP Projector with an Embedded 2400-fps Homography Warping Engine. In *SIGGRAPH 2018 Emerging Technologies*.

Stephen H. Pevnick. 1981. Program Controllable Free Falling Water Drop Fountain. US Patent 4,294,406. (1981).

L. Kenneth Rosenthal. 1984. Optical Illusion Beverage Dispensing Device. US Patent 4,426,021. (1984).