AngleMetric: mobile sessile-drop goniometry

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Abstract

We introduce AngleMetric, an iOS application that measures the contact angle of a sessile droplet. The app segments macro images of droplets in real time, and fits their profiles to the axisymmetric Young–Laplace equation to report a gravity-corrected contact angle alongside left and right tangent angles. A top-down mode extends measurement to geometries where a side silhouette is impractical, e.g., water on a hydrophilic surface. In preliminary trials, measurements varied by under 2° (top-down) and 3° (side-on), and top-down angles held constant across a sixfold change in droplet volume. For regulated work, optional modes maintain an append-only, SHA-256 hash-chained ledger with signed exports and webhooks (supporting, though not by itself conferring, 21 CFR Part 11 compliance) and a guided multi-drop protocol aligned with ASTM D8597. Here we describe the motivation, operation, preliminary performance, and the mathematics under the hood.

1 Why the contact angle?

When a droplet rests on a surface, the angle at its edge is directly determined by the physical chemistry between that liquid, that solid and that gas. This single angle is the most accessible readout of wettability, and wettability is a gatekeeper property. It reveals whether a coating worked or your liquid is contaminated. It predicts an adhesive will bond, or a water drop will bead up and roll off. All you need is a droplet, a surface, and a way to measure the angle.

Industry measures contact angle wherever surface preparation must be verified before an irreversible step. For example, composite and metal surfaces are checked for cleanliness before adhesive bonding or painting (a fingerprint's residue measurably raises the water contact angle), polymer films are checked after corona or plasma treatment, and wafer and medical-device cleaning lines use the angle as a pass/fail cleanliness gate. In academia the angle is a routine characterization step: confirming a silane monolayer deposited, verifying plasma treatments, or quantifying engineered superhydrophobicity. The same physics shows up at home: a worn raincoat whose water repellent has failed, the seasoning on a cast-iron pan, and the lotus-leaf effect are all quantified by the contact angle.

Most of these measurements never happen. The measuring instrument, often called a goniometer, is typically an another room, or another budget.

2 The opportunity

Four technologies have converged on the modern smartphone, and together they are sufficient for goniometry. First, high resolution cameras with macro lenses can focus on tiny droplets on surfaces. Second, machine-learning image-segmentation (MobileSAM[1], a compact Segment Anything[2] variant) now run at interactive rates, identifying droplet profiles in the messy backgrounds of the real world. Third, the numerical machinery of drop-shape analysis (integrating the axisymmetric Young–Laplace equation and optimizing its parameters, Section 6) costs milliseconds on a phone processor. Fourth, MEMS accelerometers report the gravity vector continuously, so the app can coach the user into the level, perspective-free orientation the geometry requires. Together these technologies can be used to accurately determine the contact angle of drops *in situ*.

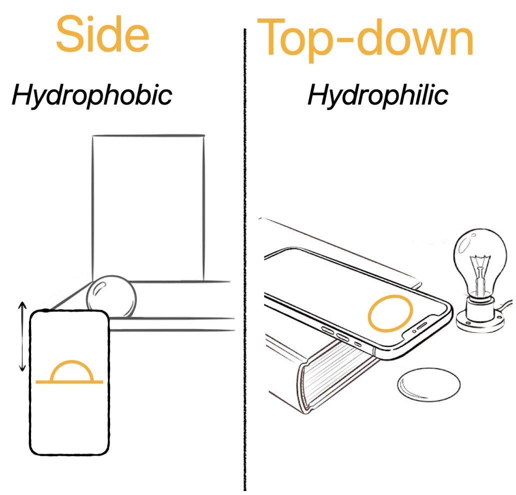


Figure 1: The two capture geometries. Side-on (left, suited to beading, "hydrophobic" drops): lower the phone until the droplet silhouette is in the target. Top-down (right, suited to flatter, "hydrophilic" drops): the phone lies level above the droplet (here propped on a book, with a desk lamp for side-illumination).

Commercial goniometers remain the right tool for much of what they do: automated dispensing, tilting stages for advancing/receding hysteresis, temperature-controlled chambers, and traceable sub-degree accuracy. We do not position the app as their replacement. Its aim is the measurement that otherwise would not happen — on a factory floor, in a research/teaching lab, at a field site, or at a kitchen counter — at roughly the price of a lab notebook rather than the \$5,000–\$50,000 of a benchtop instrument.

3 Using the app

The app boots directly into a live camera view with two modes (Figure 1) and starts looking for droplets to fit. Everything runs on-device; no image leaves the phone unless the user exports it.

Side-on capture The user places a droplet (∼5–20 μL; see Section 5) on the surface and lowers the phone so the lens sits at droplet height, and follows two coaching elements (Figure 2, left): a bubble-level gimbal that turns green when the device

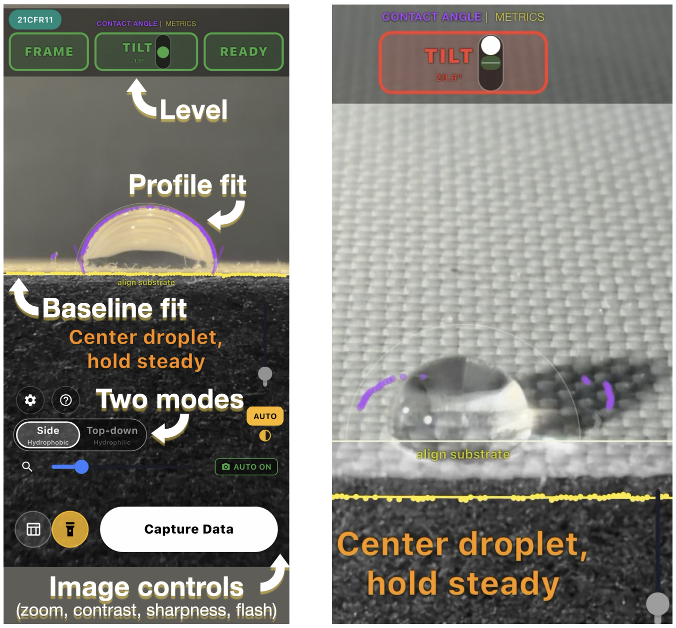


Figure 2: The side-on capture screen. Left: annotated anatomy — the level gimbal, the profile fit (purple), the baseline fit (yellow), the mode toggle, and the image controls. Right: guidance blocking a bad geometry — at 29.6° of tilt the gimbal turns red.

is vertical within tolerance, and a visual guide for how far to digitally zoom in. If the phone is held obliquely, the gimbal turns red and the app declines to report angles rather than serve a perspective-distorted number (Figure 2, right). The overlay can show the detected baseline (yellow), the segmented contour (purple dots), tangent lines at the triple points, and purple Young–Laplace curve with its gravity-corrected angle θ_{YL} above the drop. When the conditions are right the system automatically captures a measurement for you to review; a kept record stores the annotated image alongside the numbers(Figure 3).

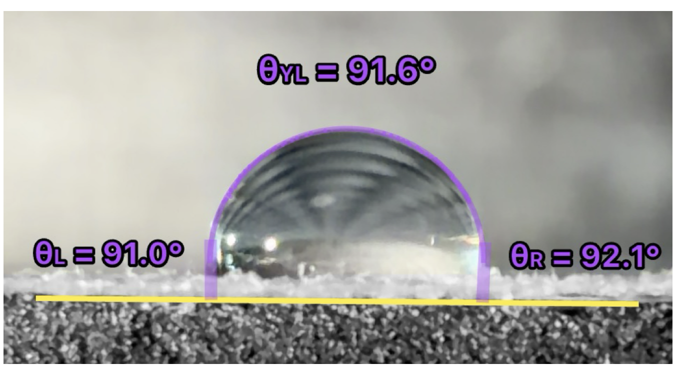


Figure 3: A saved side-on image. The Young–Laplace curve (purple) overlays the droplet with its gravity-corrected θ_{YL}; the tangent angles θ_L and θ_R sit at their triple points on the fitted baseline (yellow). The left/right pair agrees to 1.1° and the profile angle lands between them.

Top-down capture When a contact angle is low (e.g., $< 30°$ it rarely provides a clean side silhouette. In top-down mode the user photographs the droplet from above, centering it in a faint guide circle (Figure 4). Scale comes from the camera's focus approximation, or by specifying the distance from the camera to the drop. The segmenter outlines the droplet footprint, a circle is fit to it (a circularity gate rejects non-round fits), and the contact radius r is measured live. The contact angle is computed from the user-entered dispensed volume via the exact spherical-cap relation (Section 6). Both assume gravity flattening is minor, and both are reported so their agreement can be judged.

Figure 4: Live top-down capture. The tilt bubble indicates a properly horizontal phone, and the segmented footprint carries its fitted contact circle (purple).

Records, review, and tiers Every kept capture is appended to a local ledger. The review screen groups records chronologically under sticky date headers, most recent first; any record can be exported individually or as a CSV through the native share sheet. A free tier runs the full live measurement with a daily capture cap and watermark; a one-time Pro Capture purchase removes both and saves annotated composites to the photo roll; a Research Suite one time purchase unlocks the ledger review, audit exports, webhooks, and the compliance modes below.

3.1 Optional compliance modes: 21 CFR Part 11 and ASTM D8597

Current Good Manufacturing Practices require controlled electronic records, often referred to by their guidance document: title 21 of the Code of Federal Regulations part 11, 21CFR11[3]. Accordingly, the app's database is an append-only ledger: there is no deletion path in the schema layer, and each record carries an ID, a timestamp, operator attribution (via the device's biometric check), and a SHA-256 signature. A parallel audit trail folds each row's hash into the next, so the sequence is tamper-evident end to end (akin to a blockchain, though local and keyless; the chain proves order and integrity, while identity rides on the operator attribution). Removing a record is a logical discard: the user must submit a justification narrative, the row flips to *voided*, and an auditor's toggle re-exposes the unbroken trail. On demand, the app re-verifies the entire chain and renders a sealed audit report (a PDF carrying a §11.50-style signature manifestation, itself checksum-locked so any edit corrupts the seal; Figure 6). CSV exports carry a compliance cover sheet, and each saved measurement can be POSTed as JSON to a user-configured webhook for LIMS ingestion.

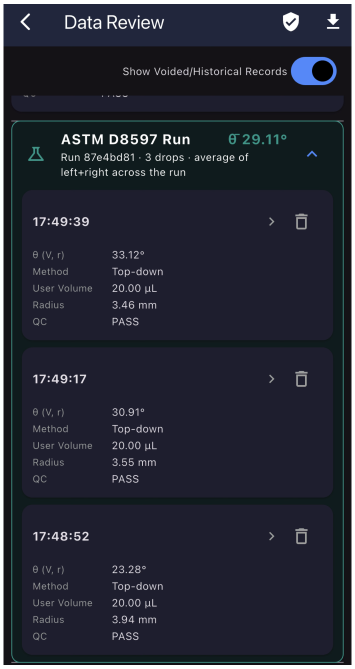


Figure 5: An ASTM D8597 run in the Data Review ledger: three properly captured measurements grouped under one run identifier with the run-average angle (upper right of the card).

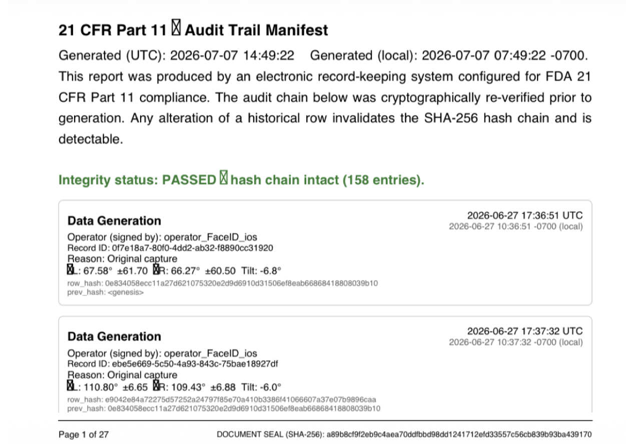
ASTM International publishes a useful standard for taking contact angle measurements: D8597-24, the Standard Test Method for Surface Wettability of Coatings, Substrates, and Pigments by Contact Angle Measurement Using Portable Goniometers. The app has a mode that complies largely with this standard, forcing the user to adhere to its best practices. In the ASTM D8597 mode a run comprises at least three drops sharing a run identifier, each drop must be captured within a 30 s window of deposition (a countdown enforces the contemporaneity), temperature, humidity, and dispensed volume become required metadata, and the left/right symmetry gate snaps to a standard's 4° criterion. A completed run appears in the ledger as one card carrying its per-drop details and the run-average angle (Figure 5).

Part 11 compliance is a property of a validated quality system, not of software alone. The app supplies the technical controls (attributable, contemporaneous, original, tamper-evident records with a retained audit trail); procedural controls — SOPs, training, access management, validation — remain the deploying organization's, and the app has not itself undergone independent validation. We therefore describe these modes as compliance-supporting rather than compliance-conferring.

4 Performance

Three preliminary studies captured with the app on a single device (iPhone 17 Pro) (Tables 2 and 1; Figure 7) demonstrate the repeatability of both modes in field conditions (my kitchen).

Side-on. Three drops on a woven PTFE textile gave $\theta_{YL} = 104.3^\circ$ with a drop-to-drop σ of 2.7° (Table 1), in the range reported for PTFE surfaces[4]. Two internal checks behaved as they should: the left/right disparity never exceeded 1.7° (comfortably inside the ASTM 4° symmetry gate), and the whole-profile Young–Laplace angle landed between the left and right tangent angles for every drop. The drop-to-drop spread likely reflects the woven surface's local heterogeneity as much as the instrument.


21 CFR Part 11 □ Audit Trail Manifest

Generated (UTC): 2026-07-07 14:49:22 Generated (local): 2026-07-07 07:49:22 -0700.

This report was produced by an electronic record-keeping system configured for FDA 21 CFR Part 11 compliance. The audit chain below was cryptographically re-verified prior to generation. Any alteration of a historical row invalidates the SHA-256 hash chain and is detectable.

Integrity status: PASSED □ hash chain intact (158 entries).

Data Generation 2026-06-27 17:36:51 UTC
2026-06-27 10:36:51 -0700 (local)
Operator (signed by): operator_FaceID_ios
Record ID: 0f7e18a7-80f0-4dd2-ab32-f8890cc31920
Reason: Original capture
□L: 67.58° ±61.70 □R: 66.27° ±60.50 Tilt: -6.8°
row_hash: 0e834058ecc11a27d621075320e2d9d6910d31506ef8eab66868418808039b10
prev_hash: <genesis>

Data Generation 2026-06-27 17:37:32 UTC
2026-06-27 10:37:32 -0700 (local)
Operator (signed by): operator_FaceID_ios
Record ID: ebe5e669-5c50-4a93-843c-75bae18927df
Reason: Original capture
□L: 110.80° ±6.65 □R: 109.43° ±6.88 Tilt: -6.0°
row_hash: e9042e84a72275d57252a24797f85e70a410b3386f41066607a37e07b9896caa
prev_hash: 0e834058ecc11a27d621075320e2d9d6910d31506ef8eab66868418808039b10

Page 1 of 27 DOCUMENT SEAL (SHA-256): a89b8cf9f2eb9c4aea70ddfbbd98dd1241712efd33557c56cb839b93ba439170

Figure 6: Excerpts of an app-generated audit report (one PDF;). The chain is re-verified at generation time ("Integrity status: PASSED," 158 entries), each entry names its operator and record UUID, and each entry's `prev_hash` equals the preceding entry's `row_hash` — the visible links of the chain. The footer carries the document's own SHA-256 seal.

Table 1: Side-on mode: three drops of water on a woven PTFE textile, with left and right tangent angles and the Young–Laplace profile-fit angle.

	θ_L	θ_R	θ_{YL}
Drop 1	106.4°	108.1°	107.2°
Drop 2	101.3°	102.5°	101.9°
Drop 3	103.0°	104.6°	103.8°
mean $\pm\,\sigma$	$103.6^\circ \pm 2.6^\circ$	$105.1^\circ \pm 2.8^\circ$	$104.3^\circ \pm 2.7^\circ$

Top-down. Measuring lower contact angle droplets is a function of the volume of liquid and the radius of the droplet. We deposited 20 μL droplets on alcohol-wiped glass slides and measured them with the app at 50mm (Figure 1-Right). Using ASTM D8597 mode we observed good repeatability across the four droplets, with a standard deviation of 1.7° (Table 2 left). Interestingly, this approach is insensitive to droplet volume in this scale. Across a sixfold change in dispensed volume (5–30 μL; contact radii 2.5–4.4 mm), the measured angle held at 23.4° with $\sigma = 0.9^\circ$. The volume-varying variation was smaller than the repeat-measurement scatter (Table 2 right).

Table 2: Top-down mode, water on a glass slide. Left: four repeat drops at a fixed volume (20 μL). Right: the dispensed volume varied sixfold at a single condition. Angles are from the volume method (Section 6).

Drop	θ
1	23.5°
2	20.8°
3	24.6°
4	24.1°
mean $\pm\,\sigma$	$23.3^\circ \pm 1.7^\circ$

V (μL)	r (mm)	θ
5	2.5	22.2°
10	3.1	23.7°
20	3.9	23.4°
30	4.4	24.4°
	mean $\pm\,\sigma$	$23.4^\circ \pm 0.9^\circ$

These are small-n, single-device results, and we present them as such.

5 Operational guidelines

Common guidance suggests droplets of [2–10] μL work best, beyond which gravity flattening makes the spherical intuition

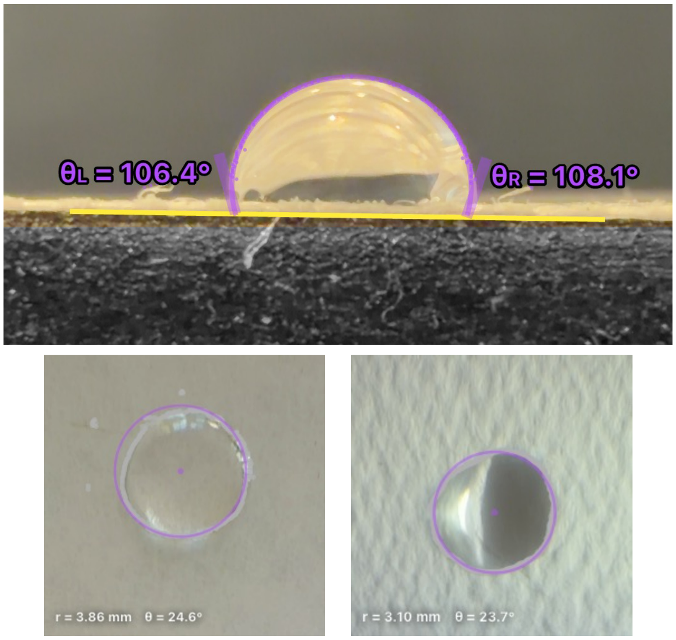


Figure 7: Top: Side-on image of Drop 1 of Table 1 as the app saved it (woven PTFE textile). Bottom: Top-down image Drop 3 from Table 2-Left and 10 μL droplet of Table 2-Right (glass slide)

unreliable for steep drops. The side-on Young–Laplace fit accounts for the sag by construction, and at shallow angles the tolerance was observed to be wide enough for 30 μL drops. Nonetheless we recommend smaller drops until you can validate that the larger ones give you comparable results in your conditions. For one thing, larger drops are more susceptible to surface inhomogeneities which would make them less round.

Lighting should be diffuse and even — a matte, uncluttered background behind the drop for side-on work, and glare kept off the droplet crown, since specular highlights are the segmenter's most likely failure mode. Once comfortable with the app it is convenient to hold a flashlight in your other hand and explore with side illumination, particularly in top-down mode. You will be able to tune the conditions with the live view of the image segmenter.

The app has controls for digital zoom; the droplet should fit within the guided gray droplet target and in side-mode the substrate line is important to line up. The app also allows contrast control (defaulting to "auto"). If you press on the contrast icon it switches to edge filtering, which is useful in some cases. The flash is also available next to the capture button. Finally, in the settings you can experiment with stabilization and fitting to more/less of the droplet profile. The "Capture Data" button glows to guide you to when imaging/fitting conditions are successful, and the "Auto On" will capture automatically as soon as they are.

6 Principles and Approach

The pipeline runs as follows: locate the surface, the drop, perform the fits then determine the angles.

Scale and level. The app selects the wide angle lens with the closest focus, and is biased for near/macro focus. A digital crop narrows the view to the chosen field. The accelerometer-driven gimbal guides the user to keep the optical axis in the surface plane, so the silhouette is orthographic rather than perspective.

Segmentation. Each frame passes through a machine learning image encoder on the phone's neural processor; a decoder with prompt points baked in at model-conversion time (positive points where the guided droplet sits, negative points on the substrate and background) returns the droplet mask profile. At the same time the substrate surface is measured by traditional edge detection and fit to a line.

Young–Laplace fit. The profile is assumed to be axisymmetric, parameterized by arc length s, inclination ϕ, and coordinates (x, z) from the apex[5]:

$$\frac{dx}{ds} = \cos\phi, \qquad \frac{dz}{ds} = \sin\phi, \qquad \frac{d\phi}{ds} = \frac{2}{b} + \frac{\beta}{b^2}\,z - \frac{\sin\phi}{x}, \quad (1)$$

where b is the apex radius of curvature and $\beta = \Delta\rho\, g\, b^2/\gamma$ is the Bond number expressing how strongly gravity distorts the shape. Equation 1 is integrated numerically (fourth-order Runge–Kutta) from the apex, and a Nelder–Mead simplex adjusts five parameters (apex curvature, Bond number, two positional offsets, and the baseline depth) to minimize the residual between the integrated curve and the segmented point cloud. The reported θ_{YL} is the inclination ϕ where the optimized profile meets the baseline — the angle the fluid pair would exhibit for a droplet too small for gravity to sag.

Geometric angles. Where the fit curve meets the fit substrate a low-degree polynomial is regressed over the bottom 10–15% of that side's edge points, and the tangent slope at the baseline intersection gives θ_L and θ_R directly. This is the classical tangent method; it reads the drop as it is, gravity sag included.

Top-down relations. A spherical cap of contact radius r and height h has volume $V = \frac{\pi h}{6}(3r^2 + h^2)$; given the user's dispensed V and the measured r, this cubic is solved for h by bisection, and $\theta = 2\arctan(h/r)$.

References

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