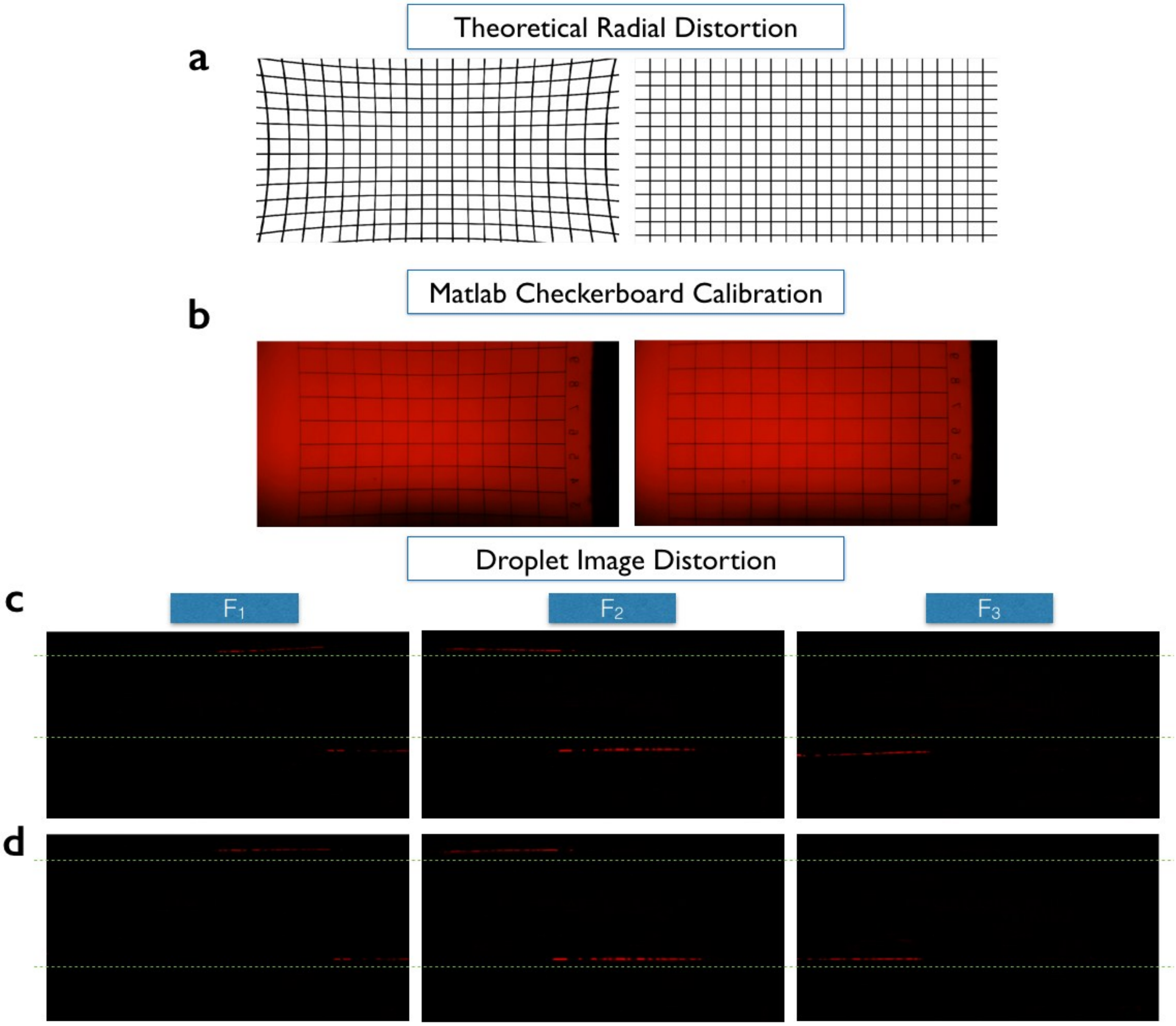
Electronic Supplementary Material (ESI) for Lab on a Chip.

Supplementary Information

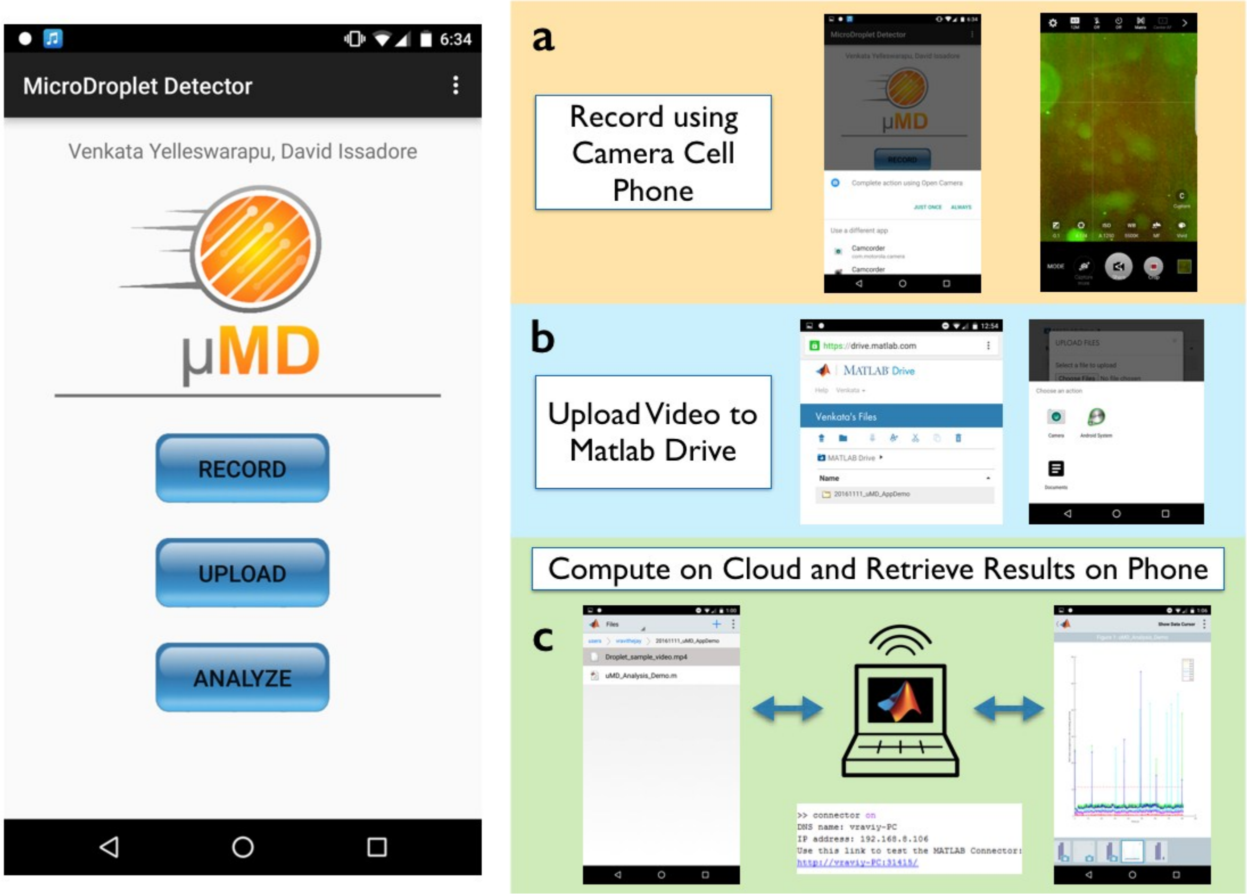
Ultra-High Throughput Detection (1 Million Droplets / Second) of Fluorescent Droplets Using a Cell phone Camera and Time Domain Encoded Optofluidics

Venkata R. Yelleswarapu[1], Heon-Ho Jeong[2], Sagar Yadavali[1], David Issadore[1,3]

1. Department of Bioengineering, School of Engineering and Applied Sciences, University of Pennsylvania. Philadelphia, Pennsylvania, United States.
2. Department of Chemical and Biomolecular Engineering, University of Pennsylvania, Philadelphia, Pennsylvania, United States.
3. Department of Electrical and Systems Engineering, School of Engineering and Applied Sciences, University of Pennsylvania. Philadelphia, Pennsylvania, United States.

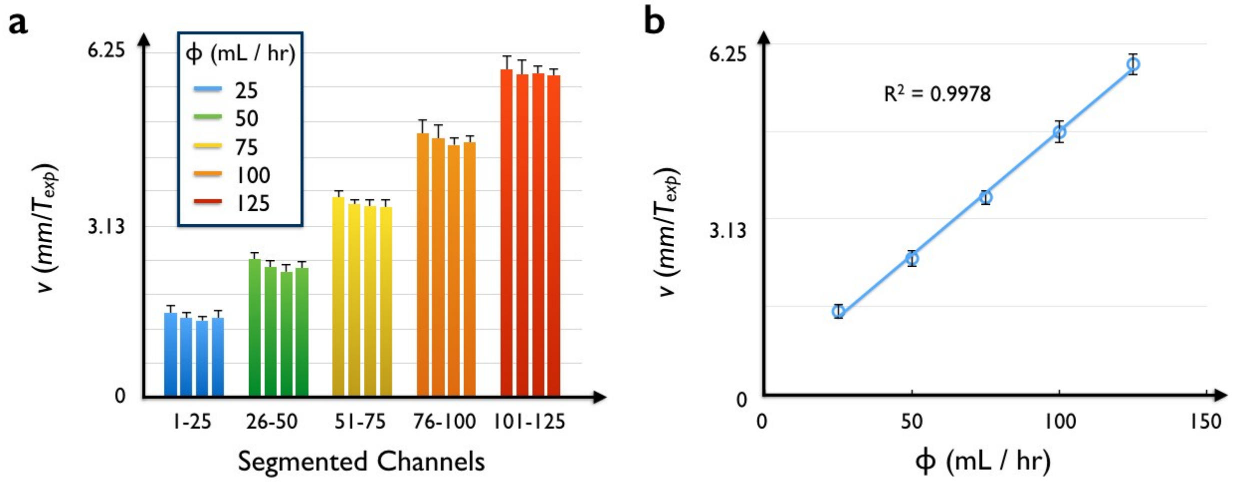


Supplementary Figure 1: Software Image Correction. a. The low cost macro lens used in our µMD caused a pincushion distortion (left) on the acquired images that could be corrected using Matlab's computer vision toolbox (right). The theoretical distortion was generated by creating a grid and running the image correction parameters in reverse to demonstrate how distortion from the lens can be corrected using software rather than resorting to expensive hardware solutions. **b.** To calculate the camera parameters for the image distortion, we used MATLAB's cameraParameters function to find how the coordinates of the checkerboard were distorted due to the lens (left). These coordinates were used to correct the distortion (right), and these parameters were also saved for the microfluidic device **c.** We then implemented this transform for our microfluidic device, where corrections from translation vectors due to misalignment were adapted. We show three sequential frames (F_1, F_2, F_3) where initially the distortion does not allow for proper segmentation as the curvature bends the channels. **d**. We show that after image correction, the channels can be properly segmented and the droplet can be followed through the frames for correlation and further analysis.



```
>> connector on
DNS name: vraviy-PC
IP address: 192.168.8.106
Use this link to test the MATLAB Connector:
http://vraviy-PC:31415/
```

Supplementary Figure 2: µMD App for Cloud computing. A custom built app allows users to record droplet video, upload the video to the Matlab drive, and retrieve results after running the code online **a.** The record button opens the Camera app on the phone. **b.** The upload button connects to the Matlab drive via a browser, where the files sync to the cloud. **c.** The analyze button opens the Matlab Mobile app, which connects to the Matlab drive and allows users to run the analysis code remotely. The app is provided in the SI as an .apk file that can be installed on Android phones.



Supplementary Figure 3: Velocity Distribution. To determine the dispersion of droplet velocity v in the μMD, we measured velocity of droplets in multiple channels at multiple flow rates ϕ. **a.** At a given flow rate ϕ, the channels were binned to determine if the droplet velocity varied as a function of the row position in the device. There was no significant change in velocity moving across the chip. The error bars represent the standard deviation. **b.** Droplet velocity scales linearly with the flow rate ($R^2 = 0.9978$). Error bars show the standard deviation at each of the given data points.

Supplementary Video 1: Animation of device setup and workflow, along with how the app interfaces with the cell phone to record and analyze the data.

Supplementary Code:

The supplementary zip file contains: (i) Matlab code for simulations, (ii) Matlab code for video analysis, (iii) Arduino code to modulate the LED, (iv) CAD schematic of detection chip, and (v) an apk to install the app on an Android phone. Each folder contains a readme on how to run the code and parameters to change.

Cell Phone Parameters:

Unlike a traditional scientific CMOS camera where the user is in control of most image acquisition parameters[35], a cell phone camera has only a handful of features that can to be optimized prior to recording. Using the S7 Edge's Camera "Pro" Mode, the following settings were used to record: *i.* the focus was manually fixed so the chip could slide in to an acrylic casing without having to align the chip; *ii.* the ISO was set to 3200 and Exposure to +2 maximize light input unless specified otherwise; *iii.* aperture was set to 1/30; *iv.* metering mode was set to Matrix; and (*v*) the color correction was set to Auto. All videos were recorded 1920x1080p size at 60 fps or 30 fps using the OpenCamera App, since this setting captured all 120 channels properly without extremely large file sizes, and with a field of view of ~12mm by 7mm. While higher resolution videos could be captured, this would create file sizes that would take much longer to analyze without significantly increasing the field of view.

Calculation of Droplet Throughput:

To calculate the droplet throughput, we first measured the droplet diameter to be $d = 35$ μm and the volume fraction of dispersed phase to continuous phase to be $\chi = 53\%$. For the volumetric throughput $\phi = 166$ ml/hr, the droplet throughput $f = \phi / (V_d * \chi) = 1.1$ MHz was calculated. To create a suspension with a filling factor of $\chi = 53\%$, we generated the droplets using a separate chip and concentrated the droplets based on buoyancy before re-injecting them into the detection region of our chip.