Polka: A Water-jet Printer for Painting on the Grounds

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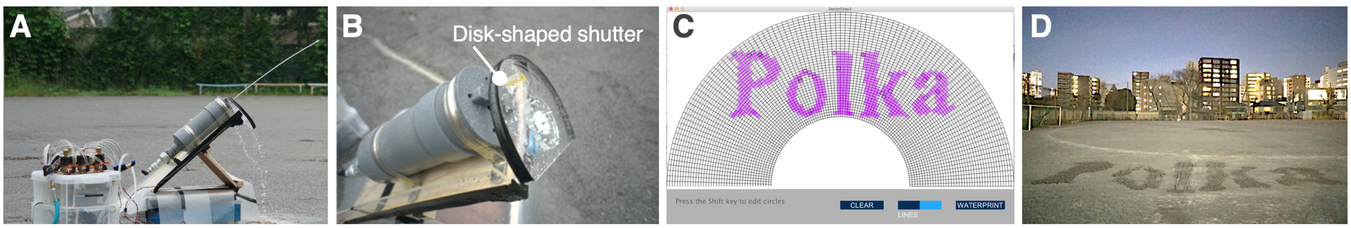

Figure 1: (A) Polka can draw letters and illustrations on large, flat surfaces. (B) Disk-shaped shutter attached to improve the valve response performance. (C) Integrated design tool for Polka. It converts the drawing into commands for water-jet painting. (D) Water-jet printed letter "Polka" on the schoolyard.

ABSTRACT

We propose a method for controlling a device that draws letters and illustrations on large, flat surfaces. Similarly to conventional inkjet printers, the device ejects a volume of water from its nozzle, with the water droplets then forming dots on surfaces such as soil, concrete, and sand. Both the direction of the nozzle and the water pressure can be controlled to enable the device to draw arbitrary two-dimensional patterns within a semicircular region with a radius of six meters. The device can draw letters and illustrations. We have investigated the pressure, the shape of the nozzle, and droplet size in order to avoid further division of the droplets into even smaller droplets while traversing the air. In this paper, we introduce the mechanism of this device and demonstrate how a user can take advantage of this new drawing tool.

CCS CONCEPTS

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

KEYWORDS

Water-jet Printing, Public Display, Sprinkler.

AVI '20, September 28-October 2, 2020, Salerno, Italy

ACM ISBN 978-1-4503-7535-1/20/09…$15.00
https://doi.org/10.1145/3399715.3399817

ACM Reference Format:
Reona Nagafuchi, Yasushi Matoba, Kaori Ikematsu, Ayaka Ishii, Yoshihiro Kawahara, and Itiro Siio. 2020. Polka: A Water-jet Printer for Painting on the Grounds. In *International Conference on Advanced Visual Interfaces (AVI '20), September 28-October 2, 2020, Salerno, Italy*. ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3399715.3399817

1 INTRODUCTION

People have used the ground as a canvas for artistic expressions since ancient times. The lines and geoglyphs of Nasca and Palpa are large works of art formed by depressions or shallow incisions made in the soil[1]. These large-scale patterns create an impressive visual effect. Recently, a large body of research has focused on large-scaled images, such as on the grass fields [22], sandy beaches [19], and flat surfaces [20]. However, these methods are limited in being adaptable only to specific surfaces, or else they require specialized "inks" (e.g., powders processed from foodstuffs [20]).

We propose a novel water-jet printing system called Polka (Fig. 1). The system enables a user to draw letters and illustrations on large, flat surfaces such as soil, concrete, and sand. Similarly to conventional inkjet printers, the device ejects a volume of water from its nozzle with the water droplets forming dots on surfaces such as soil, concrete, and sand. Both the direction of the nozzle and the water pressure can be controlled to enable the device to draw arbitrary two-dimensional patterns within a semicircular region with a radius of six meters. The printing area can be designed in our integrated design tool. The tool converts a pattern drawn by a user or an uploaded image into a command for printing; then the device ejects a volume of water from its nozzle with the water droplets forming dots on surfaces. In this paper, we investigated (1) how the appearance of water droplets changes depending on

[1]http://whc.unesco.org/en/list/700/

the surface types and the traveling distance, and (2) the accuracy of controlling the traveling distance of a water droplet. We also show some examples drawn using Polka.

2 RELATED WORK

Public Display Systems. An emerging stream of research has focused on displays that presents digital information on public spaces. These displays are often installed outdoors or in large indoor spaces vertically because they can save space located [10, 14, 15]. Furthermore, based on the fact that many pedestrians look at the floor regularly, a large interactive display using floor space through laser projection was proposed [13]. In our work, Polka can print information computationally in a manner similar to that of public interactive displays while targeting the surface of the land.

Drawing systems that can provide personally customized information have also been proposed. SweepScreen is a digital paintbrush for printing lasting free-form images [12]. A user sweeps it onto magnetophoretic surfaces to leave messages and images. Dotanco is a stamp-based product, controlling a stamp pattern electronically [7]. A number of studies utilizing everyday physical materials as pixels have been conducted. Sugiura et al. developed a tool for drawing letters and pictures on carpets by manipulating the fibers' directions [21]. They also proposed a display technology that enables a user to draw large-scale images on a grass field [22]. Sustainabot is a small robot printer that deposits foodstuffs such as salt in patterns on a flat surface, controlled by a mobile phone [20]. We propose a computer-controllable sprinkler device to create the larger-scale drawings than the conventional examples. BeachBot is a system similar to our system that can perform large-scale drawing [19]. This system consists of an autonomous robot that crawls around the beach and creates large-scale sand drawings. Although the robot can draw only on flat sandy beaches, our system uses watering and can draw on various land surfaces.

Display Methods Using Water. In Polka, we use water as ink to draw characters and images on the ground. In a similar vein, there are artworks that write temporary messages on roads by spraying water from multiple nozzles behind a bicycle or car [4, 17]. Several display systems using water itself as pixels to present information have also been proposed. Bit.Flow [16] is a display that uses water drops moving in a tube as pixels. Several tubes are arranged vertically, and characters can be displayed by controlling the positions of colored water drops poured from each tube. In association with Bit.Flow, a system called Tuve, has been proposed that uses a single tube that wraps around various objects to create a dynamical shape-changing display [6]. All of the display systems mentioned above have the property of ephemerality. For example, water sprinkled on the road evaporates, disappearing over time. In the tube-like systems, characters are formed gradually from a mere collection of bits that eventually flow and disappear. Therefore, the information displayed is precious , and it is considered that users will naturally pay attention to it. Consequently, user interfaces that use properties of materials that exist only temporarily are classified as ephemeral user interfaces [2, 3]. Since our system displays large, public, and ephemeral information, we believe that it could provide the possibilities for brand new experiences in the context of ephemeral user interfaces.

Some studies have used water as display screens. FogScreen is a system that projects images onto fog [18]. We can touch or walk through the fog, as the images appear to float in mid-air and the screen feels just like air. Barnum et al. proposed a multi-layered display using water drops as voxels [1]. A 2.5-dimensional display is created by projecting pictures and video onto water droplets using a single projector-camera system. AquaTop display is an interactive water surface display system used within a bathing environment [8]. A user in a bathtub can browse information using water-specific gestures that are intuitive for water-based interaction without a tablet or a smartphone. Scoopirit is a display system that enables users to scoop a mid-air image at an arbitrary horizontal position under and on a water surface [11]. These display systems are limited in that they cannot be used in bright light. Our method utilizes the water as pixels and enables to draw various patterns on the ground.

3 POLKA

We propose Polka, a water-jet printer for painting on large, flat surfaces. Similarly to conventional inkjet printers, the device ejects a volume of water from its nozzle with the water droplets forming dots on surfaces. Polka can draw letters and illustrations on surfaces by controlling the traveling distance and angular direction of droplets computationally.

3.1 Hardware Configuration

Figure 2 shows the hardware configuration. The water supply is branched into multiple (six in the prototype) waterways, each of which is gathered into a single water channel using a pressure regulating valve and an electric valve. Various water pressures can be set at the nozzle using the multiple regulating valves. In the case reported here, the six regulating valves are set to different water pressures (e.g., 1: 2: 4: 8: 16: 32). It can theoretically create 64 linear levels (the number of combinations selecting one or more values) of water pressure on opening or closing the electric valves. It takes time to reach the indicated water pressure because the electric valve takes time to open and close. When the water pressure is insufficient, a small amount of waterfalls on the line segment between the nozzle and the target point. To prevent this, we added a disk-shaped shutter in front of the nozzle (see Fig.1 (B)). This shutter shuts off the water when the electric valves are in their transition states, that is, when the valves are not perfectly opened or closed. The water channel is connected to the injection nozzle installed on a turntable. The turntable adjust the horizontal angle

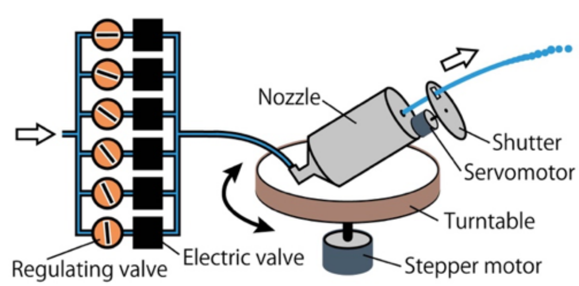

Figure 2: Hardware Configuration.

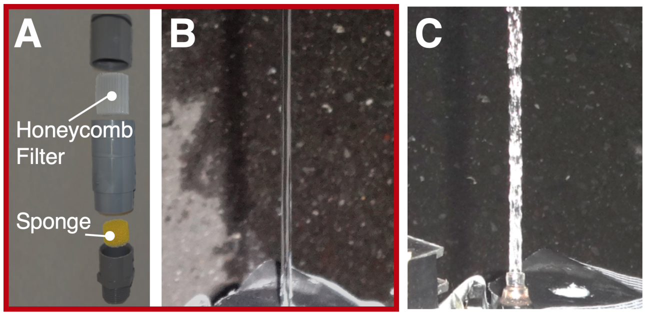

Figure 3: (A) Nozzle structure. The diameter of the nozzle tip is 5.0 mm. (B, C) Comparison of turbulence between (B) with and (C) without nozzle improvement. Note, (B) and (C) were taken at the same shutter speed with photoflash.

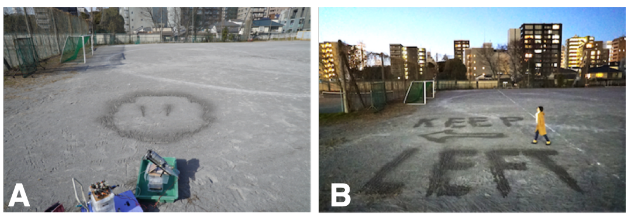

Figure 4: Execution results for (A) a sports track, and (B) "KEEP LEFT" letters.

of the nozzle by rotating with a stepping motor. The electric valve and the stepping motor are controlled using the microcomputer Raspberry Pi.

It is desirable that droplets land on the ground with minimum scattering, but owing to air resistance, an ejected beam of water does not fall to one point. Many water droplets are scattered because as shown in Fig. 3 (C), ejected water is unstable in air, and the surface of the moving water generates waves before landing. To reduce scattering, we installed a sponge and a honeycomb filter inside the nozzle (Fig. 3 (A)). This mechanism produces laminar flow and is known to be effective for regulating water flow [5, 9]. Fig. 3 (B) and (C) shows the water column immediately after it is ejected from the nozzle. In (B), the turbulence of the water surface is smaller than in (C). In our preliminary testing, even with an improved nozzle, we observed too excessively satellite droplets for traveling distance greater than six meters. Consequently, we limited the maximum range to six meters as an appropriate distance in the prototype.

3.2 Design Tool

We also implemented an integrated design tool for water-jet printing that runs on macOS. The tool enables a user to design the water-printing areas from a graphical user interface. The application window includes a fan-shaped area that is divided into 40 × 100 subareas (Fig.1 (C)). Subareas correspond to the traveling distances in 40-step intervals, and in angular directions in 100 steps (1.8-degree). The entire area corresponds to a semicircle with a radius of six meters in the real world. A user can specify watering areas and amounts of water by drawing on the window, and then specify the watering sequence by clicking the drawn areas. Once a user has finished editing, the user-specified areas including the amount and sequence are converted to commands for water-jet printing. The commands are processed using the control program on Raspberry Pi. Then, Polka changes the angle of the nozzle in the direction given by the coordinates, opens and closes the solenoid valve, and then ejects water.

4 EXAMPLES OF WATER-JET PRINTING

Using the design tool, we tested the printing of simple characters and marks. All examples were printed on a schoolyard on a non-rainy day with a light breeze (under 3.3 [m/s]) day.

Drawing Characters. Figure 1 (D) shows the word "Polka" printed on the schoolyard. The original input designed in the tool is shown in Figure 1 (C). The actual size of this example was 3 × 2 m. The elapsed time for drawing all the characters was approximately five minutes.

Drawing a Sports Track on the Field. Figure 4 (A) shows the printed Sumo track. Sumo is a Japanese form of wrestling in which two competitors fight until one of them is pushed or dragged out of a circular track. The actual size of this example was four meters in diameter. The elapsed time for drawing the track was approximately three minutes.

Extra-large Drawing. Although the drawing area of the prototype is limited, large drawings can be produced by dividing an area into smaller areas and performing water printing on the respective areas. Figure 4 (B) shows the words "KEEP LEFT" and a "⇐" that which could be used as a temporary traffic sign. The full drawing range was 9 × 12 m. The original design was split into five areas. Polka was installed on a dolly and manually moved five times, drawing the letters and symbol. The elapsed time for drawing the letters and symbols was approximately ten minutes excluding the elapsed time for moving the device.

5 TECHNICAL EVALUATION

5.1 Appearance of a Water Droplet

The appearance of the water-jet printing is affected by both the surface conditions (i.e., the granularity of the surface material) and the traveling distance of the water. The water absorbency of the surface affects the spread of droplets on the ground. Regarding the traveling distance, the longer the distance, the stronger the water pressure needed and thus, the wider the water droplets spread in the ejected direction. Thus, we investigated the shape of the spread droplets on different surfaces (sand, soil, and concrete) and traveling distances (one, three, and six meters). All measurements were taken outdoors in non-rainy conditions with a light breeze (under 3.3 [m/s]). We measured the shape of droplets 3 times for each condition.

Figure 5 shows the mean width in the radial and angular directions for each condition. As we expected, the longer the traveling distance, the greater the width in the radial direction for all surface conditions. On the other hand, the width in the angular direction had less influence on the traveling distance than the width in the radial direction (the standard deviations for the width in the angular and radial directions were 0.042 m and 0.240m, respectively). The spread size in the concrete condition was the largest in both the

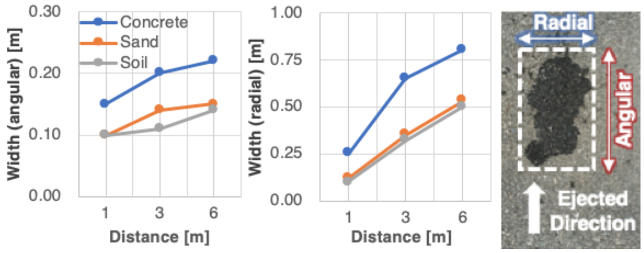

Figure 5: Mean width in the angular and radial directions of a fallen droplet.

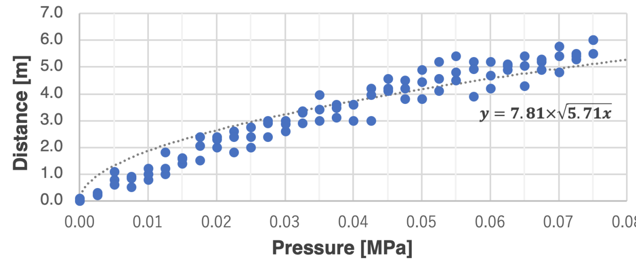

Figure 6: Each dot represents the measured traveling distance of a droplet for each pressure value. The mapping function is shown by the dotted line.

angular and radial directions in all conditions. We estimated that this is because the concrete condition has a lower absorbency than the other two conditions.

5.2 Traveling Distance of Water Droplets

The velocity of ejected water increases in proportion to the square root of the pressure. Consequently, Polka can produce multiple flying distances of a droplet by controlling the water pressure of each regulation valve. Here, we investigate the relationship between water pressure and actual traveling distance. As mentioned above, with the six regulating valves, Polka can theoretically create 64 levels of water pressure. Considering the width in the radial direction of a spreading droplet (results of the previous experiment), 64 levels of resolution within 6.0 m can not be achieved because the spread droplets will overlap. Thus, we limited our tests to the number of combined pressure levels at a maximum pressure value of 0.075 MPa with 0.0025 MPa intervals. We measured the traveling distances three times for each pressure level. This distance is measured from the nozzle to the center of the droplet on the sand. All measurements were conducted outdoors in non-rainy conditions with a light breeze (less than 3.3 m/s).

Figure 6 illustrates, that this mechanism can control multiple traveling distances of droplets. We can fit a nonlinear least-squares model based on the square root of the pressure. With this, we can compute an approximation of the function $f(p) = a\times\sqrt{b \times p}$, where $a = 7.81$, $b = 5.71$, and p is the pressure. The residual standard error was 0.50 m.

6 DISCUSSION AND LIMITATION

The weather conditions are crucial for Polka's water-jet printing. Because the water-jet printing utilizes the contrast between wet and dry surfaces, it does not work during rain and snow. It is also affected by wind conditions; that is, strong winds can prevent the water from landing at its target position. This problem could be overcome by attaching a wind meter to Polka, that is, introducing processing that dynamically changes the water pressure and nozzle orientation or pausing for printing, taking wind direction and air pressure into account.

The water-jet printing could be adapted to various surfaces, but there are some limitations. First, to make the contrast between wet and dry surfaces visible, the surface must have water absorbency. Second, the surface must be flattened. In the case of an excessively bumpy surface, the printing will be difficult to see. Finally, the refresh rate of water-jet printing depends on the surface conditions, humidity, and temperature. For example, printing on fine sand, such in a desert, will vanish very rapidly, while printing on soil, such as in a farm field, might remain longer.

The current prototype supports only batch printing. In addition to this, real-time printing as a result of users' actions such as pausing or part-by-part printing can be included by dividing the processing commands. Although further empirical investigations are required in terms of user interaction (e.g., response speed or printing speed), we believe that real-time printing will expand the technological possibilities for large-scale display systems.

Our future work includes implementing the design tool in a manner that reflects the results of the investigations. Our investigations revealed that the shapes of fallen droplets and the surface conditions must be considered. For example, considering that the shape of a droplet changes according to the traveling distance, the grid width in the ejection direction must be larger as the distance increases. We confirmed that the prototype was capable of drawing simple characters or illustrations, but further optimization and investigation are required.

7 CONCLUSION

We developed a computer-controlled sprinkler called Polka, which is capable of drawing letters and illustrations on large, flat surfaces. The printing method solves the problem pf pressure dropping as a result of the response performance of the electric valves by making use of a disk-shaped shutter and modifying the interior of the nozzle to produce uniform water flow. We also developed a design tool for watering. The tool enables users to specify the watering position and watering sequence easily. In our initial testing, we confirmed that simple characters and symbols including an extra-large design can be printed using the prototype under a lightly breezy condition. We also investigated (1) how the appearance of a water droplet changes depending on the surface conditions and the traveling distance and (2) the accuracy of controlling the traveling distance of a water droplet. The results demonstrated the performance of the prototype and will be helpful in improving both the prototype and the design tool. We are planning to use changes in the states of ejected liquid. For example, we could use a liquid that changes to a solid after release. For example, sprinkling super-cooled water in a sub-freezing environment or sprinkling heated liquid resin will generate three-dimensional objects in a large space.

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