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Accessing individual 75-micron diameter nozzles of a desktop inkjet printer to dispense picoliter droplets on demand

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Electronic Supplementary Information (ESI)

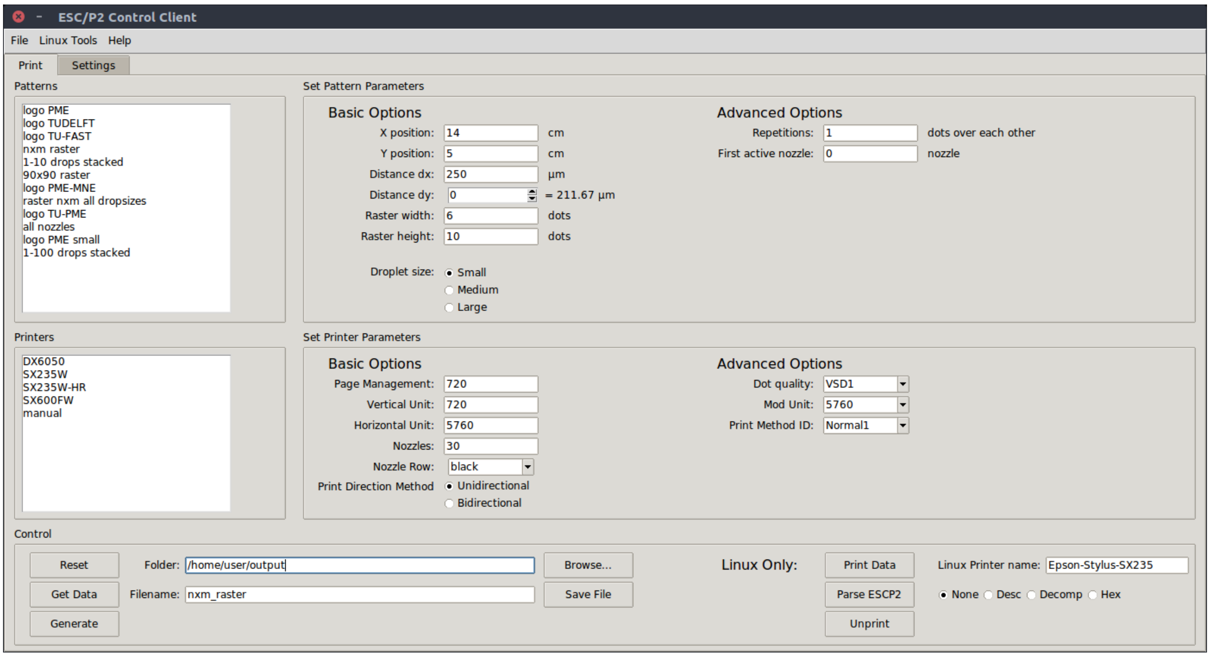


Figure S1: Screen capture of Pyhthon ESC/P2 command generator Graphical User Interface (GUI).

The complete software package that is used to control the printer, accompanied by a manual, is included as separate ESI, and can be downloaded from the publisher's webpage.

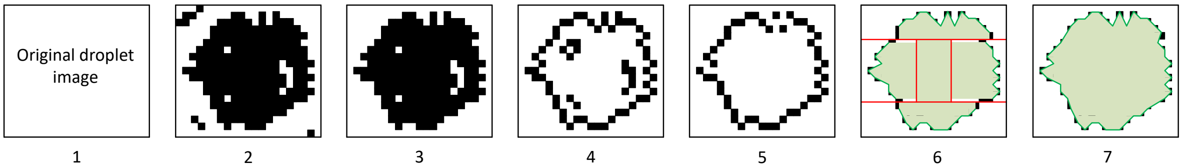


Figure S2: The circularity was measured starting with the original image of a droplet (1). This image was then converted to a binary image (2) by replacing each pixel with a one or a zero, based on its luminance level. Satellite droplets and random undesired pixels from contamination were then removed manually to obtain an image (3) containing only the droplet itself in binary version. This image is then ready to be processed by the written Matlab script. The script first determines the edges of the droplet, resulting in an image (4) with possibly irregularities within the droplet itself. These irregularities are then removed from the image by converting all the black pixels inside the perimeter to white, resulting in an image (5) with a clean edge. The image is then divided into five sections (6) and for each section the perimeter length (the dark green line) and the area underneath it (the light green area) are determined using linear approximations between the pixels. The perimeter of the droplet is now cut at four different locations. The area and perimeter are not well approximated at those locations. The last step of the algorithm closes the gaps in the perimeter and determines the new area as well, which is shown in the last picture (7).

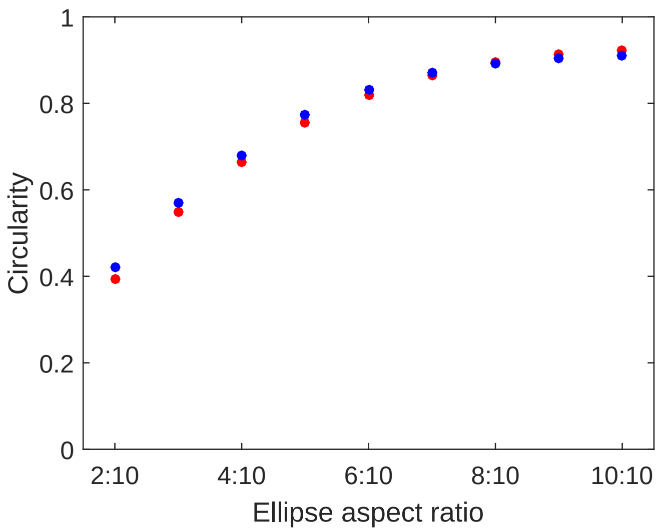
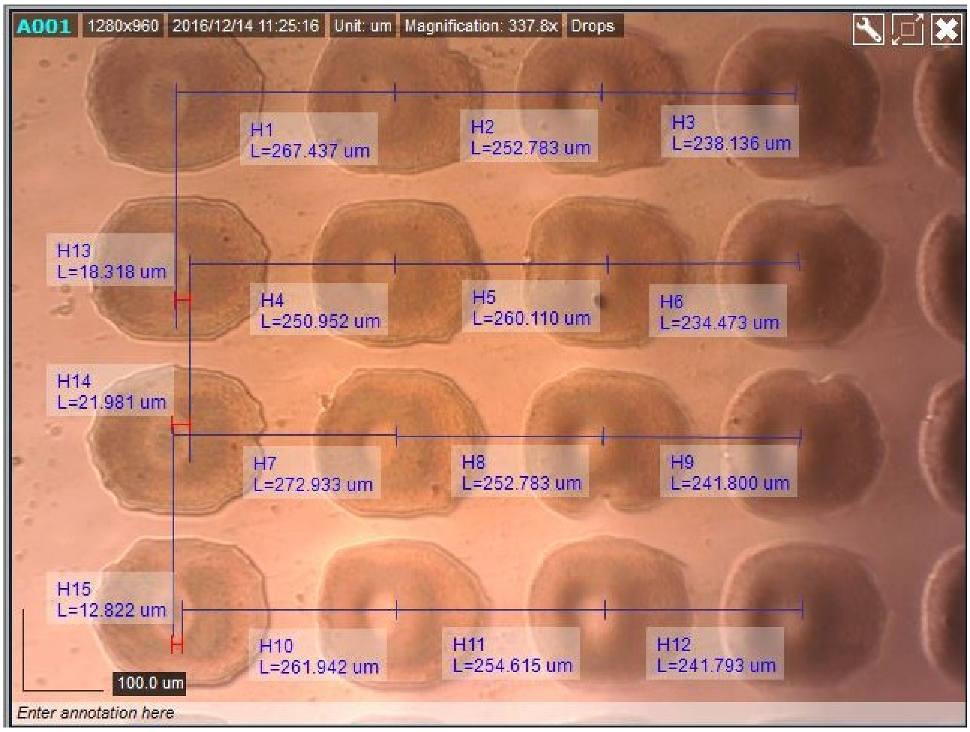
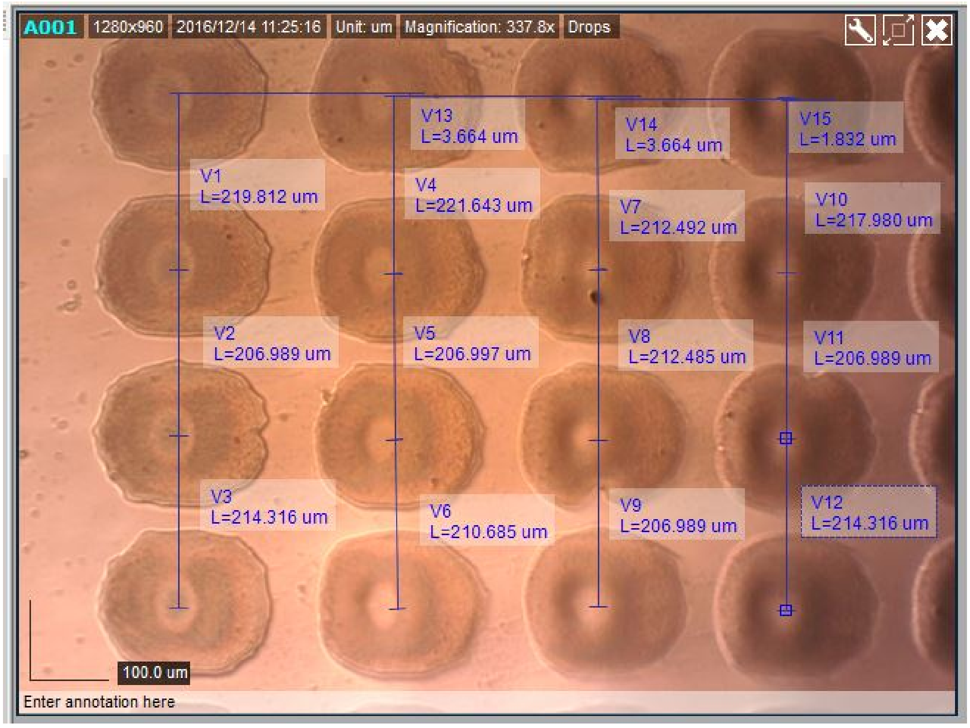


Figure S3: To validate the algorithm that determines the area and perimeter of the evaluated droplets, the circularity value was compared to the circularity value obtained by Takashimizu and Iiyoshi for ellipses with different aspect ratios. This figure shows that the their values in blue and the values produced by our algorithm in red. The maximum measured deviation of our values from the values of Takashimizu and Iiyoshi is 6.4%. The range in which the droplets were measured is between aspect ratios from 7: 10 to 10: 10, in which the deviation is even smaller.

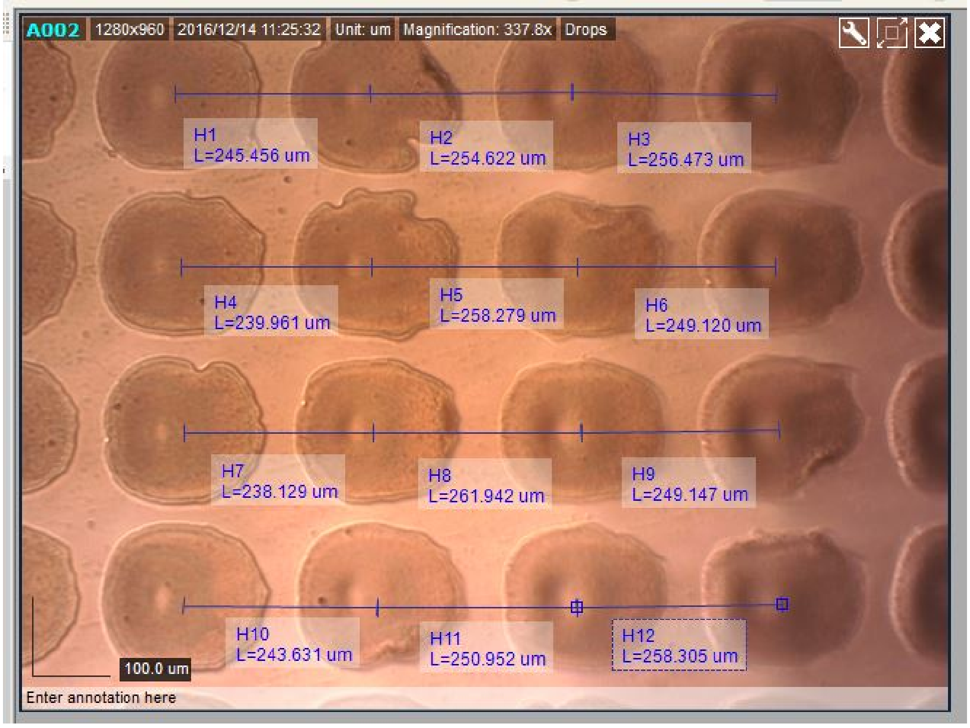


(a) Horizontal

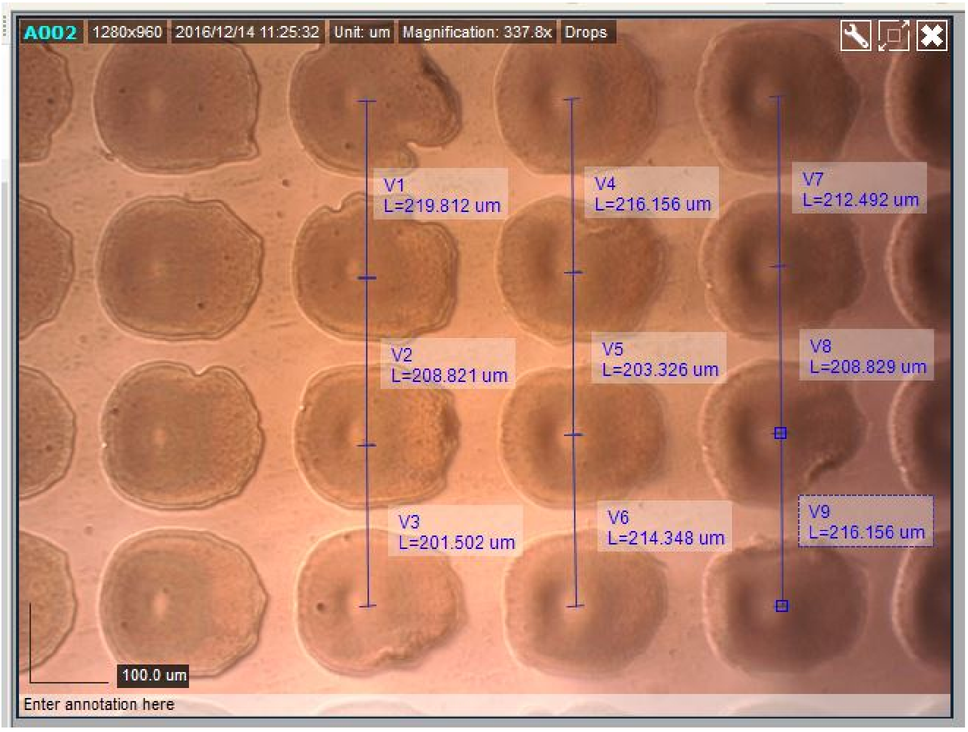


(b) Vertical

Figure S4: Measurement of droplet location deviation, **image 1 of 3** of 4x13 raster with **large** droplets, **(a)** horizontal deviation, **(b)** vertical deviation

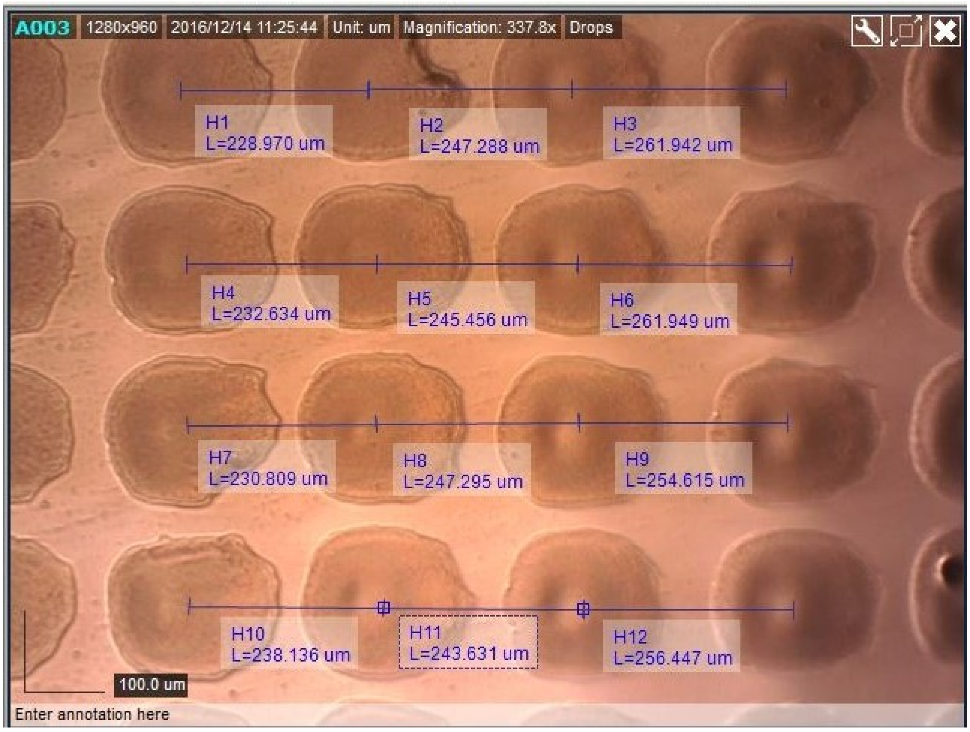


(a) Horizontal

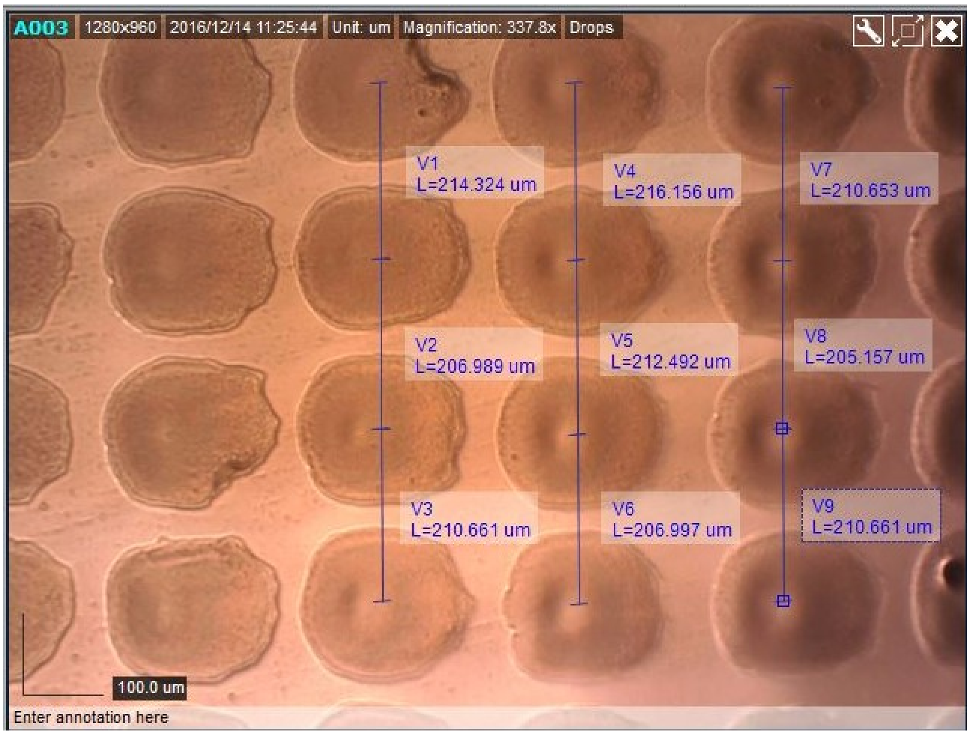


(b) Vertical

Figure S5: Measurement of droplet location deviation, **image 2 of 3** of 4x13 raster with **large** droplets, **(a)** horizontal deviation, **(b)** vertical deviation

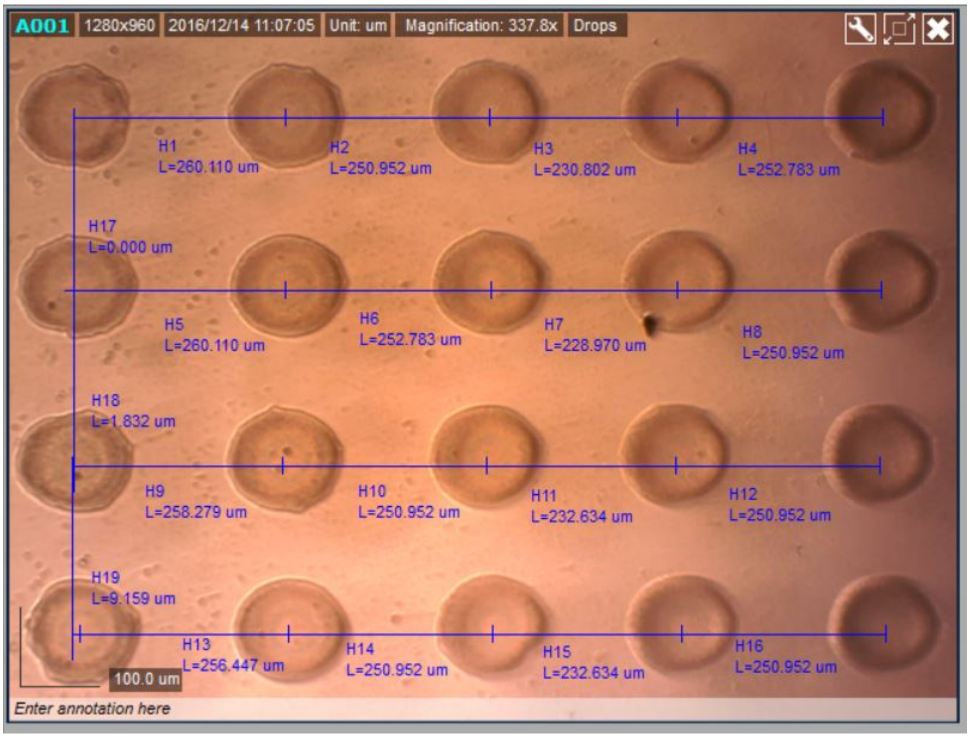


(a) Horizontal

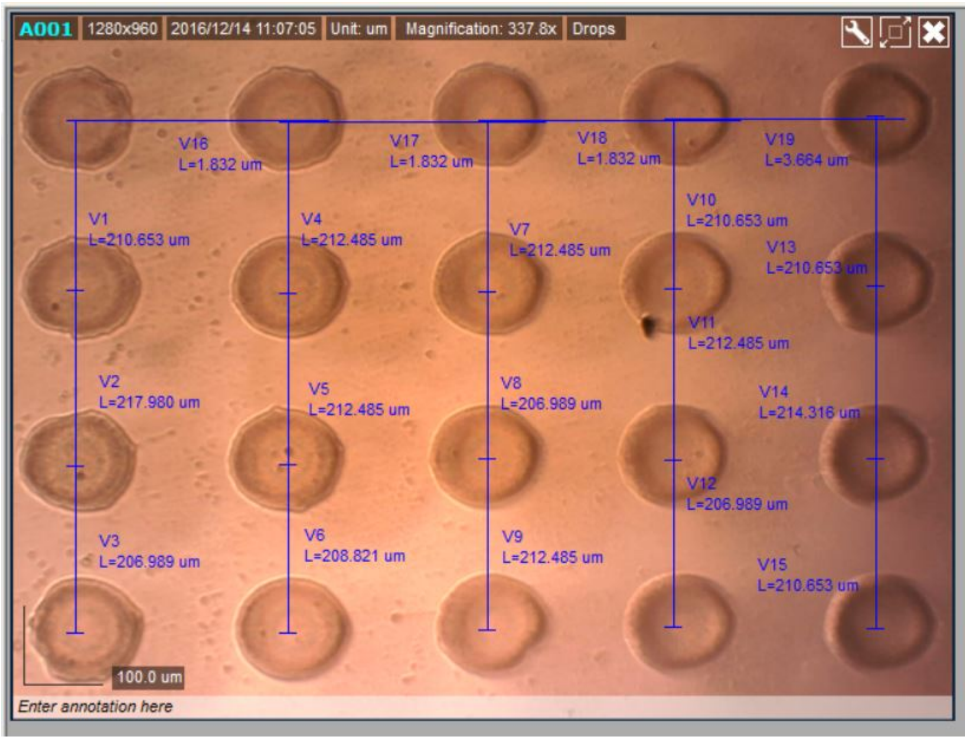


(b) Vertical

Figure S6: Measurement of droplet location deviation, **image 3 of 3** of 4x13 raster with **large** droplets, **(a)** horizontal deviation, **(b)** vertical deviation

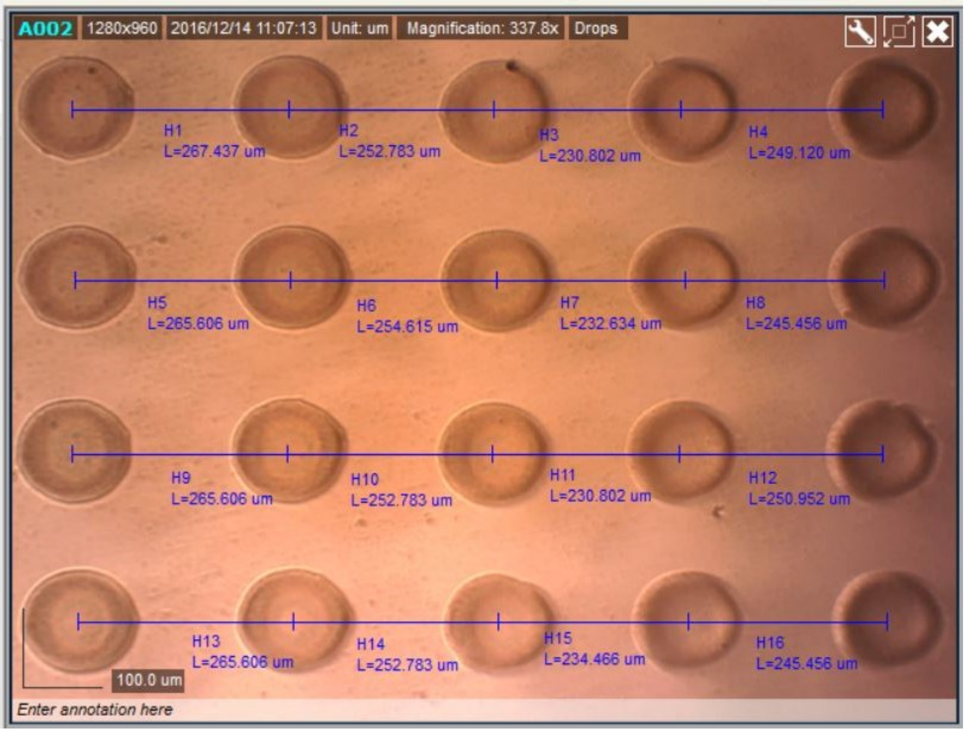


(a) Horizontal

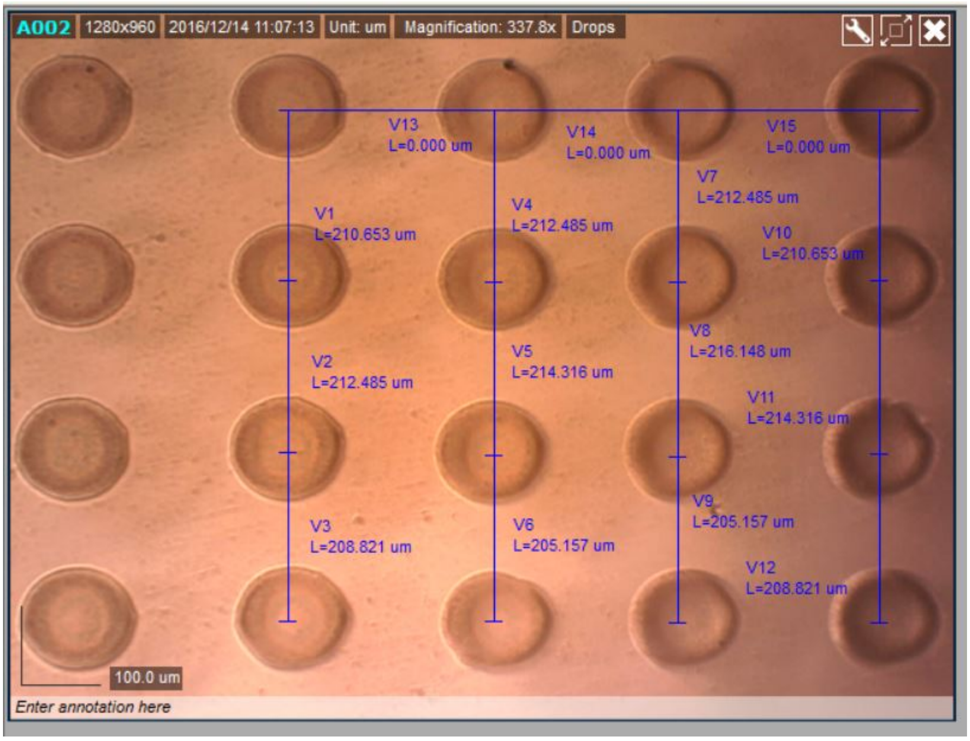


(b) Vertical

Figure S7: Measurement of droplet location deviation, **image 1 of 3** of 4x13 raster with **medium** droplets, **(a)** horizontal deviation, **(b)** vertical deviation

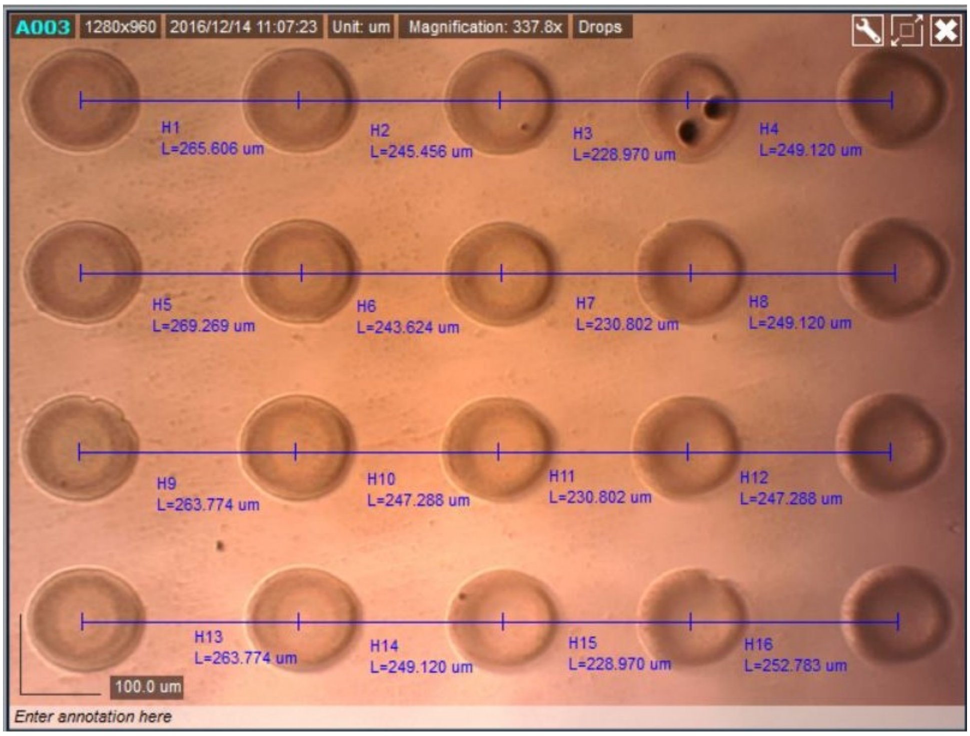


(a) Horizontal

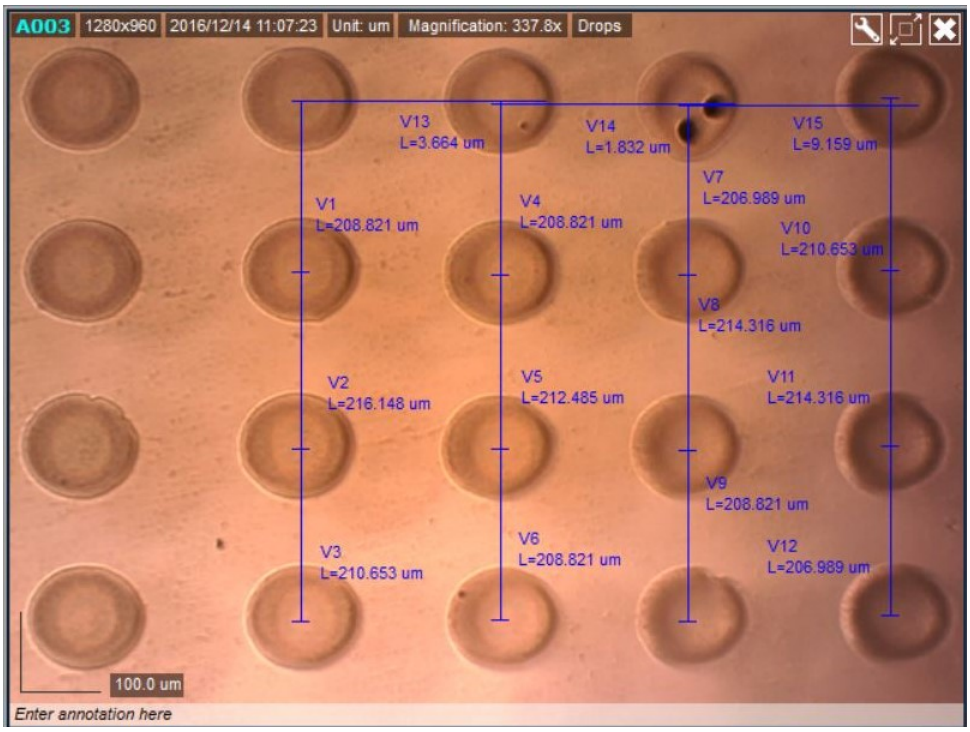


(b) Vertical

Figure S8: Measurement of droplet location deviation, **image 2 of 3** of 4x13 raster with **medium** droplets, **(a)** horizontal deviation, **(b)** vertical deviation

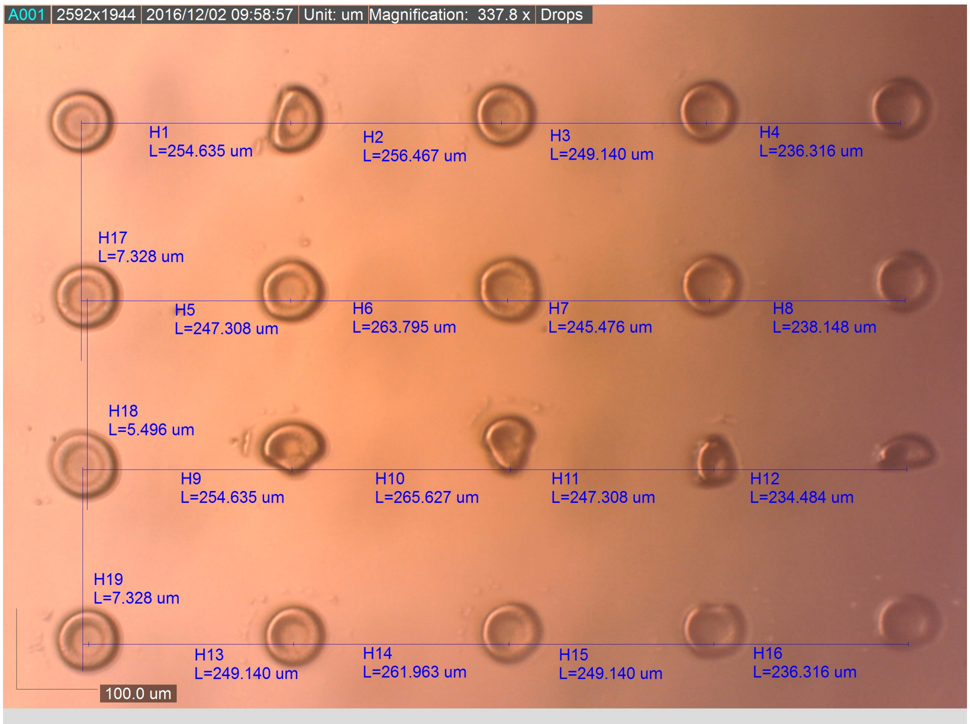


(a) Horizontal

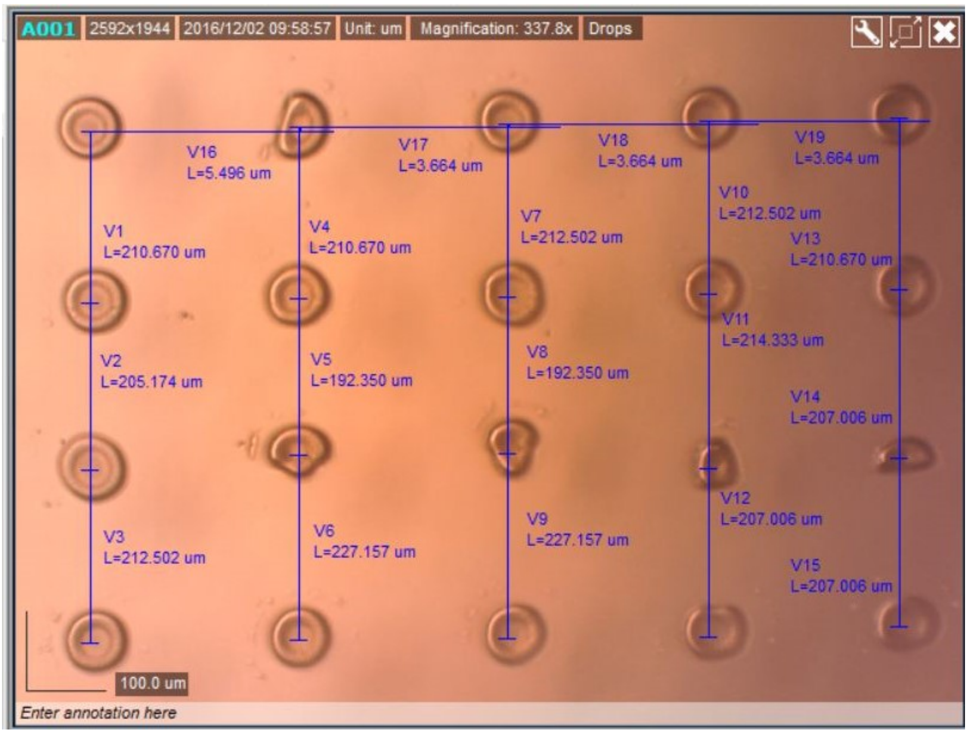


(b) Vertical

Figure S9: Measurement of droplet location deviation, **image 3 of 3** of 4x13 raster with **medium** droplets, **(a)** horizontal deviation, **(b)** vertical deviation

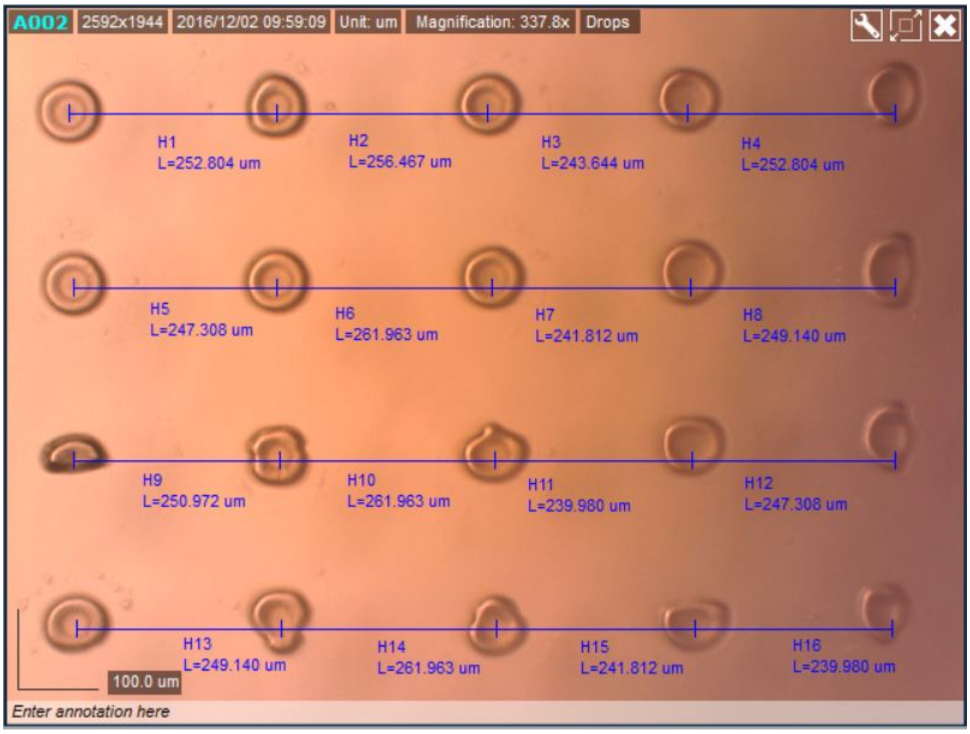


(a) Horizontal

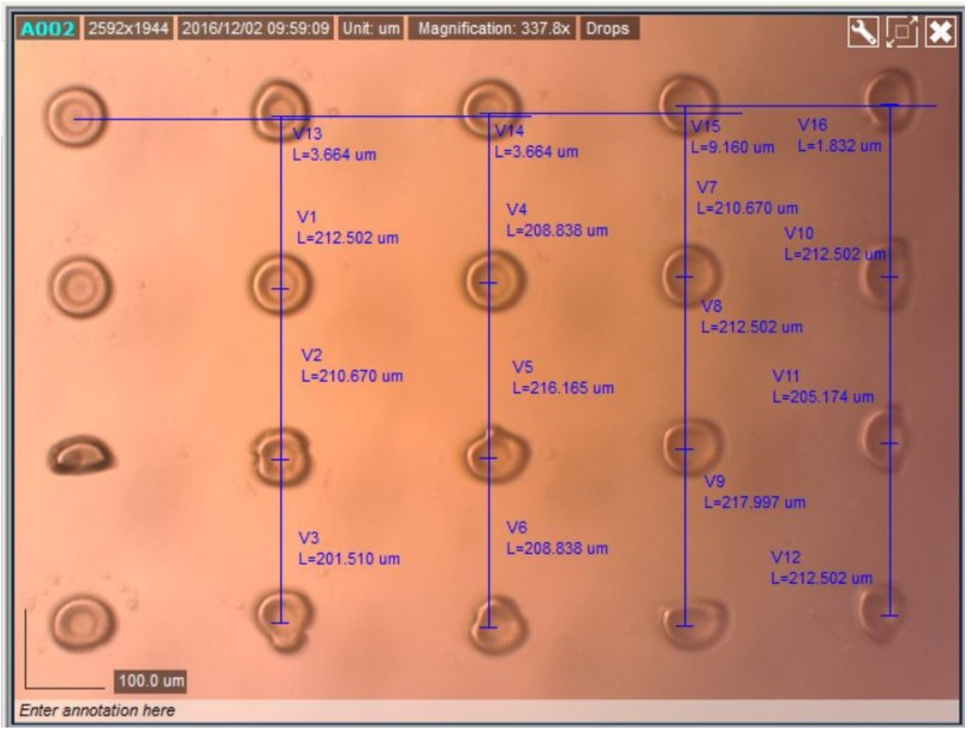


(b) Vertical

Figure S10: Measurement of droplet location deviation, **image 1 of 3** of 4x13 raster with **small** droplets, **(a)** horizontal deviation, **(b)** vertical deviation

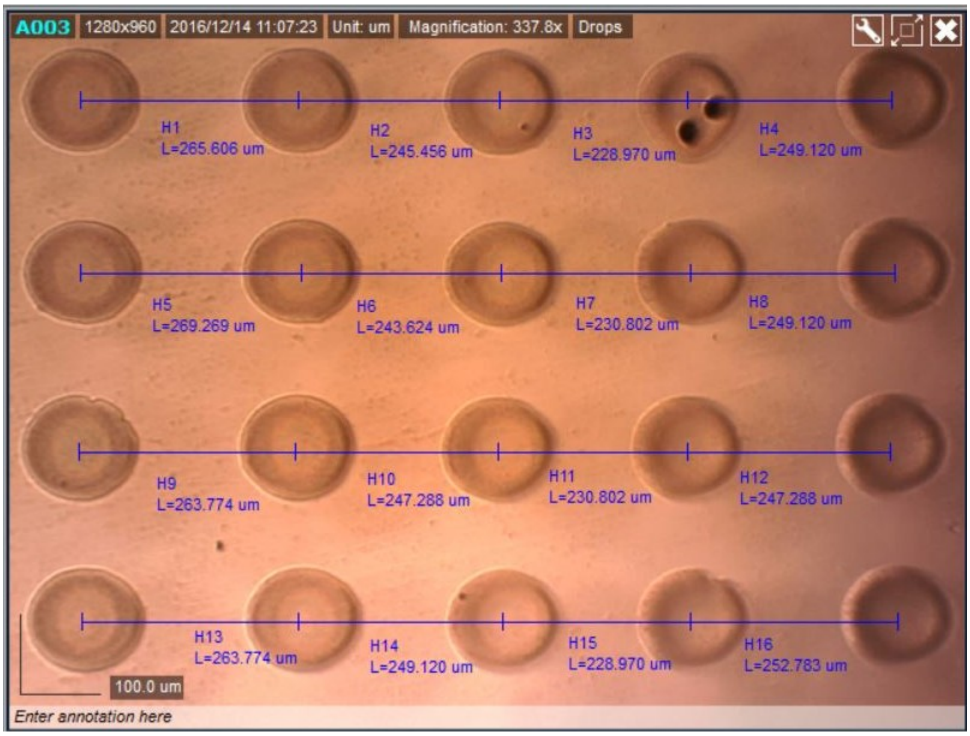


(a) Horizontal

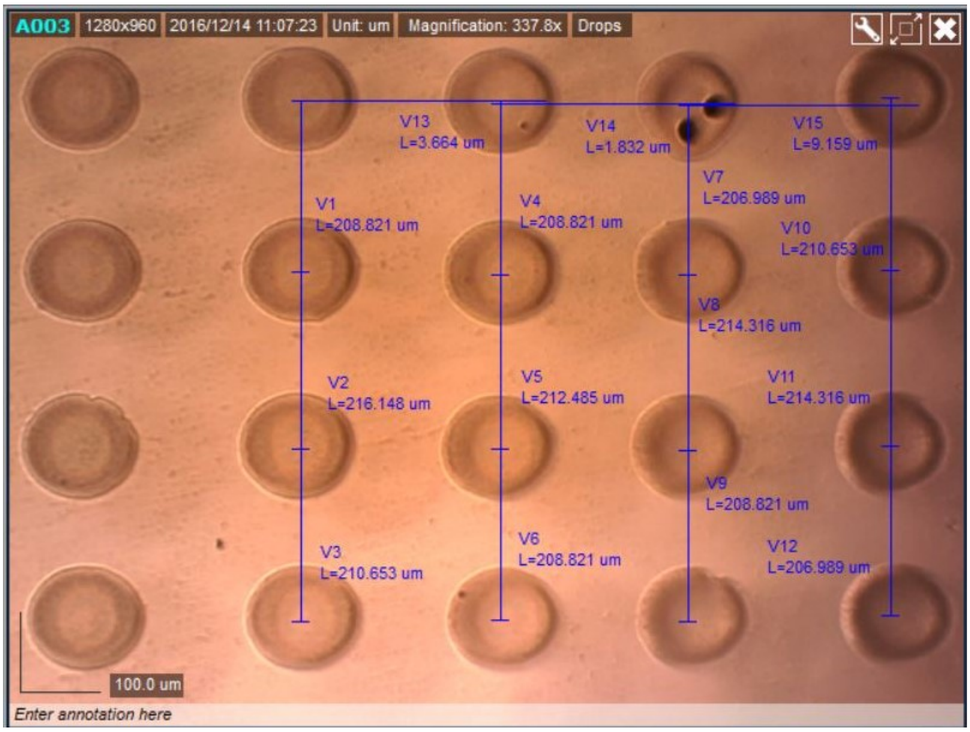


(b) Vertical

Figure S11: Measurement of droplet location deviation, **image 2 of 3** of 4x13 raster with **small** droplets, **(a)** horizontal deviation, **(b)** vertical deviation



(a) Horizontal



(b) Vertical

Figure S12: Measurement of droplet location deviation, **image 3 of 3** of 4x13 raster with **small** droplets, **(a)** horizontal deviation, **(b)** vertical deviation

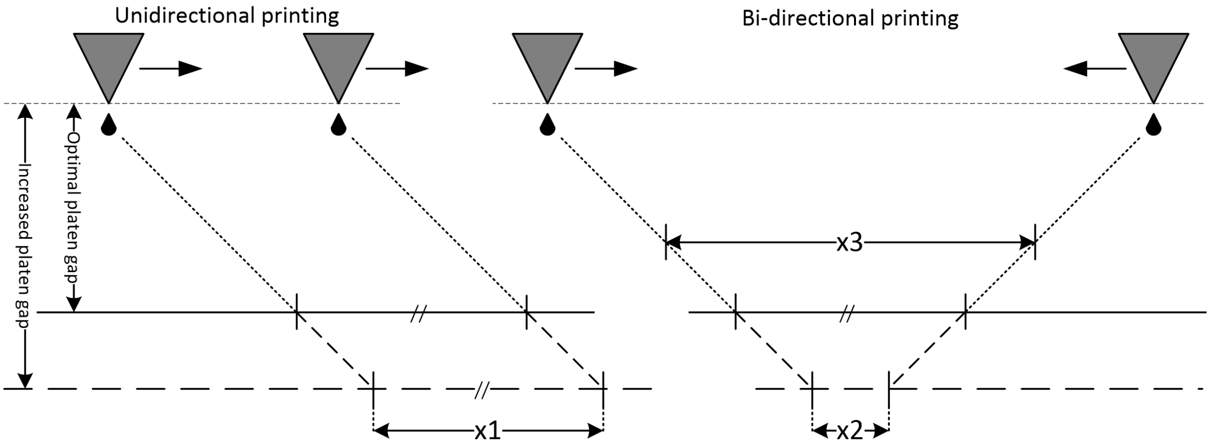


Figure S13: Hypothesis of the effect of increasing the platen gap on the relative spacing of the droplets when printing uni- and bi-directional. When printing in unidirectional mode, all droplets have the same initial horizontal speed (i.e. the speed of the printhead) and will land with the same distance from each other regardless of the platen gap. However, when using bi-directional mode, the horizontal speed changes direction with each stroke. If the platen gap is chosen correctly, this does not lead to a disturbed pattern, but it might be if the platen gap is chosen larger or smaller than the optimal platen gap. The surfaces for optimal and increased platen gap are shown as horizontal lines. The arrows next to the nozzles show the direction in which the printhead is moving while dispensing a droplet. When using the optimal platen gap, the distances between the droplets on the surface equals $x1$ for both uni- and bi-directional printing. It can be seen that when using bi-directional printing and an increased platen gap, the distance $x2$ between the droplets on the surface decreases with respect to $x1$. vice versa when using a decreased platen gap in bi-directional printing mode, the distance $x3$ increases with respect to $x1$. Since microscope glass slides (height of 1.1 mm) were used to variate the platen gap with steps of this height, it is not sure if the platen gap was determined correctly. That is why unidirectional printing is used to determine the limits of the printer in this study. It is known that by using the default printing methods, a correction is being made in the print spool process for the horizontal location of the droplet when printing in bidirectional mode.

Figure S14: Substrate with large medium and small droplets with a platengap of 6.8 mm

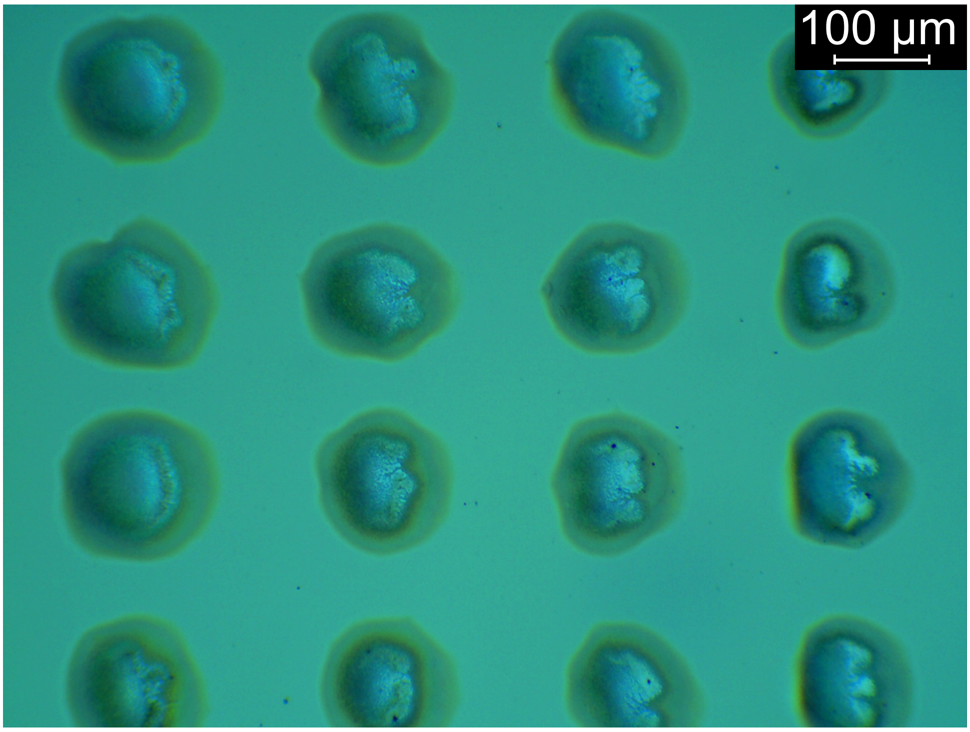


Figure S15: Silver ink droplets of large size on an untreated glass substrate

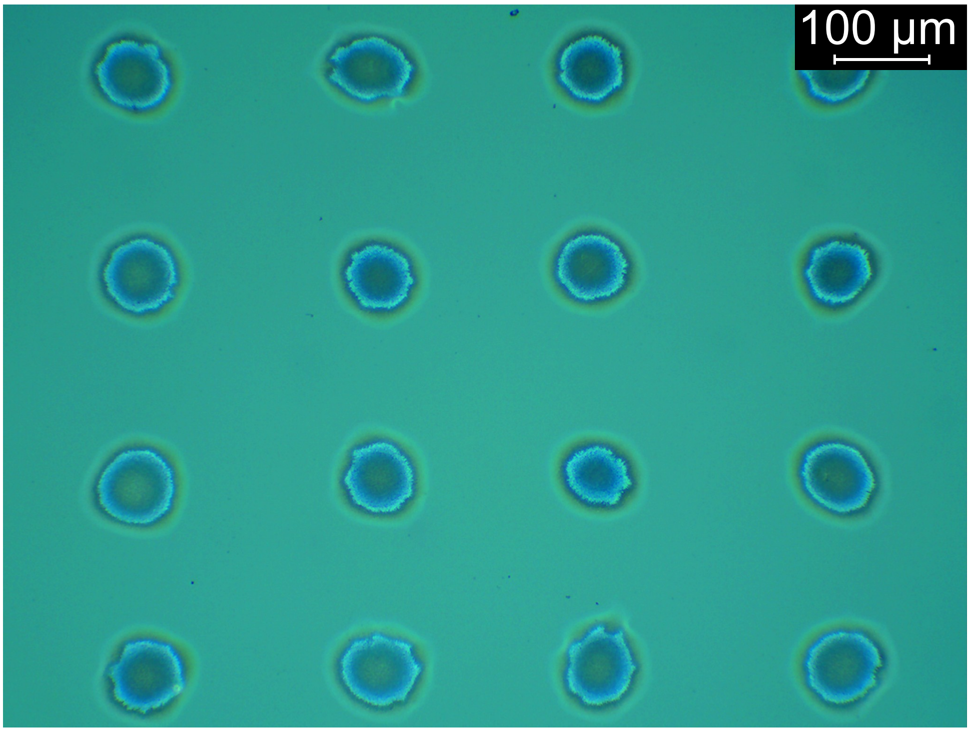


Figure S16: Silver ink droplets of medium size on an untreated glass substrate

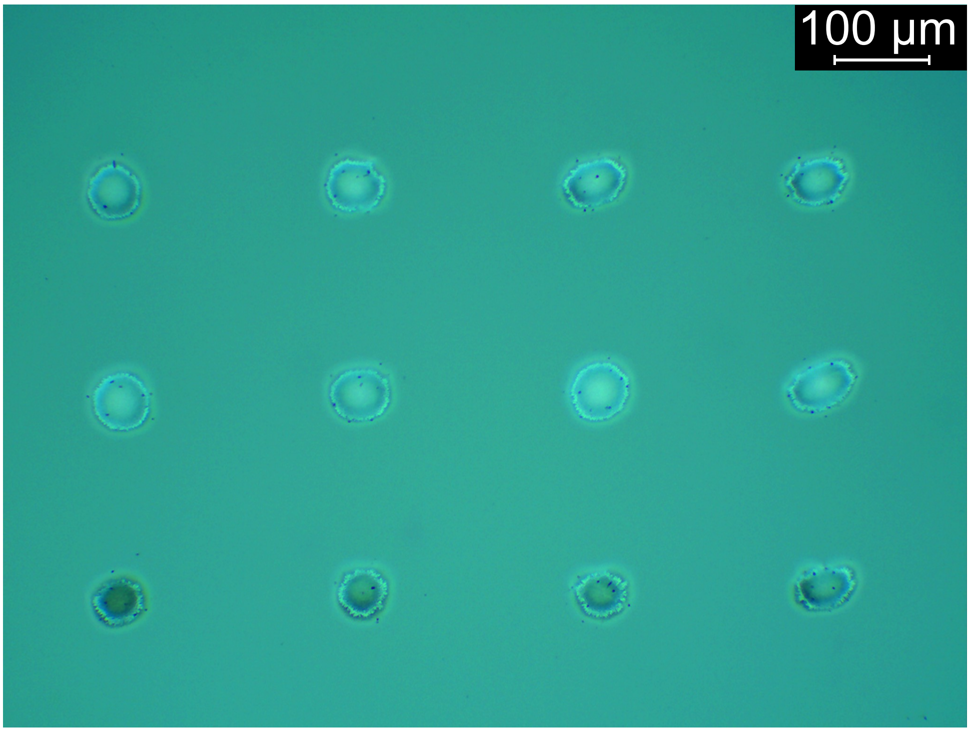


Figure S17: Silver ink droplets of small size on an untreated glass substrate

The life time of the nozzle depends on variety of things. The size of the particles, solvent drying rate, accumulation near the nozzle, hydrodynamic bridging, shear induced gelation. For our initial tests on a single nozzle using the commercial silver conductive ink (JSB25P, from Novacentrix), we found that till 2000 droplets there was no clogging, after that the droplets got degraded from their circularity. However, droplets were still printing.

Supplementary videos

Note that all videos are looped twice.

Supplementary video 1: For 7 strokes, 2 nozzles dispense one single droplet on the first available location of the printable area.

Supplementary video 2: For 9 strokes, 2 nozzles dispense droplets on the first 512 available locations of the printable area.

Supplementary video 3: For 9 strokes, 2 nozzles dispense droplets on the first 1024 available locations of the printable area.

Supplementary video 4: For 4 strokes, 2 nozzles dispense droplets on the first 1536 available locations of the printable area.

Supplementary video 5: For 9 strokes, 2 nozzles dispense droplets on the first 2048 available locations of the printable area.

Supplementary video 6: For 9 strokes, 2 nozzles dispense droplets on the first 2560 available locations of the printable area.

Supplementary video 7: For 14 strokes, 2 nozzles dispense droplets on every available location (2888) of the printable area.

Supplementary video 8: Modified Epson Stylus SX235W (Fig. 4 in main text) printing the TU Delft logo (Fig. 9 in main text) on a microscope glass slide. The logo is printed in one stroke.