

Detecting Counterfeit Liquid Food Products in a Sealed Bottle using a Smartphone Camera

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National University of Singapore *Yonsei University



A Huge Amount of Deadly Fake Booze Was Confiscated from Resorts in Mexico

Death By Fake Alcohol

The ASEAN Post Team

16 January 2021



This file photo shows seized bottles of alcohol displayed before being destroyed by Indonesian customs.

In recent months, we have increasingly heard stories of counterfeit or sub-quality masks, medicines and sanitisers during the pandemic.

Fake honey scandal widens to Australian-sourced brands

The Real Reason Your Olive Oil Is Probably Fake



BY MICHAEL SOMMERS / UPI

There are healthy for authentic **extra virgin** seemingly unlimited case.

Investigative journal which blew the lid of shocked America where **olive oils** sold in the

Food Fraud Costs the Global Food Industry \$10-15 Billion Annually

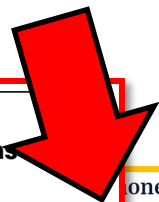
By Chris Cattini on 04-Apr-2016 10:00:00



In 2008, melamine was added to milk and infant formula to increase its protein content. This led to the hospitalisation of around 54,000 infants, 6 deaths from kidney stones and, ultimately, a number of criminal prosecutions, resulting in 2 executions.

Counterfeit Liquid Food Products

- Detrimental health effects to consumers



MUNCHIES

A Huge Amount of Deadly Fake Booze Was Confiscated from Resorts in Mexico

Regulators seized 10,000 gallons of tainted alcohol from a local supplier after raiding dozens of resorts and nightclubs across Cancun and Playa del Carmen.

By Miss Pearl

16 August 2017, 3:00am



A series of recent police raids in Mexican resort towns have turned up stockpiles of low-quality alcohol produced under "bad manufacturing practices," the Milwaukee Journal-Sentinel reports. The official discovery of a rash of fake booze may begin to explain why tourists in the area have recently been experiencing adverse—and in at least one case, fatal—reactions to their all-you-can-drink refreshments.

Honey scandal widens to Australian-sourced

Death By Fake Alcohol

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16 January 2021



This file photo shows seized bottles of alcohol displayed before being destroyed by Indonesian customs in Jakarta. (AFP Photo)

In recent months, we have increasingly heard stories of counterfeit or sub-quality face masks, medicines and sanitisers during the pandemic.

Reason Your Olive



site awful and unhealthy foods that taste like or as intimates refer it: EVVOO – which benefits – if, indeed, it's authentic. Unfortunately,

seller is author of the whistleblowing of the oil trade by exposing how rampant it is. It is estimated to 60 Minutes that "around 75 to 80 percent" of extra virgin is adulterated.

Food Fraud Costs the Global Food Industry \$10-15 Billion Annually

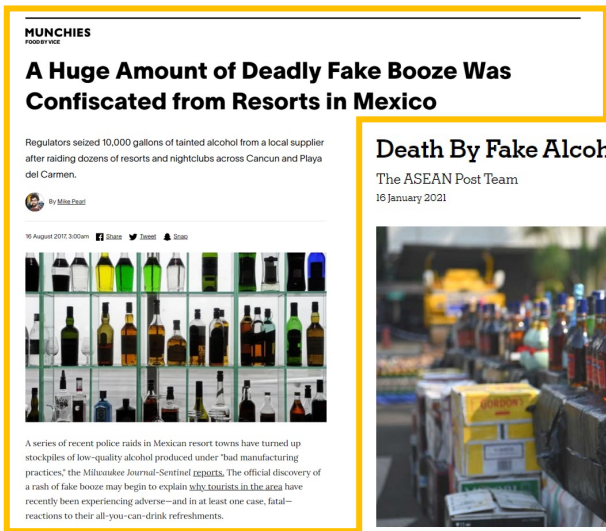
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In 2008, melamine was added to milk and infant formula to increase its protein content. This led to the hospitalisation of around 54,000 infants, 6 deaths from kidney stones and, ultimately, a number of criminal prosecutions, resulting in 2 executions.

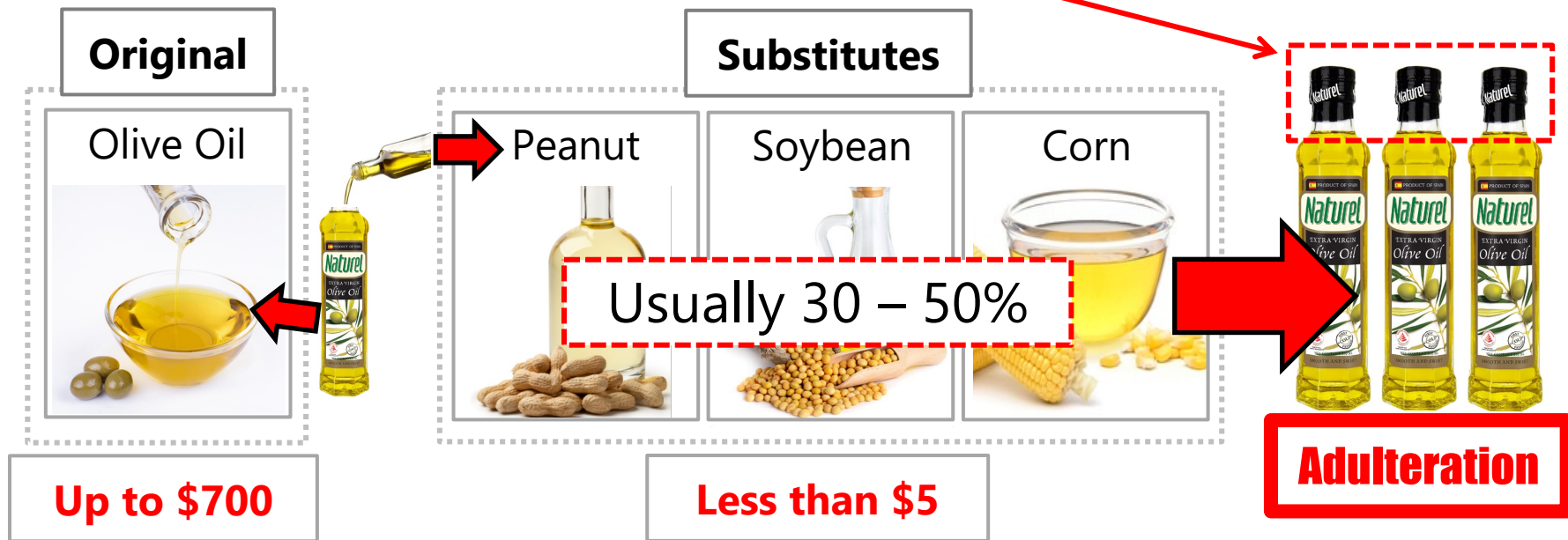
Counterfeit Liquid Food Products

- Detrimental health effects to consumers
- Significant monetary loss to manufacturers



Adulteration - Main Source of Counterfeits

- Replace a large portion of liquid content with substitutes
- Package in authentic bottles and **seal** to factory standards



Use Case: Verify Authenticity of Olive Oil



Use Case: Verify Authenticity of Olive Oil



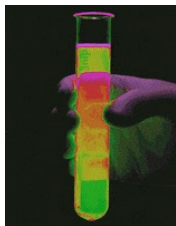
How can you tell which one is authentic?

State-of-the-Art Solutions

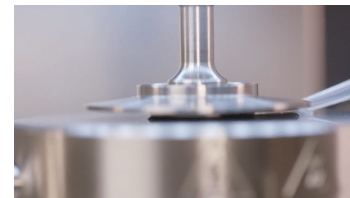


- Industrial and laboratorial solutions

Optical-based



Mechanical-based



Disadvantage:

- Require **costly** and **specialized** equipment
- Require **opening** of the bottle to take liquid **samples**

State-of-the-Art Solutions



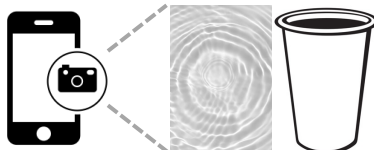
- Academic proposals

Wireless signals



[Ha, NSDI'20]

Smartphone vibration



[Yue, MobiSys'19]



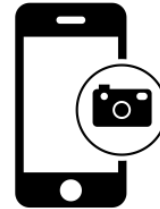
[Huang, MobiCom'21]

Disadvantage:

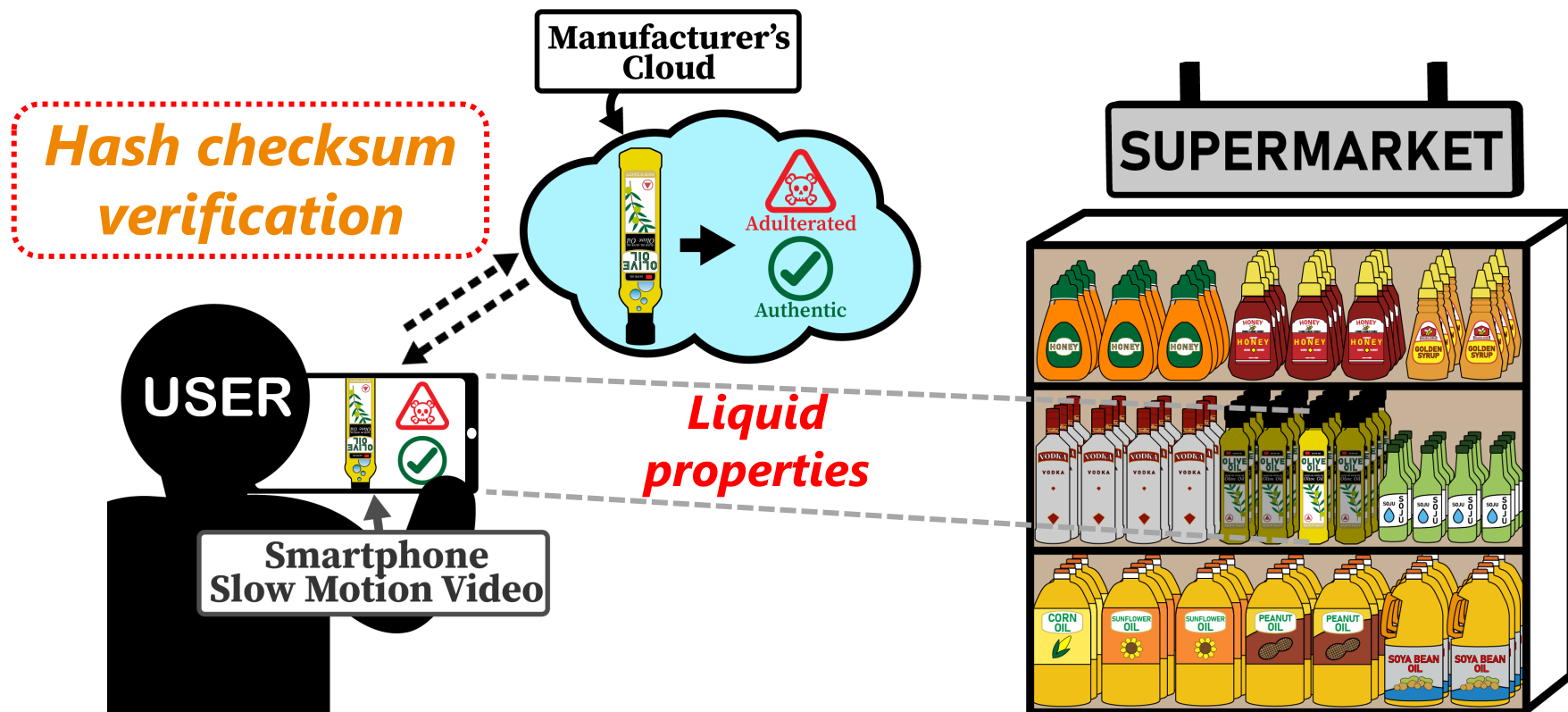
- Require **additional** and **specialized** equipment
- Require **opening** of the bottle and **controlled** settings



Can we detect adulteration without opening bottles and using only commodity devices?



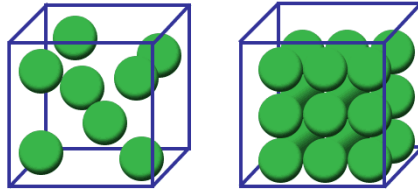
Our Work: *LiquidHash*



Liquid Properties

- Unique **liquid properties** in each type of liquid

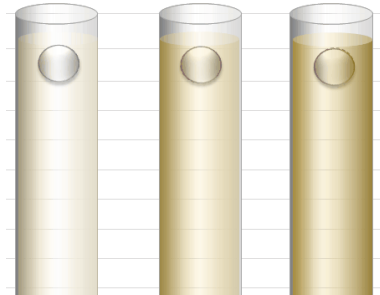
Density



Surface tension

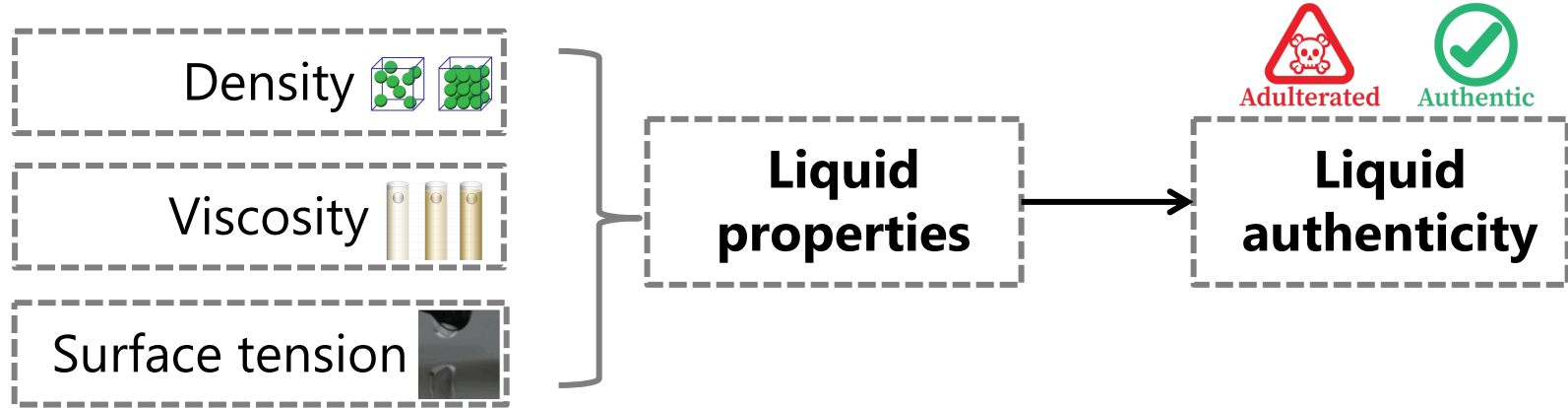


Viscosity



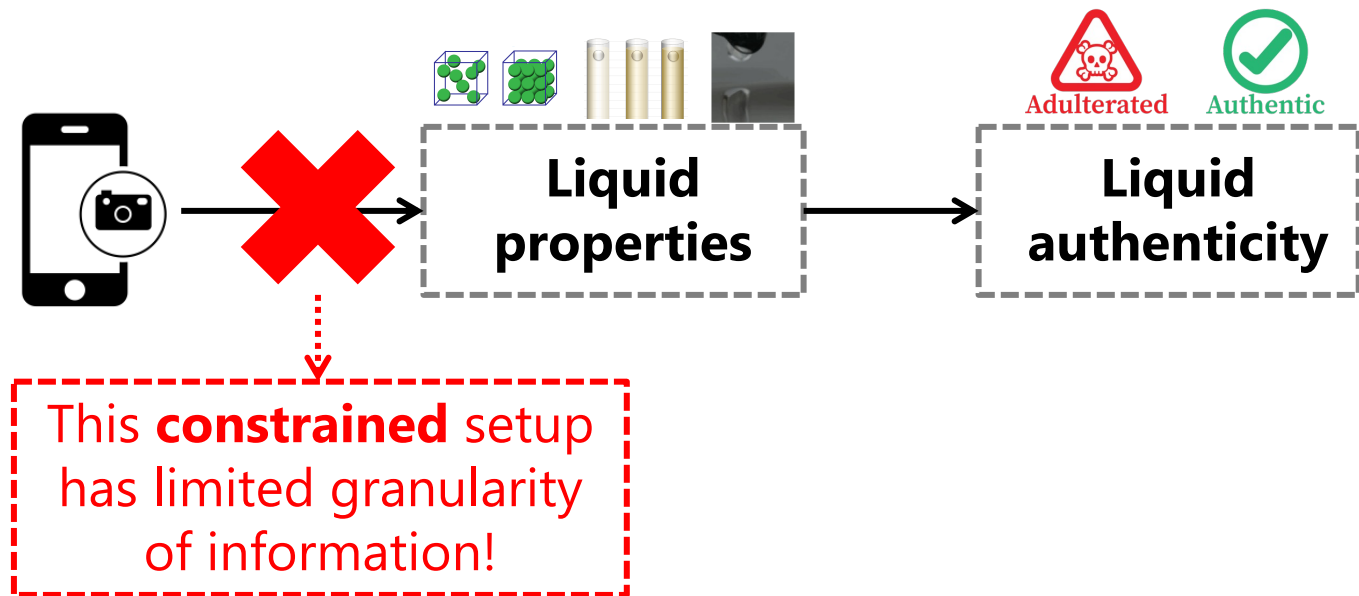
Liquid Properties

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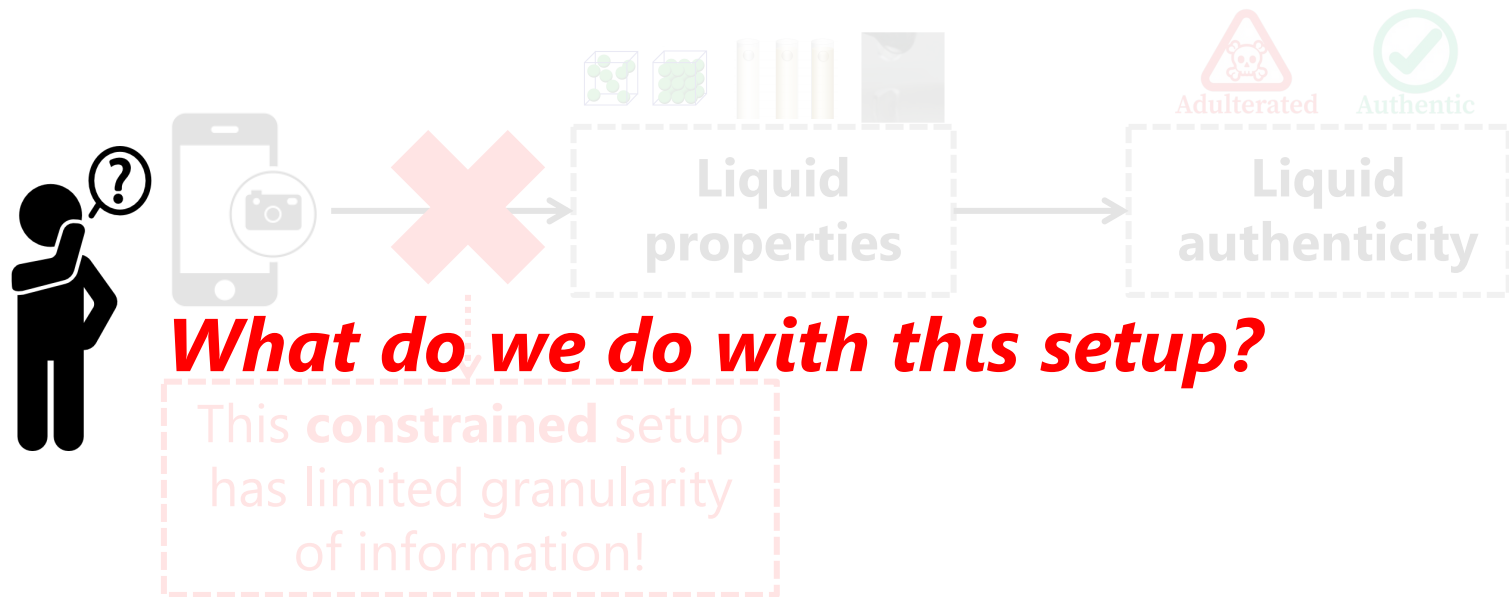
Liquid Properties

- Unique **liquid properties** in each type of liquid
- **Quantifying** liquid properties is impractical



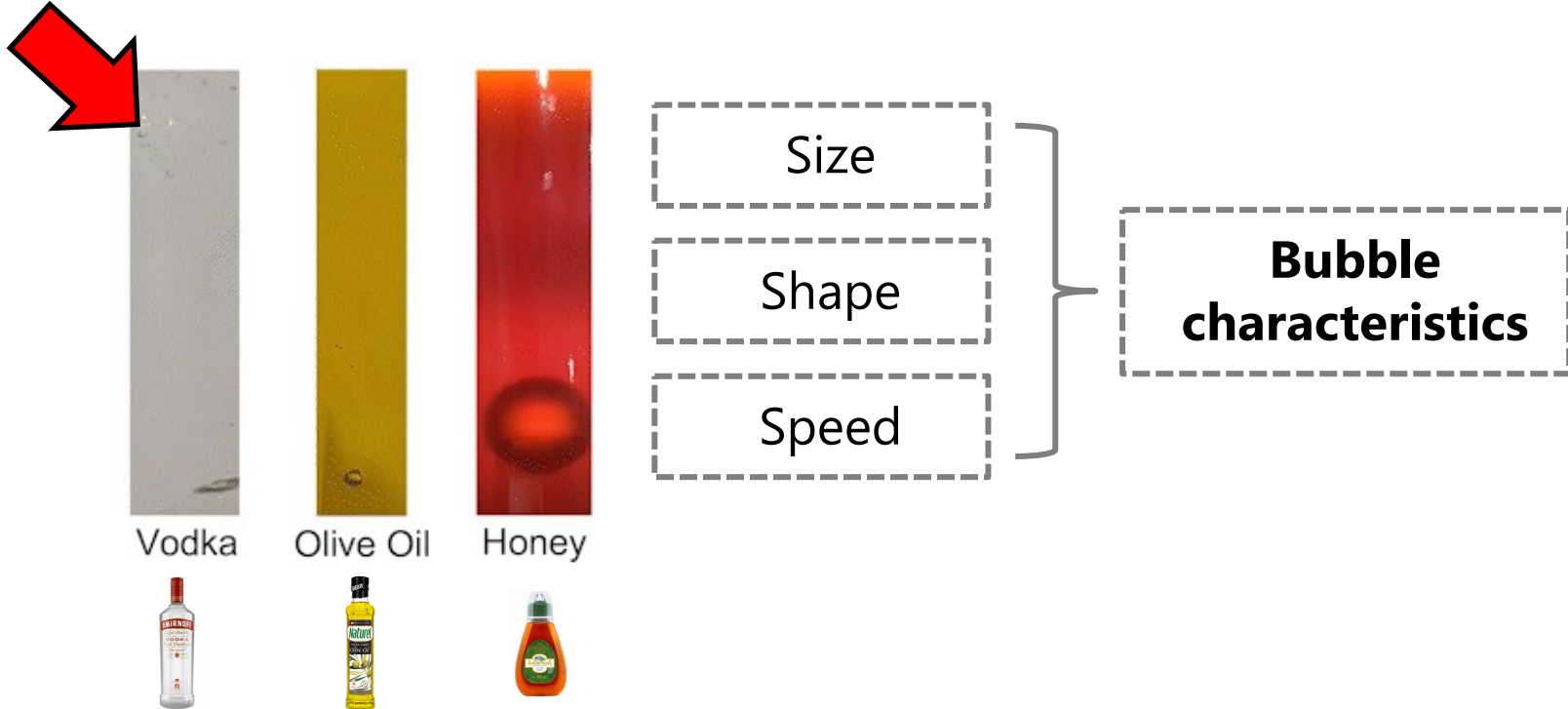
Liquid Properties

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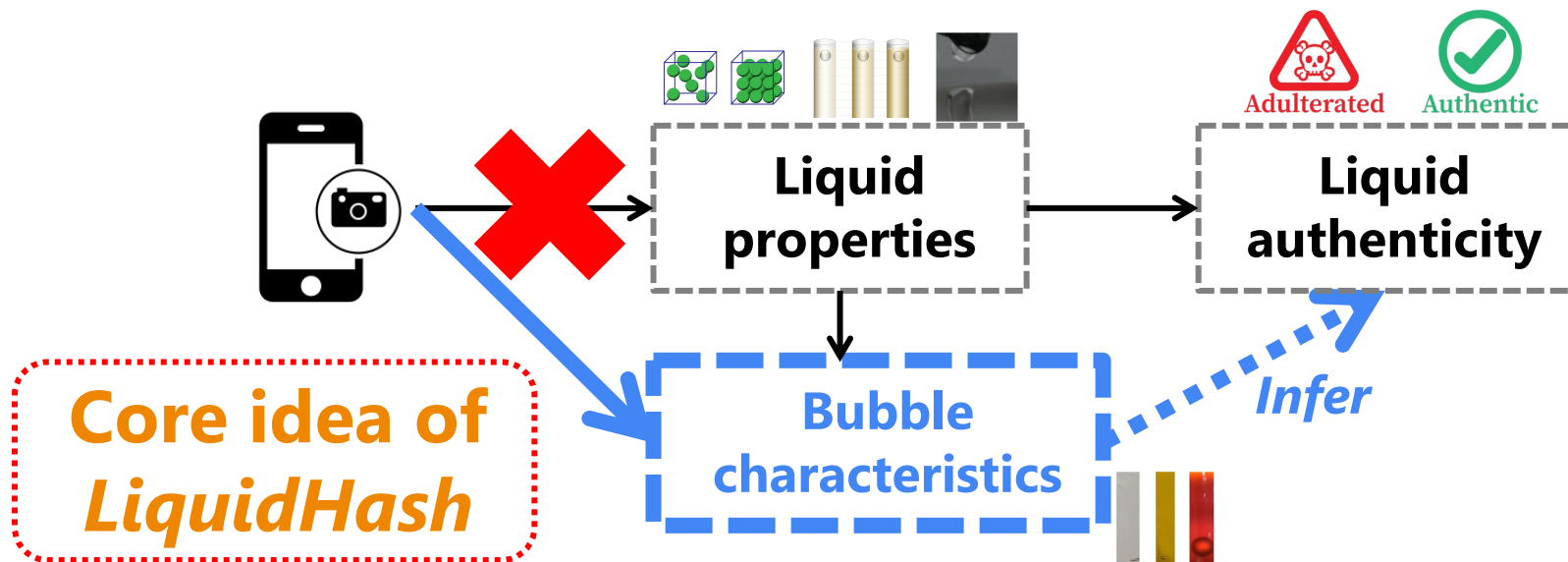
Bubble Characteristics !!!

- **Bubble characteristics** are a model of liquid properties



Bubble Characteristics

- **Bubble characteristics** are a function of liquid properties
- Use bubbles to **infer** liquid authenticity

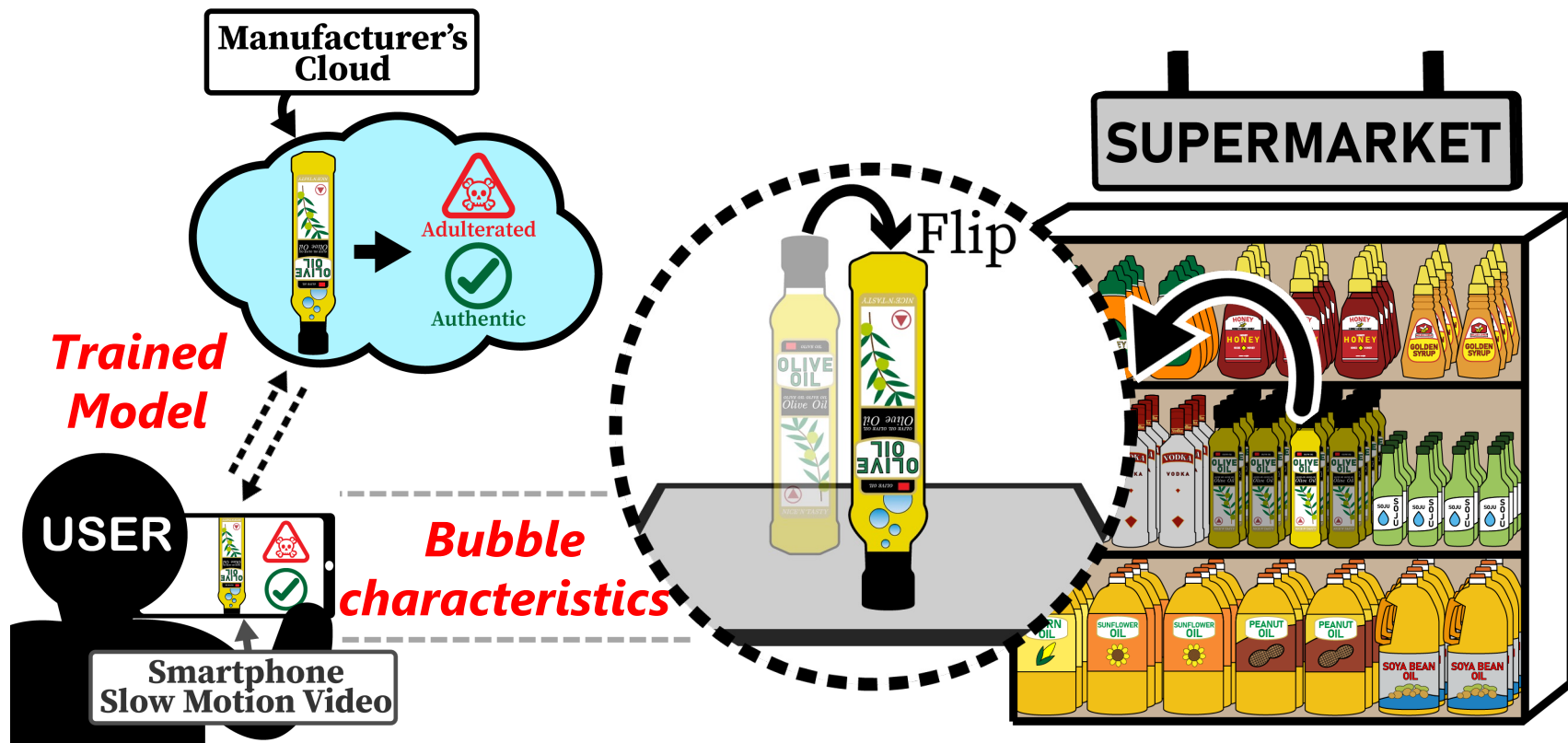


Our Work: *LiquidHash*

Human interaction:
Flip once!

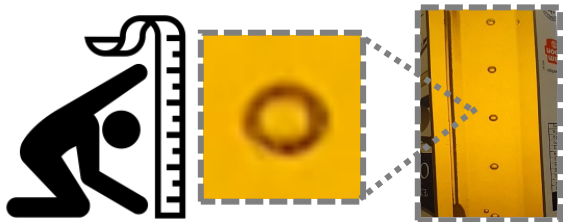


Our Work: *LiquidHash*



Challenge (1): Multiple Sources of Noise

- Noise in measuring bubble characteristics in each test



- Noise due to **human behavior**

① Rotation Motion

② Camera Placement

- Noise due to **liquid movement**

③ Bubble Shapes

④ Bubble Trajectories

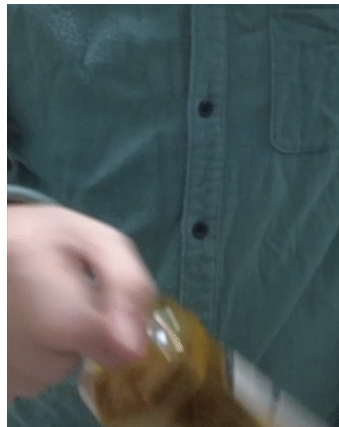
Challenge (1): Multiple Sources of Noise

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① Rotation Motion

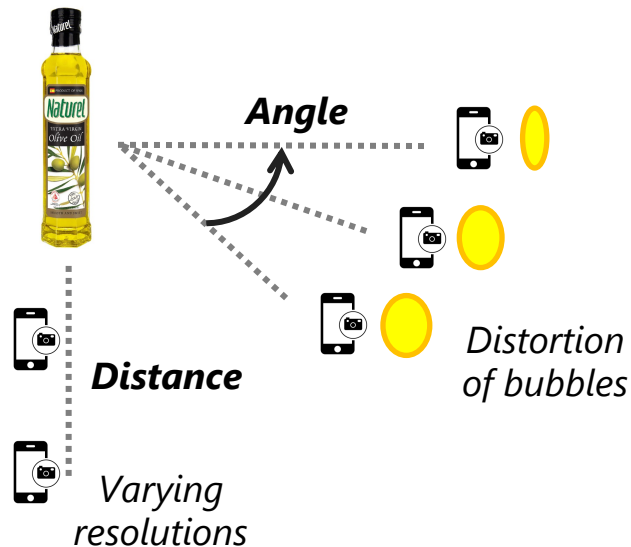


Test 1



Test 2

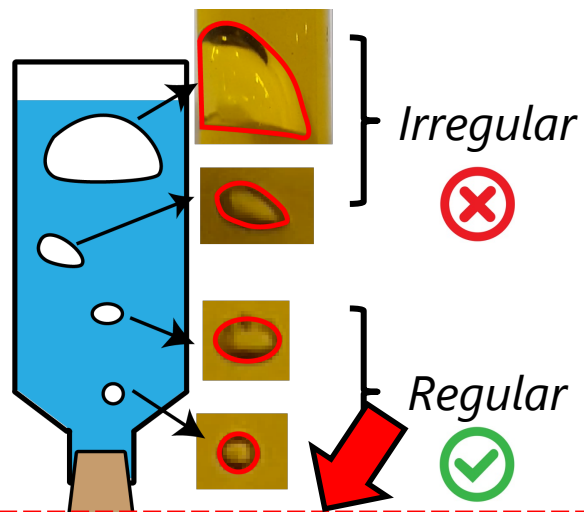
② Camera Placement



Challenge (1): Multiple Sources of Noise

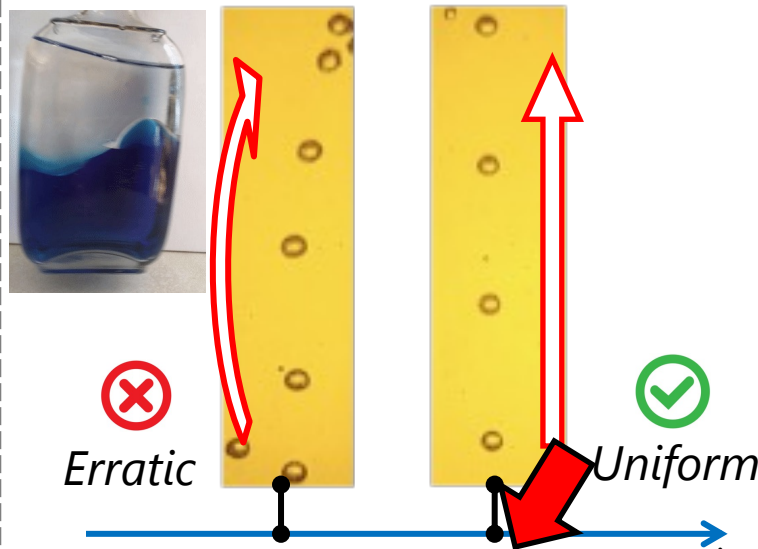
- Noise due to **liquid movement**

③ Bubble Shapes



Consistent across tests

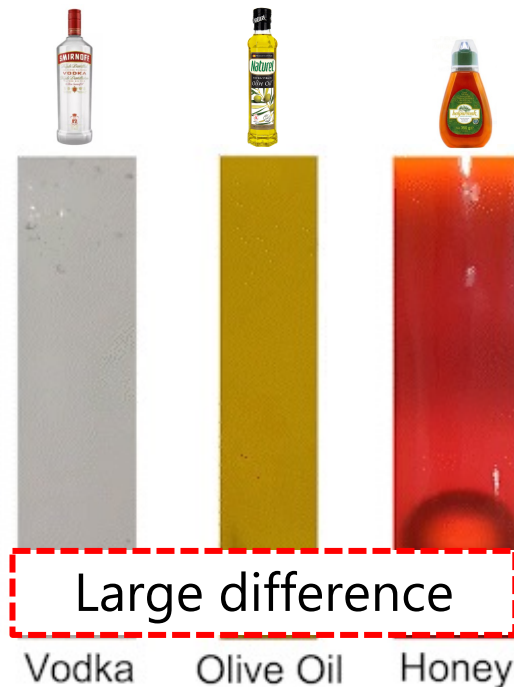
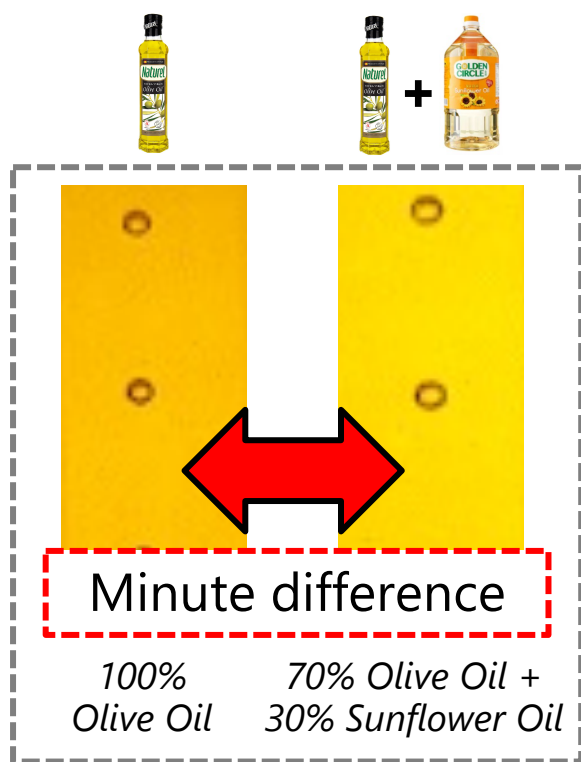
④ Bubble Trajectories



Consistent across tests

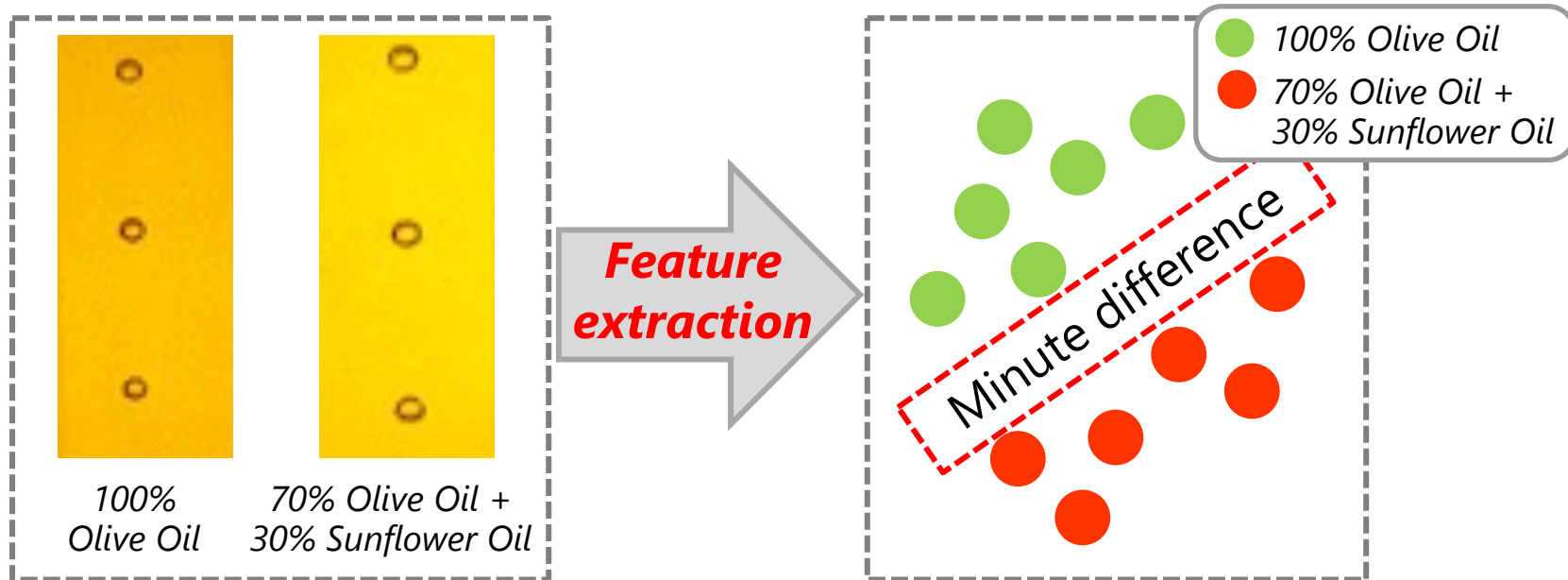
Challenge (2): Minute Difference in Characteristics

- Difference in bubble characteristics could be **minute**



Challenge (2): Minute Difference in Characteristics

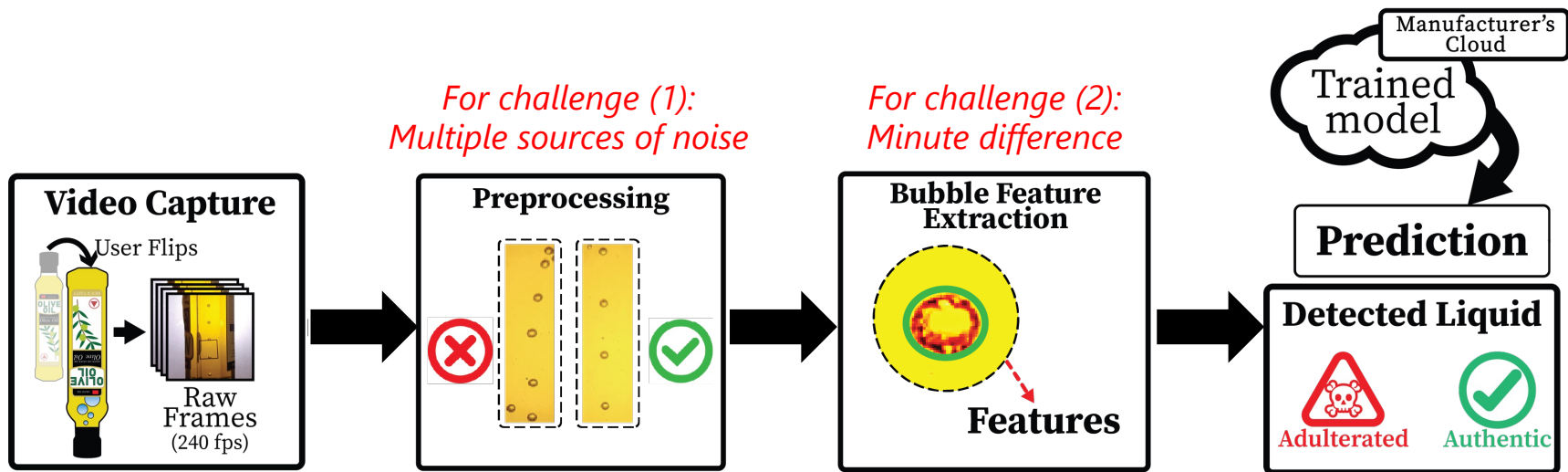
- Difference in bubble characteristics could be **minute**
- Require fine-grained and accurate **feature extraction**



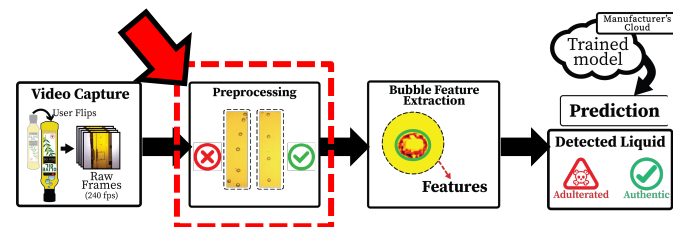
**How can we solve the combined challenges of
(1) multiple sources of noise and (2) minute difference?**

System Design of *LiquidHash*

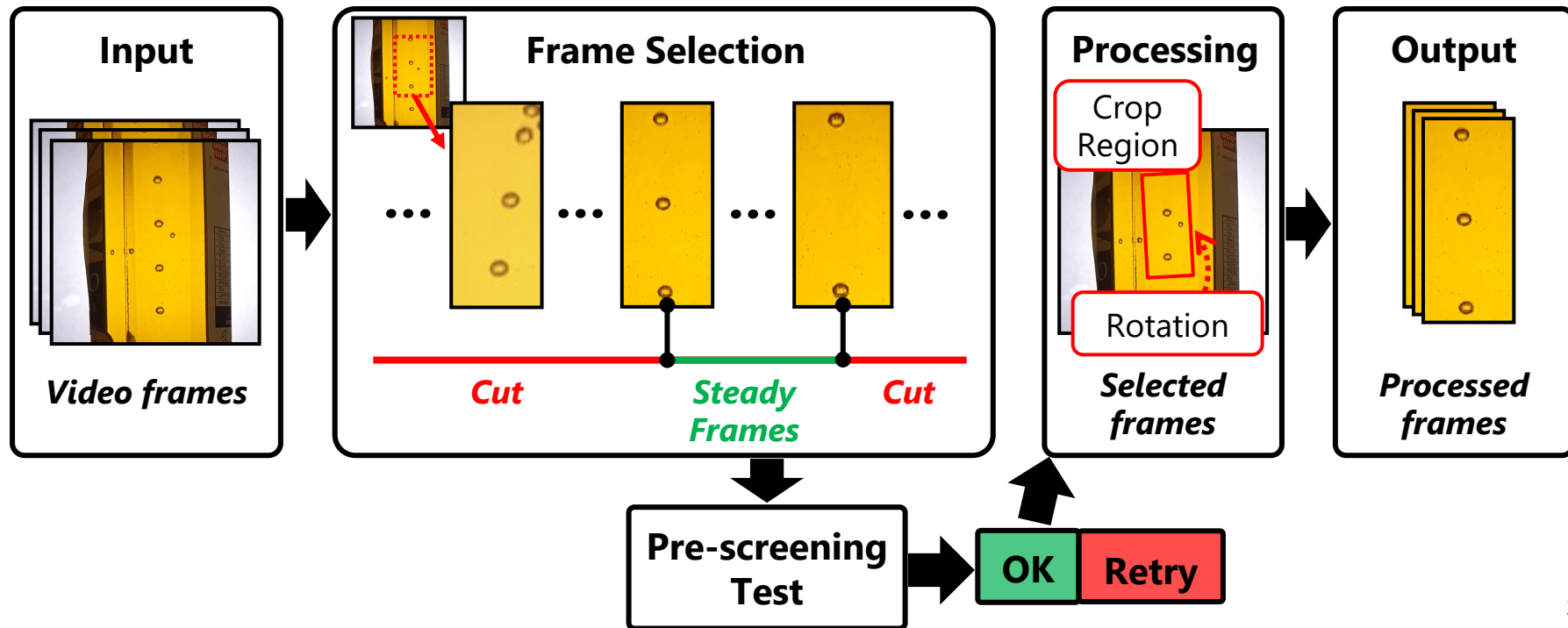
Goal: To verify authenticity leveraging observed bubble characteristics



Pre-processing

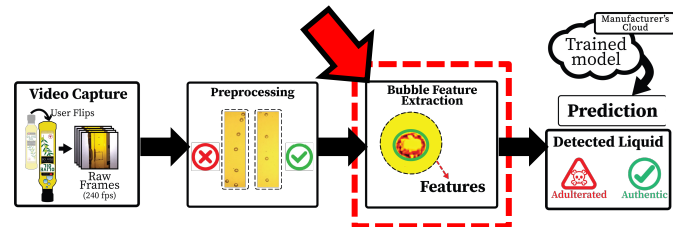
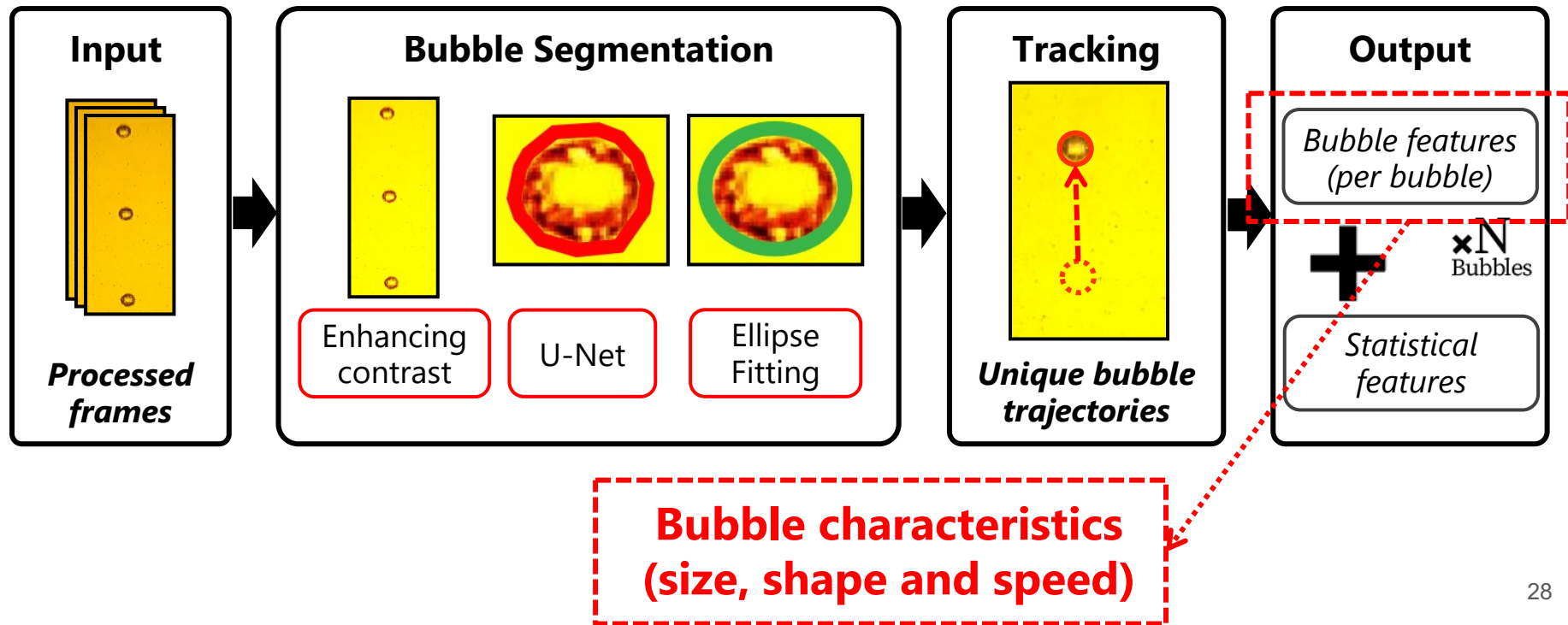


Goal: To select and process frames to **remove noise** from multiple sources



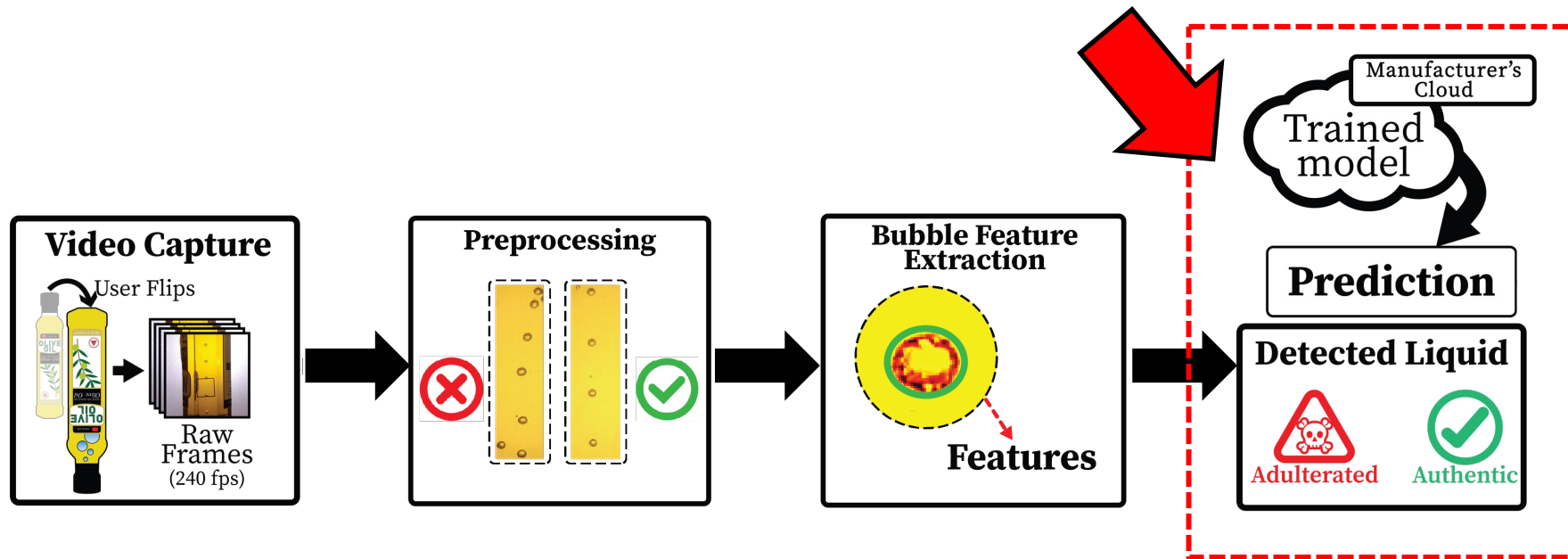
Bubble Feature Extraction

Goal: To extract **fine-grained** and **distinguishable** features



Prediction

Goal: To decide liquid authenticity leveraging extracted bubble features

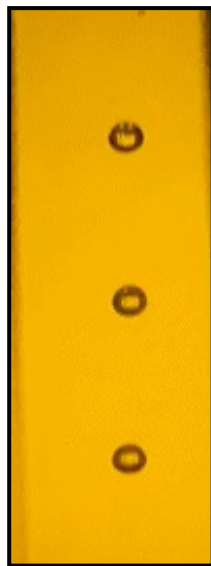


Enhancing Bubble Generation

Goal: To further improve **performance** and **usability**



**Without
cap accessory**



**With
cap accessory**



**Our proposed
cap accessory**

Deployment concerns



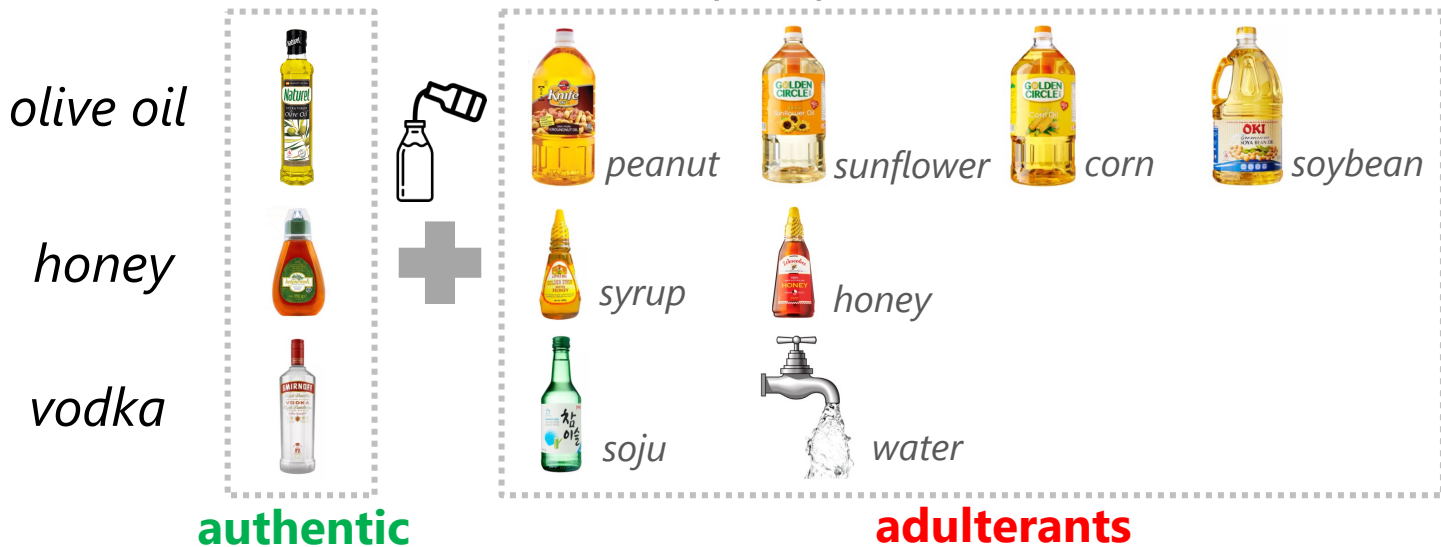
Tube-like cap accessory



Peel-off layer

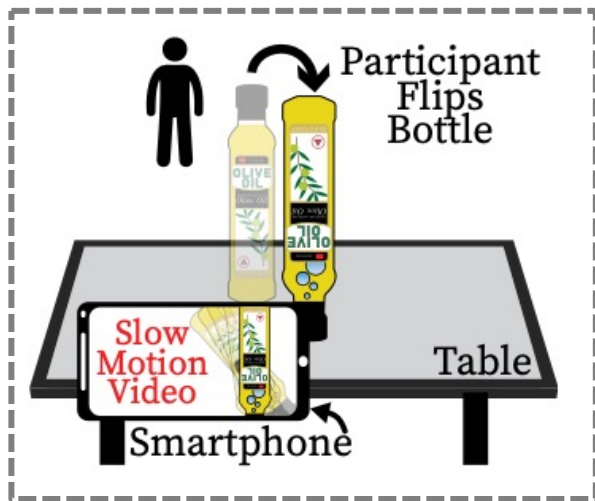
Evaluation Setup (1)

- We test **LiquidHash** with olive oil, honey and vodka
 - 3 instances of **authentic** liquid products
 - 8 instances of **adulterated** liquid products



Evaluation Setup (2)

- For each instance, we test **two** detection methods



LiquidHash

70 tests x **5** Participants
Leave-one-out approach

VS



Baseline: No Assistance

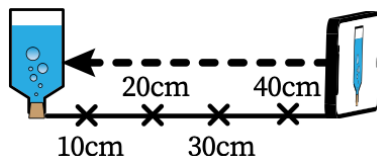
Participants can **interact freely** with liquid products **except opening** the bottles

Summary of Evaluation Results

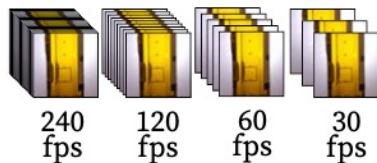
- Demonstrates **overall detection accuracy up to 95%**



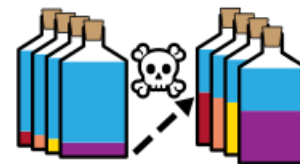
- Robust against **camera-to-bottle distances**



- Robust against **video framerates**



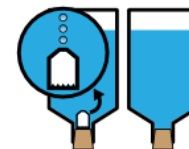
- Generalizes across **adulterant concentrations**



- Generalizes across **bottle dimensions**

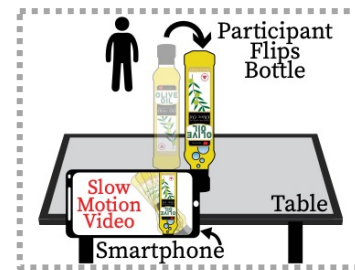
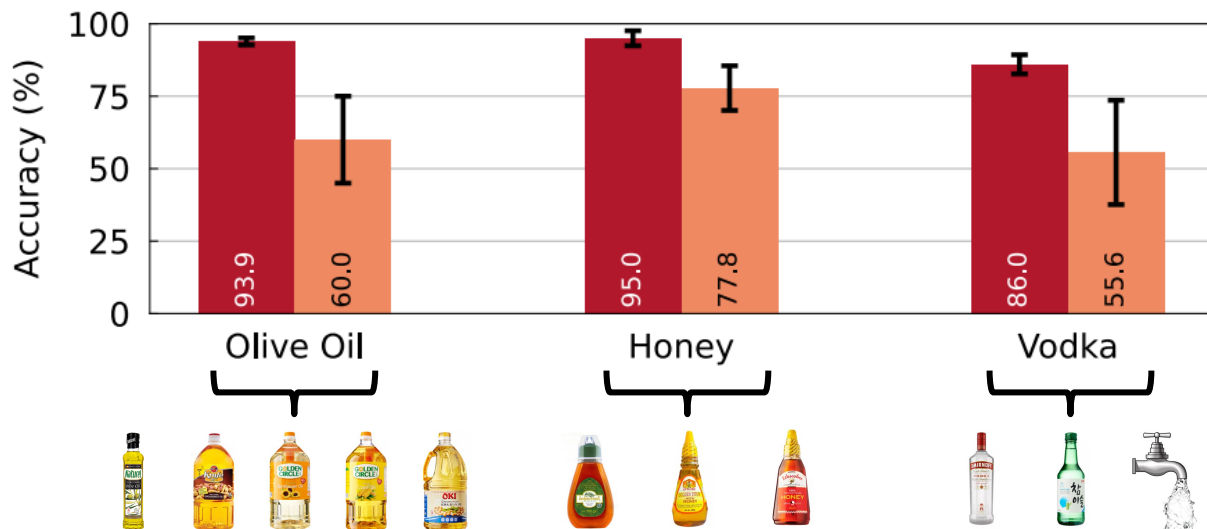


- Moderately reduces accuracy without using the **bottle cap accessory**



Main Result

- **LiquidHash** outperforms **No Assistance** baseline in all use cases of olive oil, honey and vodka



■ LiquidHash

■ No Assistance



Discussion: Deployment Considerations

- Applications in **supply chain** to prove integrity of products



Producers



Distributers



Retailers

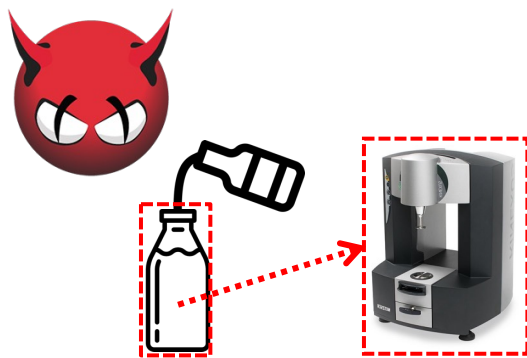


Consumers



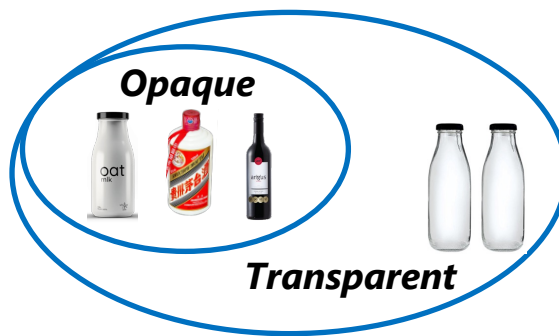
Discussion: Limitations and Future Work

① Powerful Counterfeiters



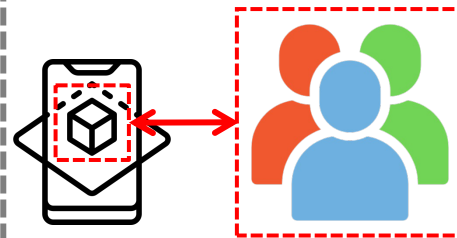
- Attack is extremely costly
- Strive to gain profit using cheap substitutes

② Opaque materials



- Increasing usage of transparent bottles
- Utilize other modalities

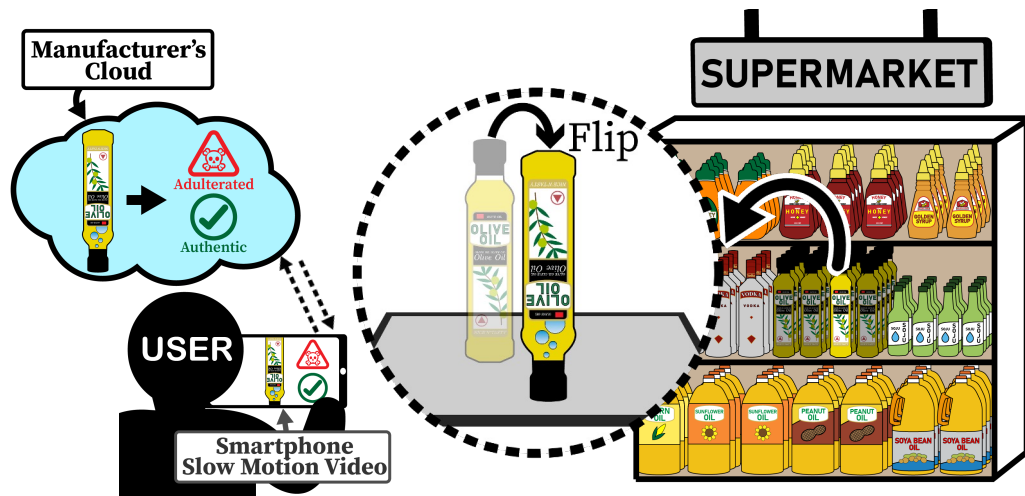
③ Moving Forward



- Utilize physical interactions to **augment** vision

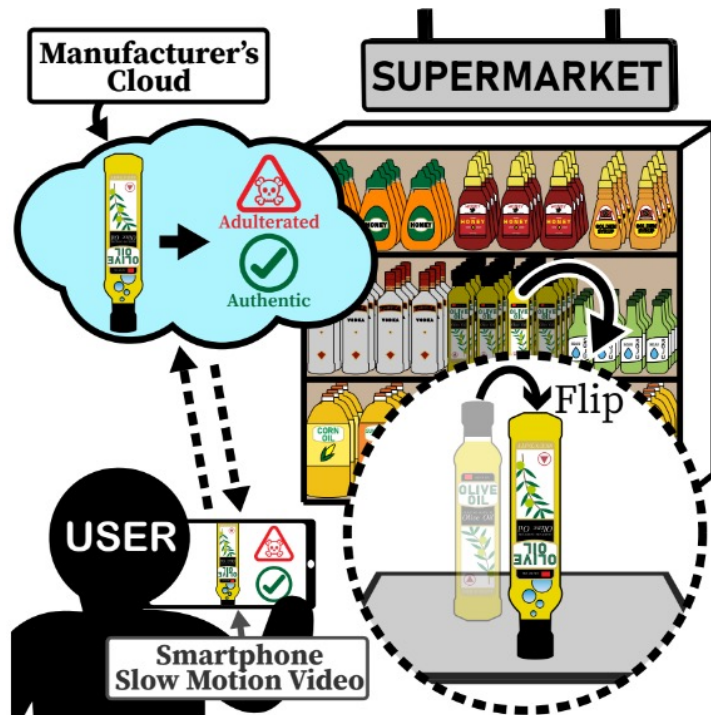
Conclusion

- **LiquidHash** uses smartphone **cameras** to detect **adulteration**
- Spur **novel ways** to **augment** computer vision on mobile platforms



<https://www.cyphy-lab.org/research/liquidhash>

Thank you!



Bangjie Sun

Graduate Tutor and PhD candidate at the
National University of Singapore

I am a passionate researcher in **computer vision**, and **sensing**. I am currently pursuing my Ph.D. in National University of Singapore (NUS). My supervisors are [Prof. Jun Han](#) in Yonsei University and [Prof. Chan Mun Choon](#) in National University of Singapore. My research interests are in the intersection of computer vision and sensing systems.

Contact: bangjie@comp.nus.edu.sg

Supplementary Slides

Types of Counterfeit Liquid Food Products

Packaging

Re-branding



Mislabeling



Content

Adulteration



A **superset** that is more difficult to detect



Liquid Properties: Olive Oil and Substitutes

- Unique **liquid properties** in each type of liquid

Oil Type	Density (kg/m ³)	Viscosity (mPa·m)	Surface Tension (mN/m)
Olive oil	908.7±0.7	74.1±2.2	31.9±0.0
Peanut oil	912.1±0.7	72.2±0.8	31.3±0.1
Soybean oil	915.7±0.7	57.1±1.1	31.3±0.4
Corn oil	915.3±0.7	59.2±0.8	31.6±0.1

Table 1: Measured properties at 23°C by [1]

Bubble Characteristics: Physics Model

- **Bubble characteristics** are a model of liquid properties

Law 1: Stokes' Law

$$V = \frac{2}{9} \frac{(\rho_{air} - \rho_{liquid})}{\mu} g R^2$$

V: Bubble terminal velocity

R: Bubble radius

ρ : Density

μ : Liquid viscosity

g: Gravity constant

Law 2: Young-Laplace Law

$$\Delta p = 2 \frac{\sigma}{R}$$

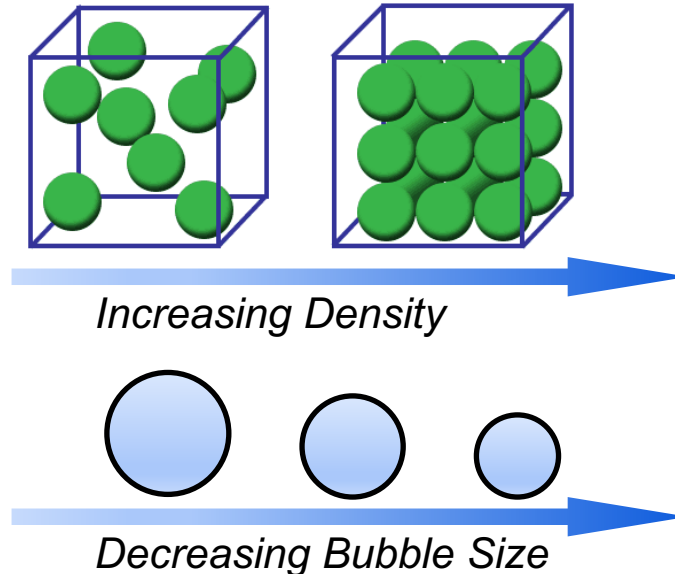
Δp : Pressure difference
between bubble and liquid

σ : Liquid surface tension

Liquid Properties: Impact on Bubbles

- Unique **liquid properties** in each type of liquid

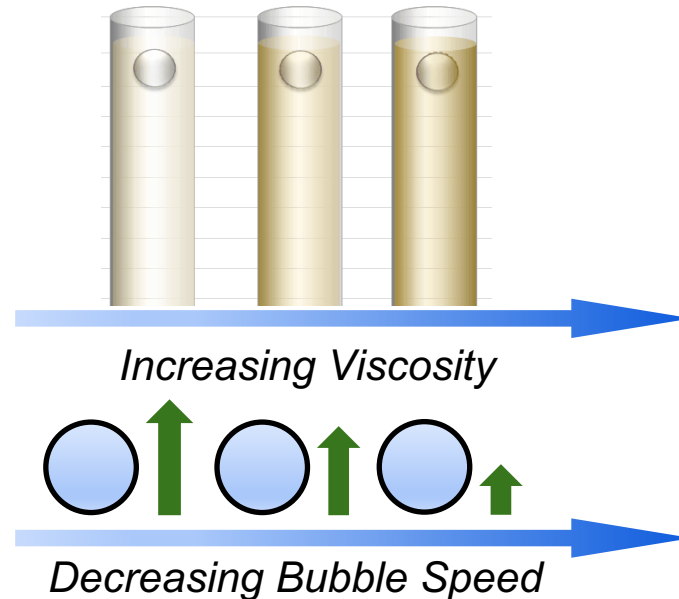
Density



Liquid Properties: Impact on Bubbles

- Unique **liquid properties** in each type of liquid

Viscosity



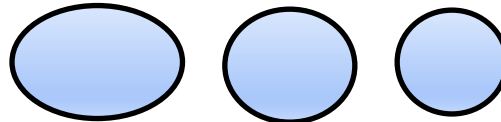
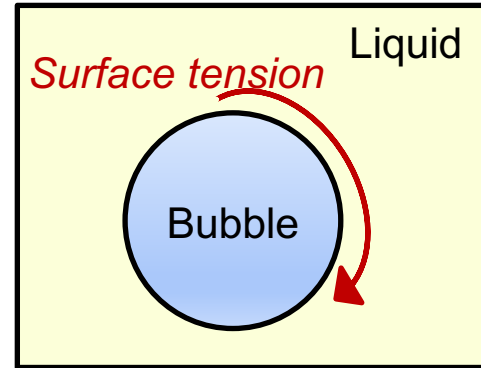
Liquid Properties: Impact on Bubbles

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Surface tension



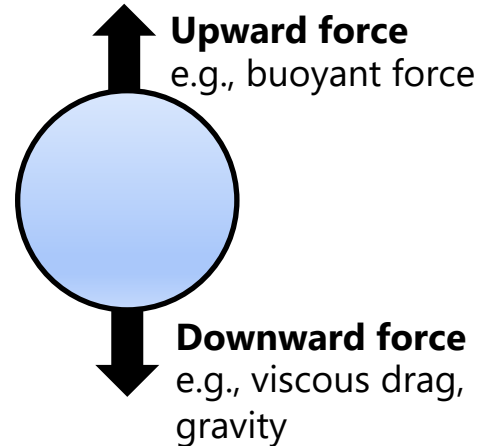
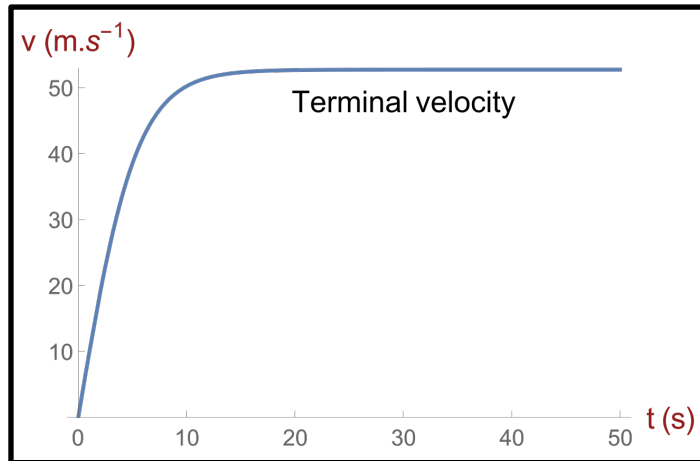
Water Droplet



Varying bubble shapes and sizes

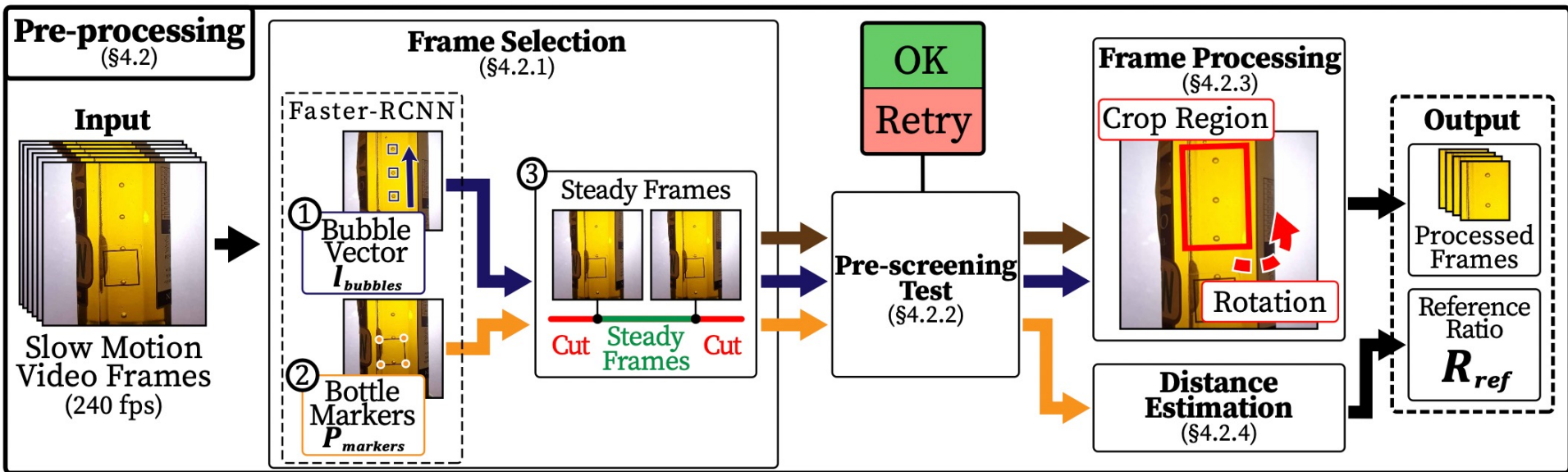
Bubble Characteristics: Terminal Velocity

- Bubbles reach **terminal velocity** after some time
- **Constant** value determined by liquid properties and bubble sizes and shapes



System Design: Pre-processing

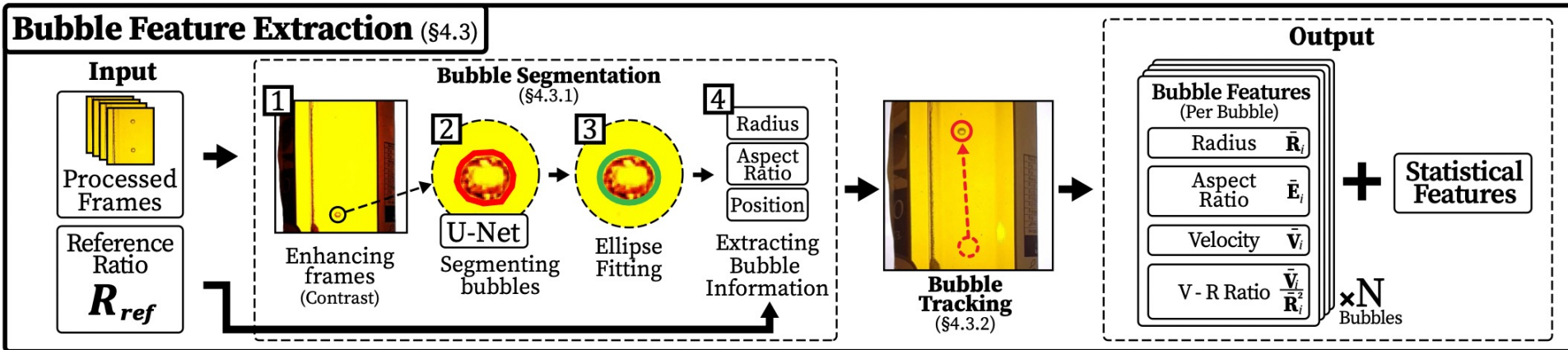
Goal: To select and process frames to **remove noise** from multiple sources



Full processing pipeline of Pre-processing Module

System Design: Bubble Feature Extraction

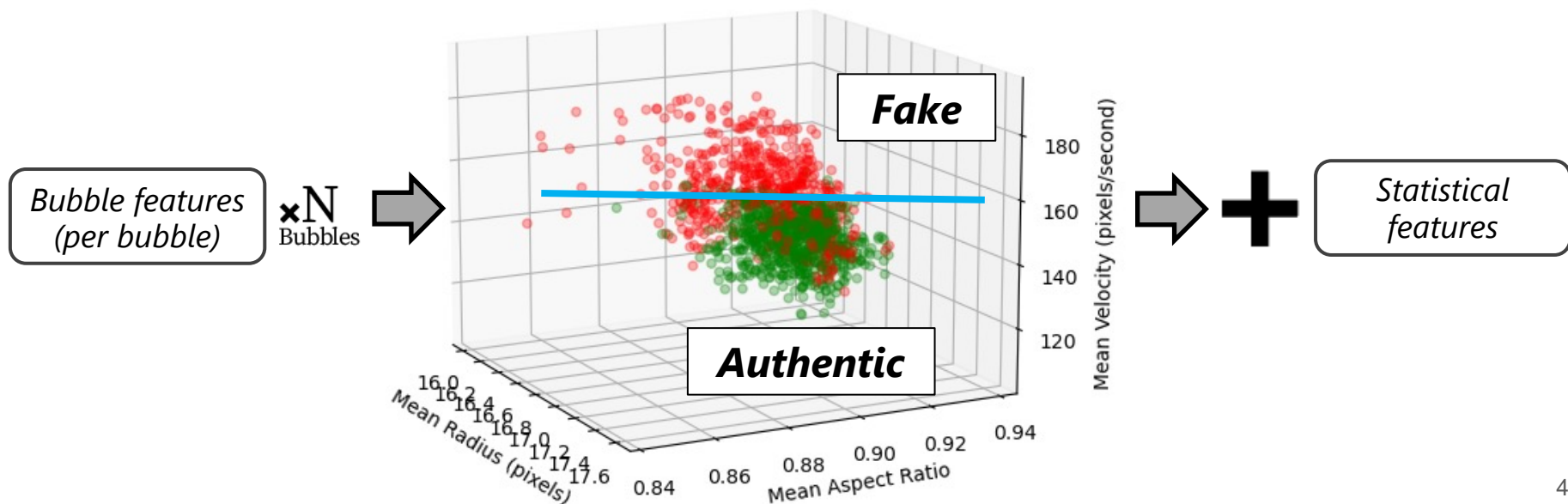
Goal: To extract **fine-grained** and **distinguishable** features



Full processing pipeline of Bubble Feature Extraction Module

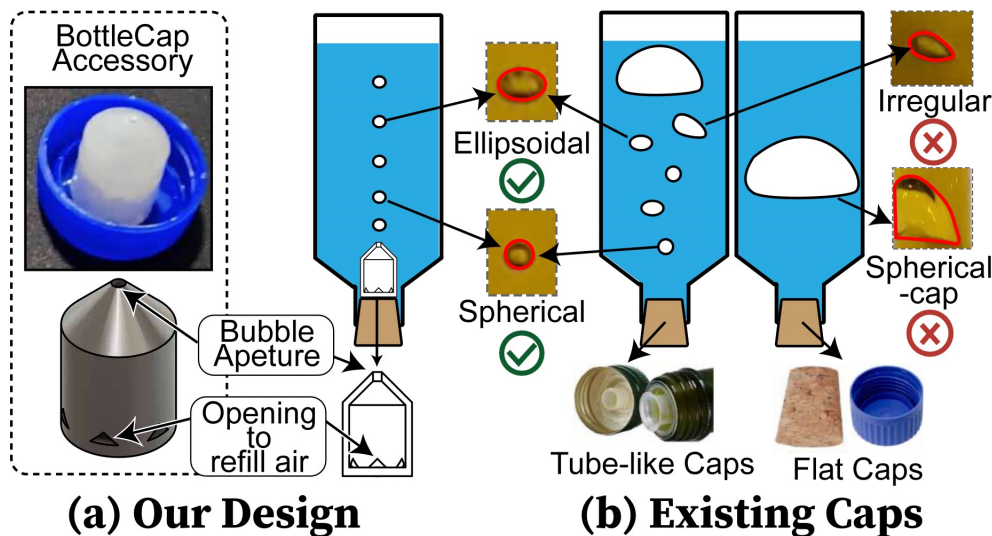
System Design: Bubble Feature Extraction (2)

- **Noisy separation** between two classes with only bubble features
- **Statistics features** to further combat noise and improve accuracy



System Design: Enhancing Bubble Generation

- Our proposed bottle cap accessory is **modified** from existing olive oil tube-like caps by (1) adding small openings to refill air (2) shrinking the aperture size to 2mm



Evaluation: Main Results for Baseline

In the use cases of olive oil, honey and vodka, **Baseline: No Assistance** has

- An overall accuracy of **60.0%**, **77.8%** and **58.3%**
- **60%**, **40%** and **70%** of fake instances misclassified as authentic
- **20%** of authentic vodka and **none** of authentic olive oil and honey misclassified as fake



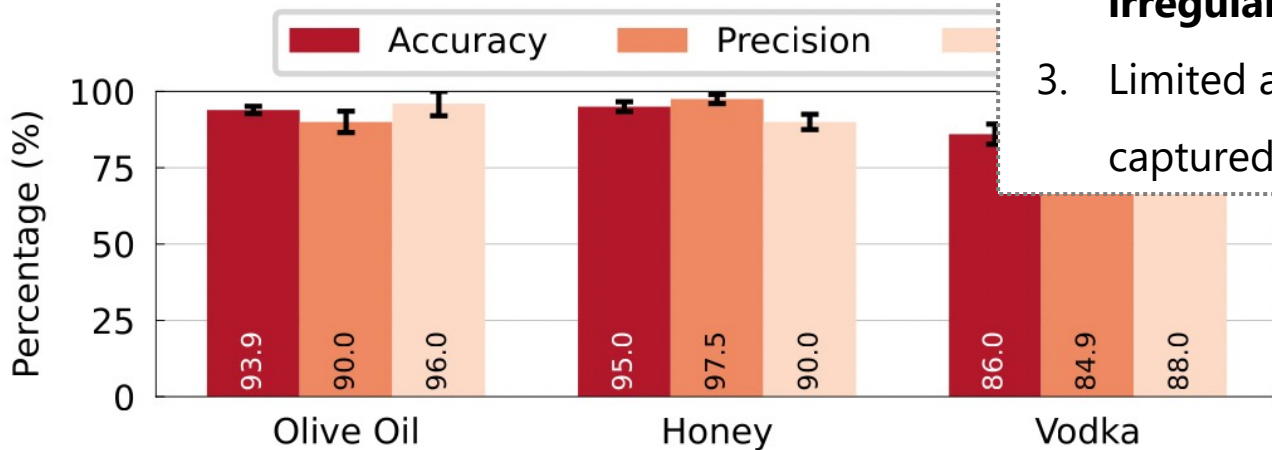
Baseline: No Assistance

Participants can **interact freely** with liquid products **except opening** the bottles

Evaluation: Main Results for *LiquidHash*

In the use cases of olive oil, honey and vodka, *LiquidHash* achieves

- Significantly higher accuracy, precision and recall than baseline
- **Lower** performance in **vodka**



1. Bubbles moving extremely **fast**
2. A large portion of bubbles have **irregular shapes**
3. Limited amount of information captured at a frame rate of 240 fps

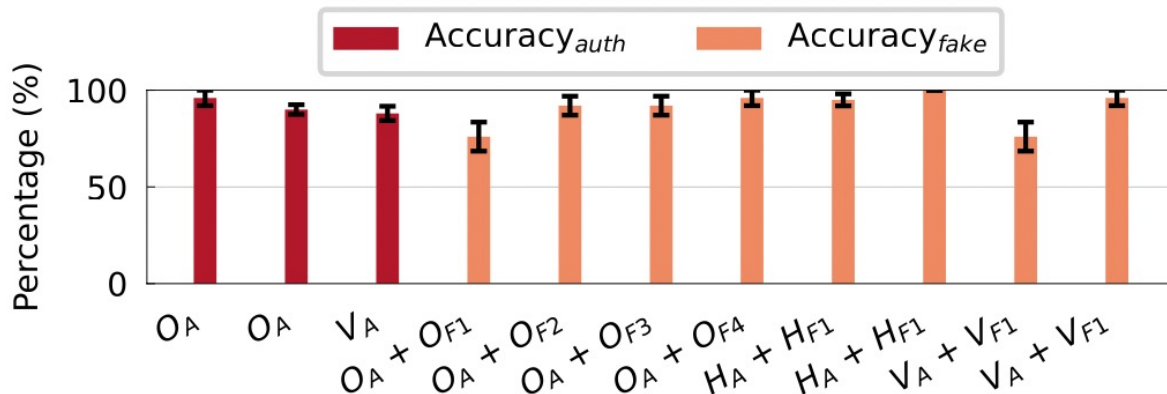
$$\text{Precision} = Ft / (Ft + Ff)$$
$$\text{Recall} = At / (At + Af)$$

Evaluation: Main Results for *LiquidHash*

For different adulterants, *LiquidHash* achieves

- **Lower** accuracy in detecting **olive oil** adulterated with **peanut oil** and **vodka** adulterated with **soju**

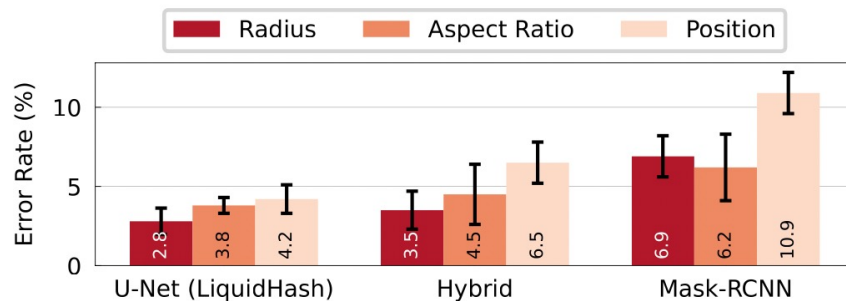
Smaller difference in liquid properties, leading to smaller difference in bubble characteristics



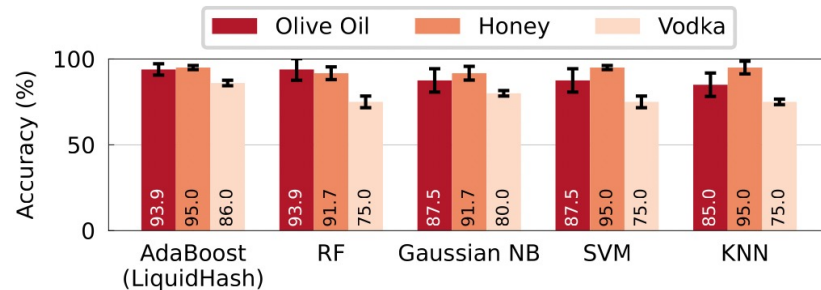
Evaluation: System Modules

We evaluate the performance of machine learning modules

- Deep learning models for **bubble segmentation**



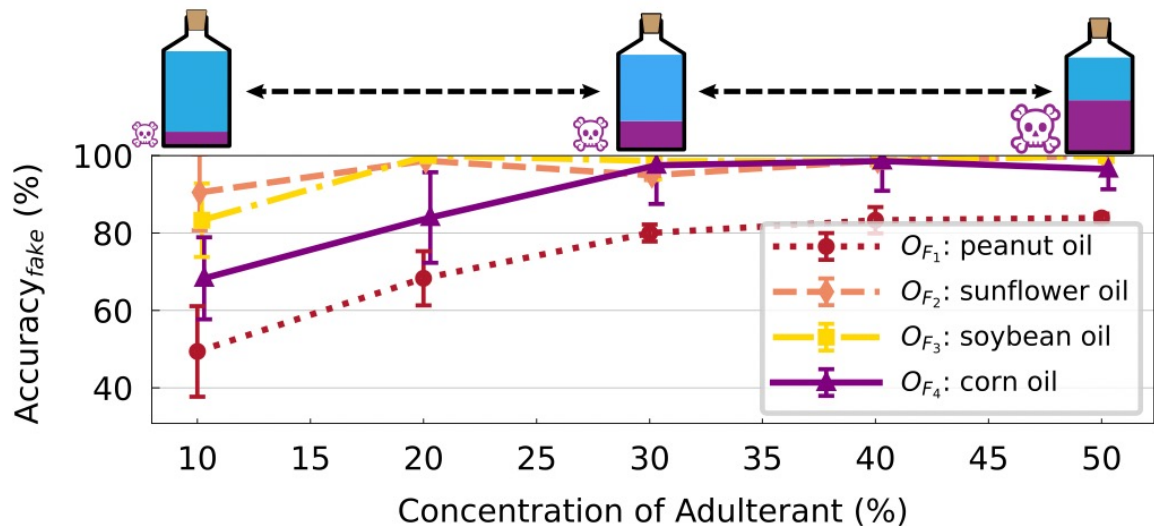
- Machine learning classifiers for **determining authenticity**



Evaluation: Adulterant Concentrations

For different concentrations of adulterants, **LiquidHash** achieves

- Higher accuracy when concentration of adulterant increases
- High accuracy (>**90%**) in sunflower, soybean and corn oil when concentration > **30%**
- Limited accuracy (<**90%**) in peanut oil even when concentration increases to **50%**

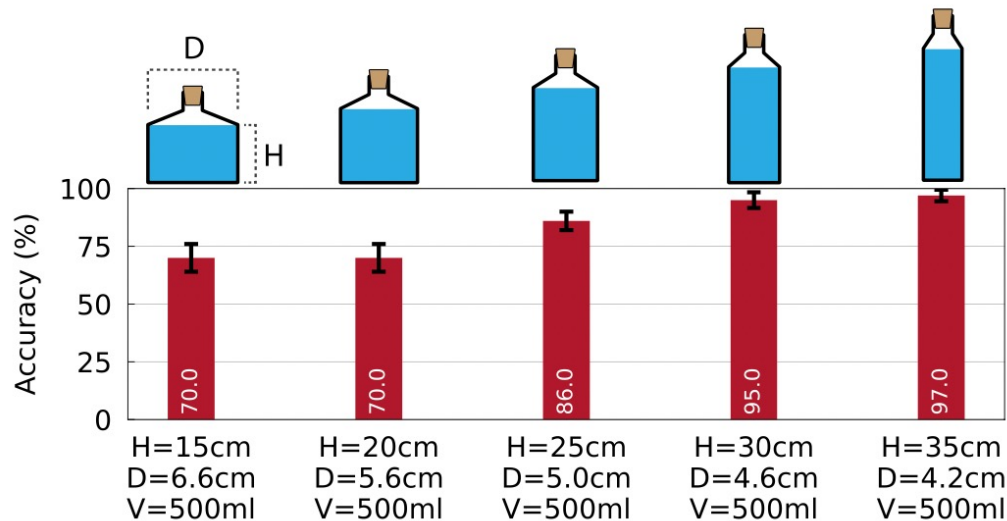


Small difference in liquid properties, leading to small difference in bubble characteristics

Evaluation: Bottle Dimensions

For bottle dimensions with a fixed volume of 500ml, **LiquidHash** achieves

- High accuracy (**>85%**) in relatively tall bottles (i.e., height above **25cm**)
- Lower accuracy (**70%**) in relatively wide bottles (i.e., diameter above **5.6cm**)

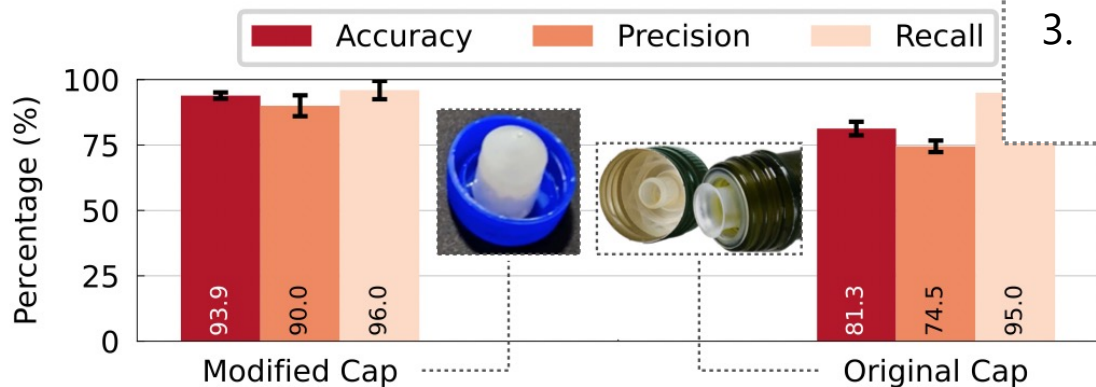


Bubbles travel in a **shorter distance** and liquid **stabilizes slowly**, leading to limited amount of information captured

Evaluation: Bottle Cap Accessory

For the proposed bottle cap accessory, *LiquidHash* achieves

- High accuracy (>**90%**) with the accessory
- Lower but decent accuracy (>**80%**) without the accessory

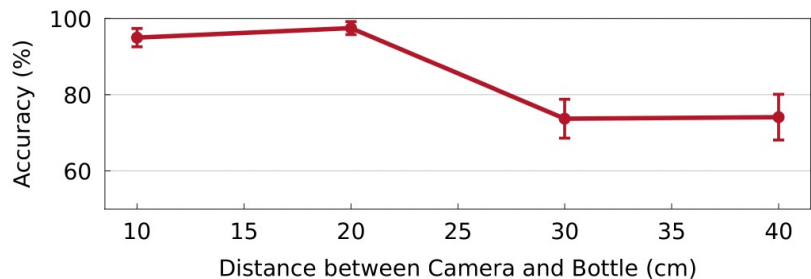
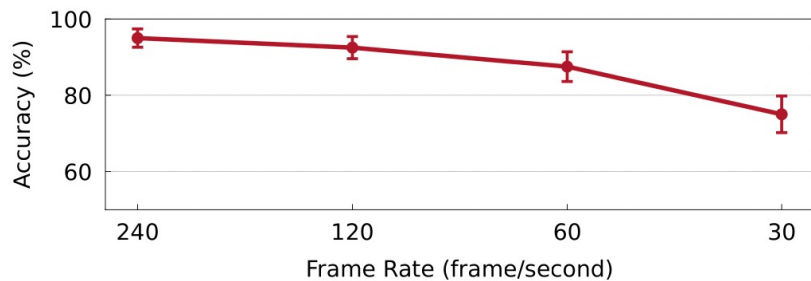


1. Smaller number of bubbles generated
2. Most bubbles have irregular shapes
3. Extremely small number of bubbles
after liquid stabilizes

Evaluation: Video Framerates and Resolutions

For varying video framerates and resolutions, **LiquidHash** achieves

- Decreasing accuracy when frame rate decreases
- Decreasing accuracy when distance between camera and bottle increases



1. Smaller number of bubbles captured
2. Limited information of bubbles
3. Large noise in measurement

Discussion: Attack Model of *LiquidHash*

- Types of liquid food products frequently attacked



Perfume



Essential Oil

- Counterfeiters replace a large portion (above 30%) of original content
- Liquid properties of adulterants are different from original content