Lili: Liquor Quality Monitoring Based on Light Signals

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Motivation

Two key periods of industrialized wine production

Fermentation

Aging

Motivation

Numerous microorganisms begin to grow and multiply, lasting from several months to **more than ten years…**

Fermentation

Aging

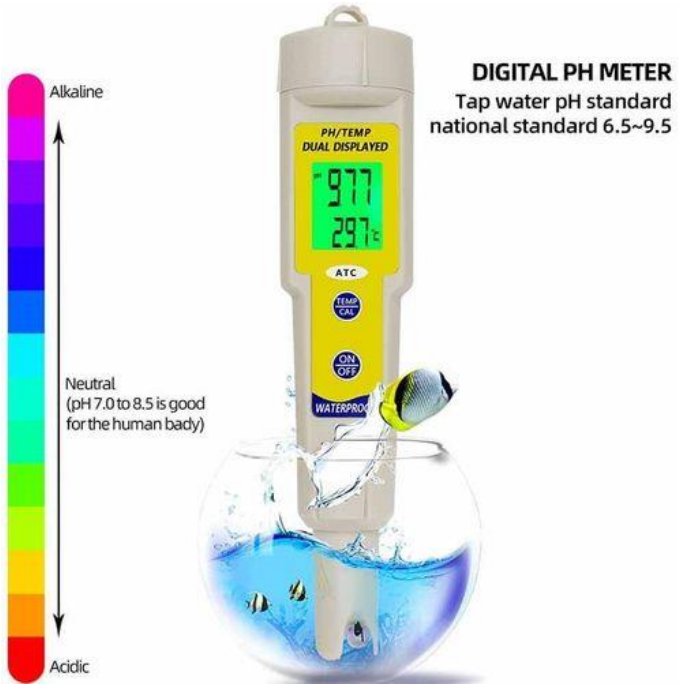
Many kinds of pathogenic microorganisms grow and multiply silently

Staphylococcus aureus, Escherichia coli, Vibrio casei, Halomonas, Aspergillus flavus, Salmonella, Penicillium, Mucor, Serratia, Aspergillus niger

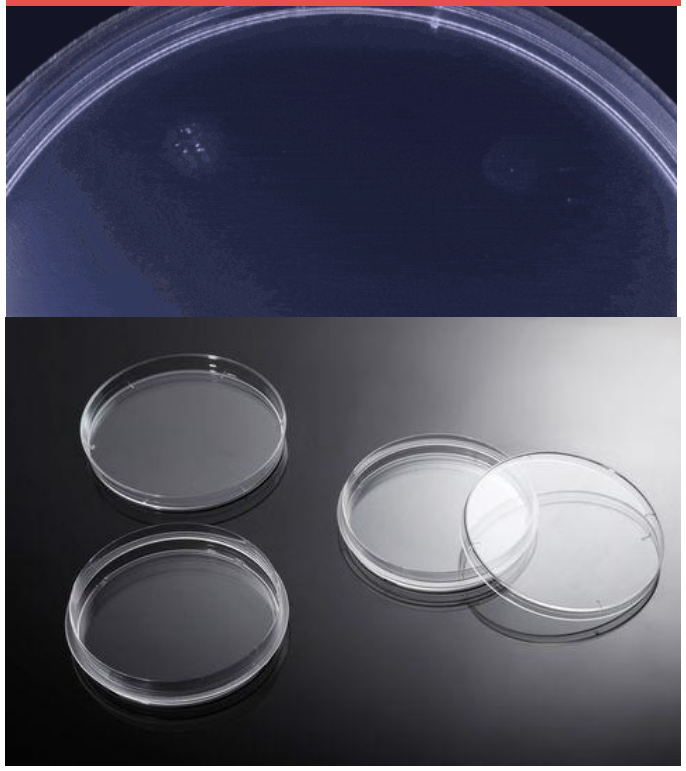
Motivation

Conventional detection testing is **time-consuming** and **cumbersome** and has **a high probability of inspection misses**

pH measurement



microbial cultures



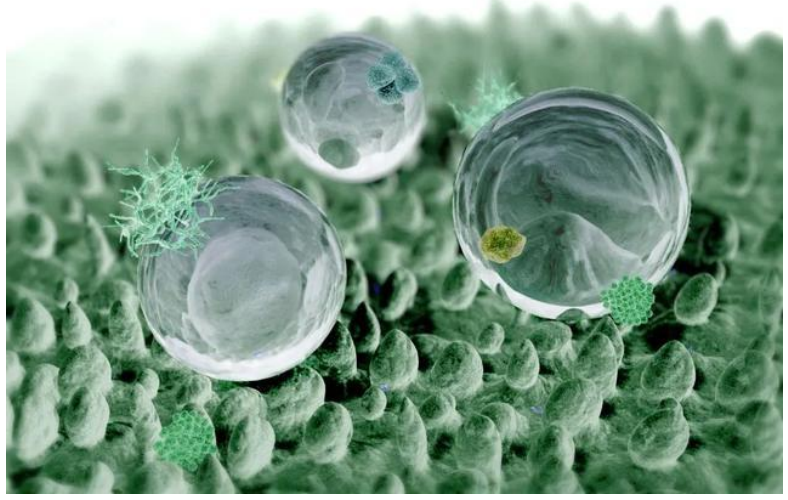
Detect deterioration only when barrels are open

Cannot detect real-time deterioration

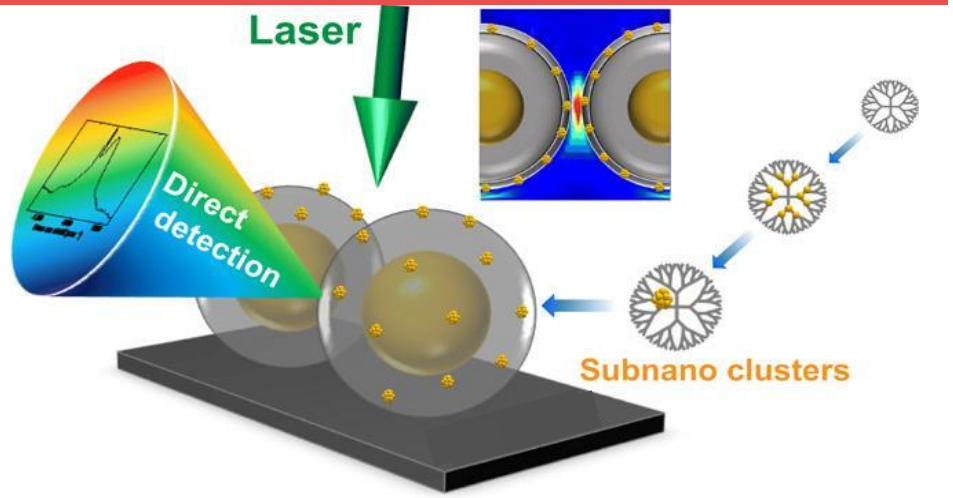
Ask And Opportunity

- Can we find an alternative to the traditional microbial cultivation?
- Is it possible to achieve real-time liquor quality measurements?
- Can they be made with common instrumentation?

Deterioration of liquid changes surface tension

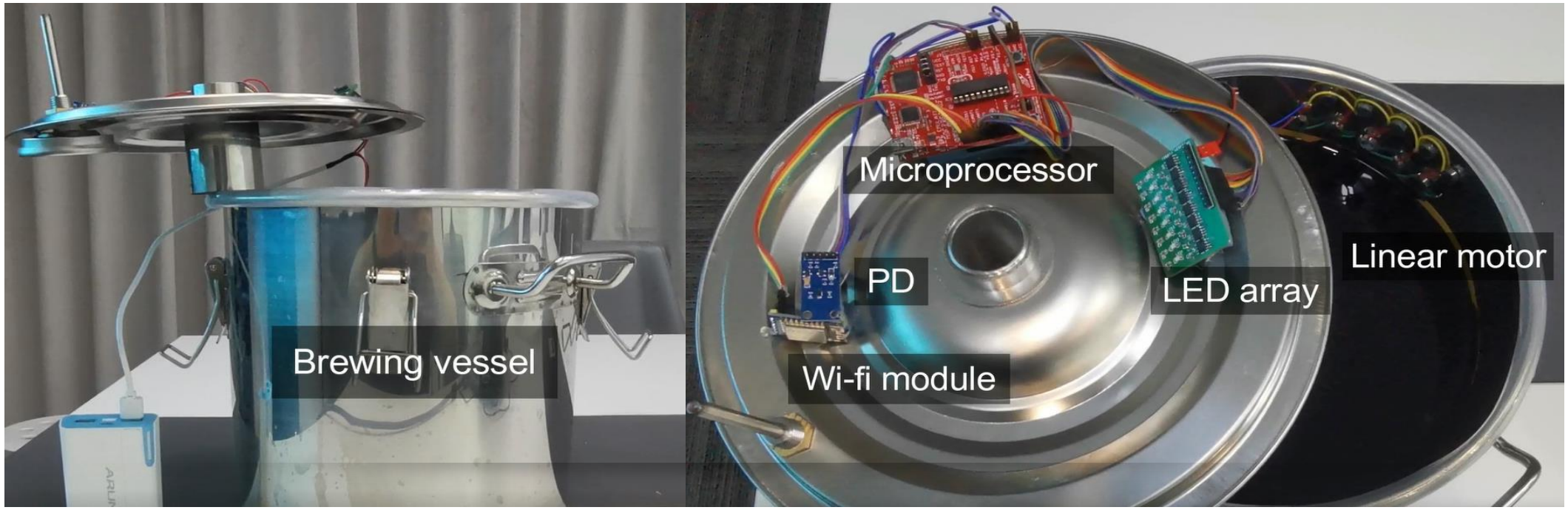


Microorganisms cause change in absorption spectrum



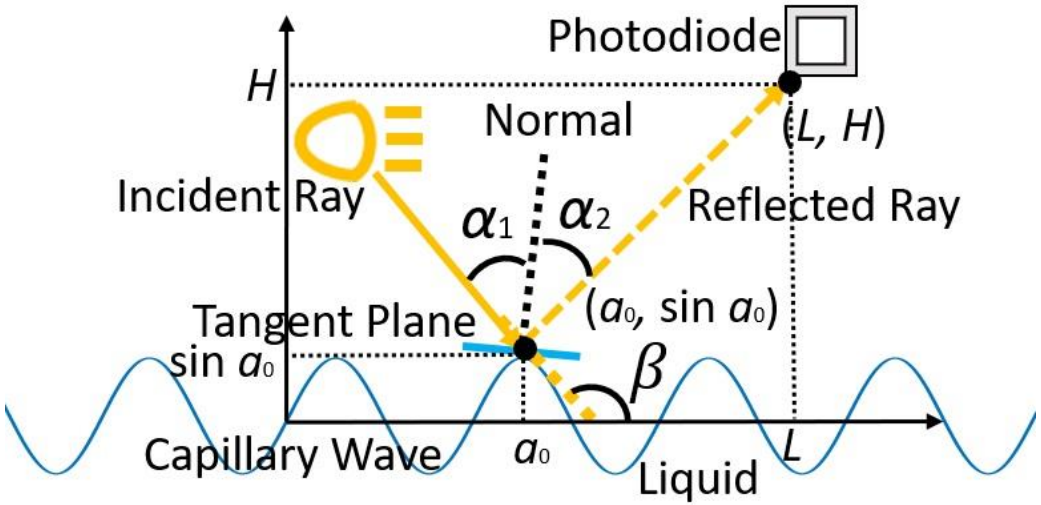
Lili

Proposed: **Surface tension** and **Absorption spectrum** Measurement based on **LED array, PD and Linear motor**.



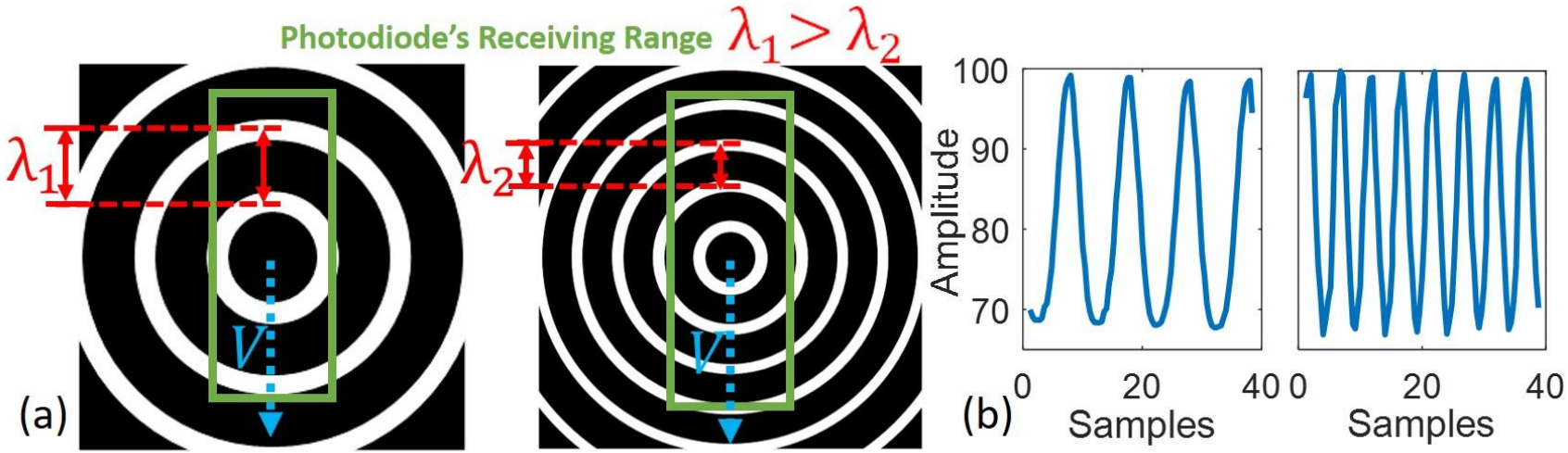
Theoretical Models

1. Surface tension measurement



Model of the location of a reflection point.

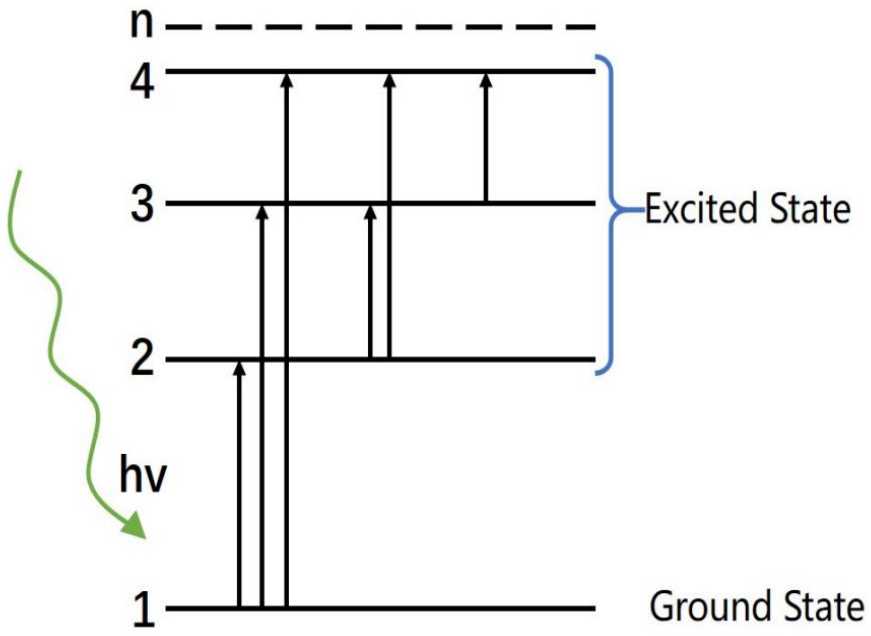
$$\begin{cases} a_0 = k\lambda + c & (1) \\ \alpha_1 = \arctan\left|\dfrac{\frac{\sin a_0 - H}{a_0 - L} + \frac{1}{\cos a_0}}{1 - \frac{\sin a_0 - H}{a_0 - L}\frac{1}{\cos a_0}}\right| & (2) \\ \alpha_2 = \arctan\left|\dfrac{\tan\beta + \frac{1}{\cos a_0}}{1 - \frac{\tan\beta}{\cos a_0}}\right| & (3) \\ \alpha_1 = \alpha_2 & (4) \end{cases}$$



Simulation model. (a) Top view. (b) Changes in the intensity of light received by the photodiode.

Theoretical models

2. Absorption spectrum measurement



Absorption Spectrum Model.

Light frequencies for transition

Excited atom energy — Ground-state energy

$$\upsilon = \frac{E_q - E_0}{h}$$

Planck constant

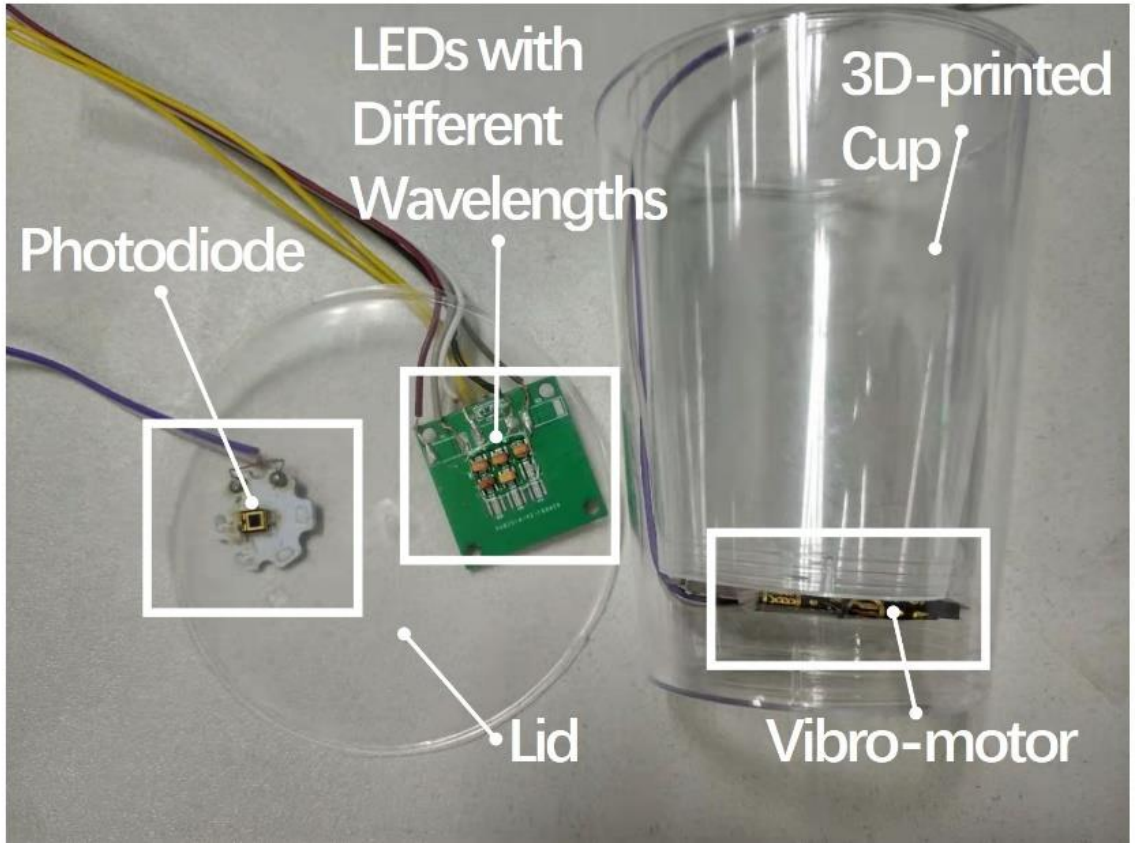
Number of atomic absorption spectra

$$N_{em} = \frac{n^2}{2}$$

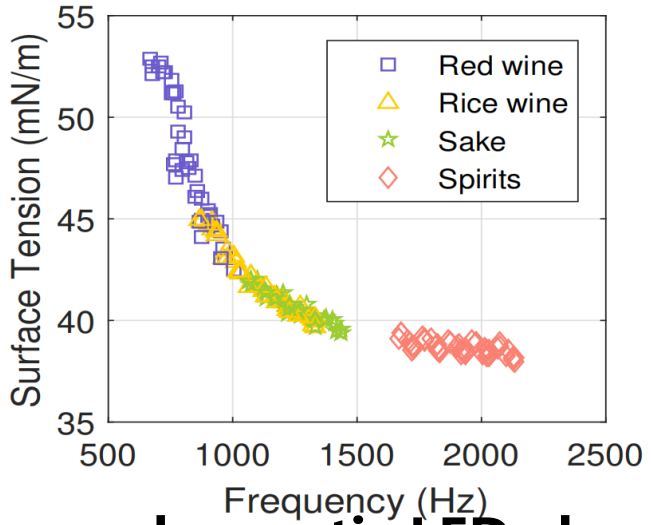
Microorganisms change the liquid composition and destroy parts of an element’s atomic structure.

Feasibility Study

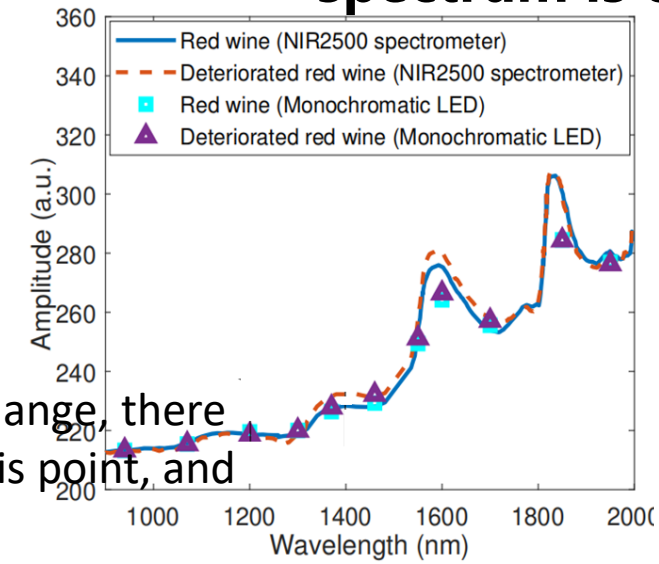
Experimental Setup

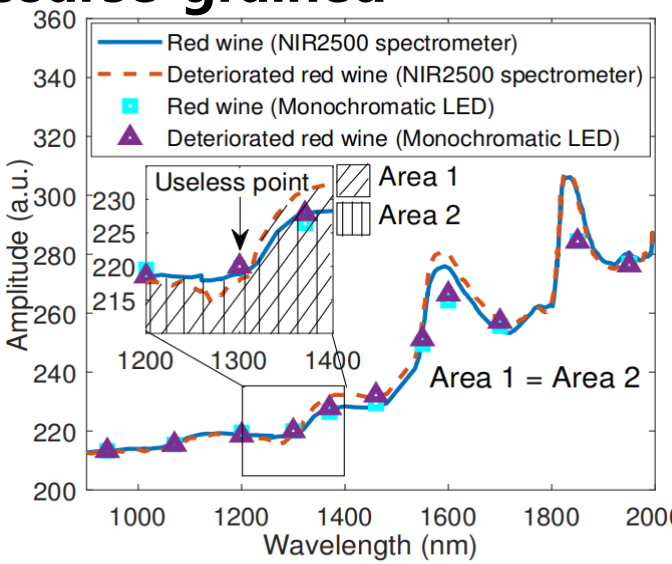


1. Matching of Surface tension model



2. The monochromatic LED absorption spectrum is coarse-grained

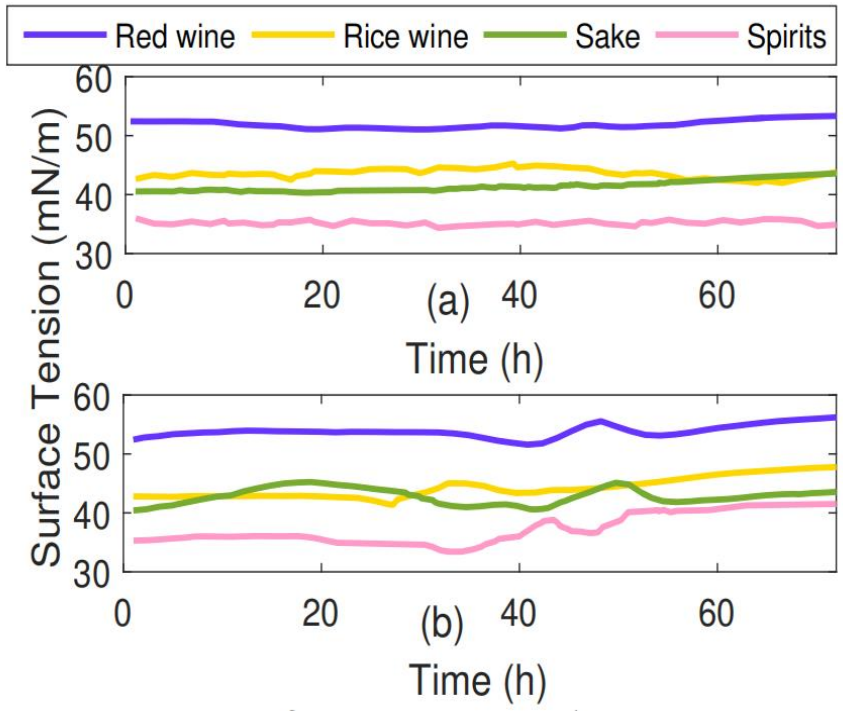




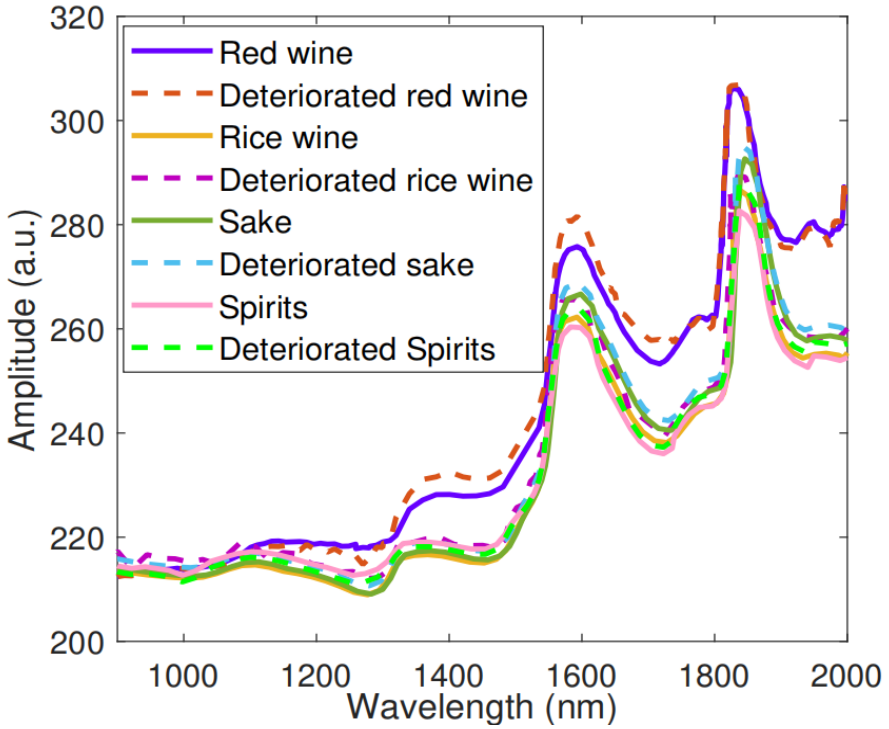
As long as the absorption spectral area does not change, there is no difference in the light intensity obtained at this point, and no deterioration can be detected

Feasibility Study

3. Effect of contaminated wine on surface tension

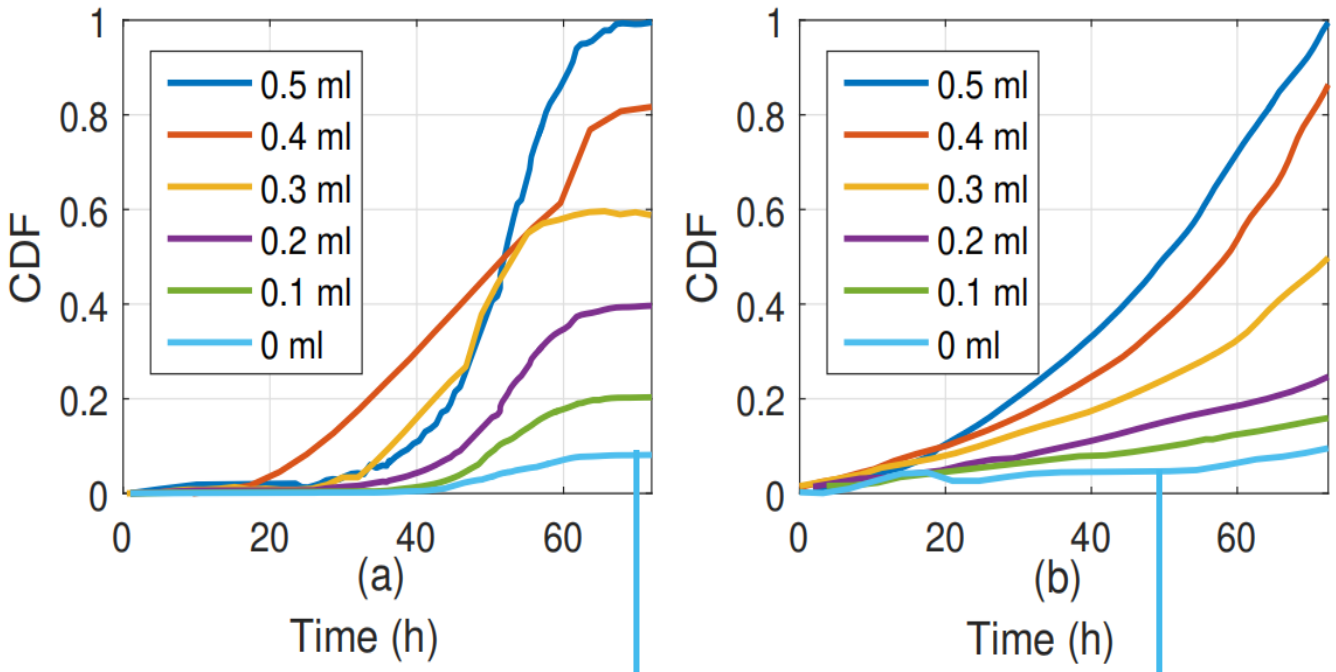


4. Effect of contaminated wine on Absorption spectrum



Feasibility Study

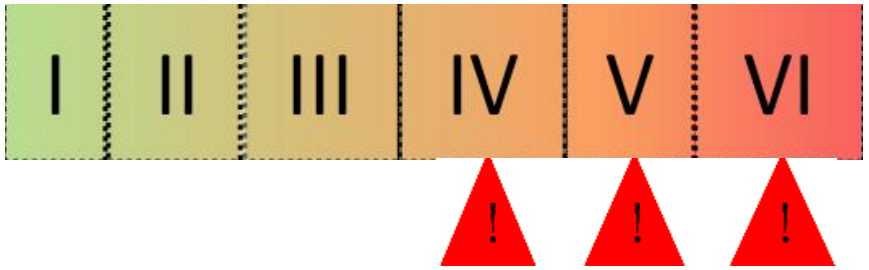
5. Measurement of Liquor Deterioration



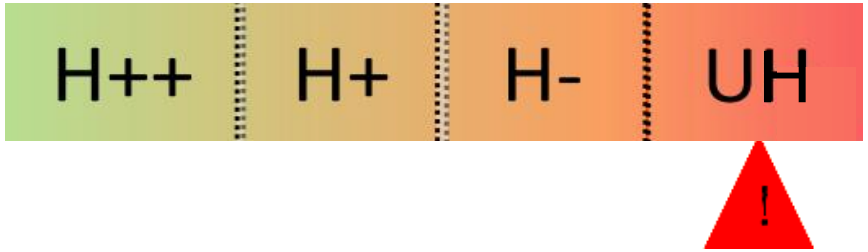
$$\vec{L}_{Mea}(t) = [MSF_t, MAS_i(t)]$$

$$\vec{L}_{Mea}(t_0) = [MSF_{t_0}, MAS_i(t_0)]$$

I (12 h)
II (24 h)
III (36 h)
IV (48 h)
V (56 h)
VI (72 h)

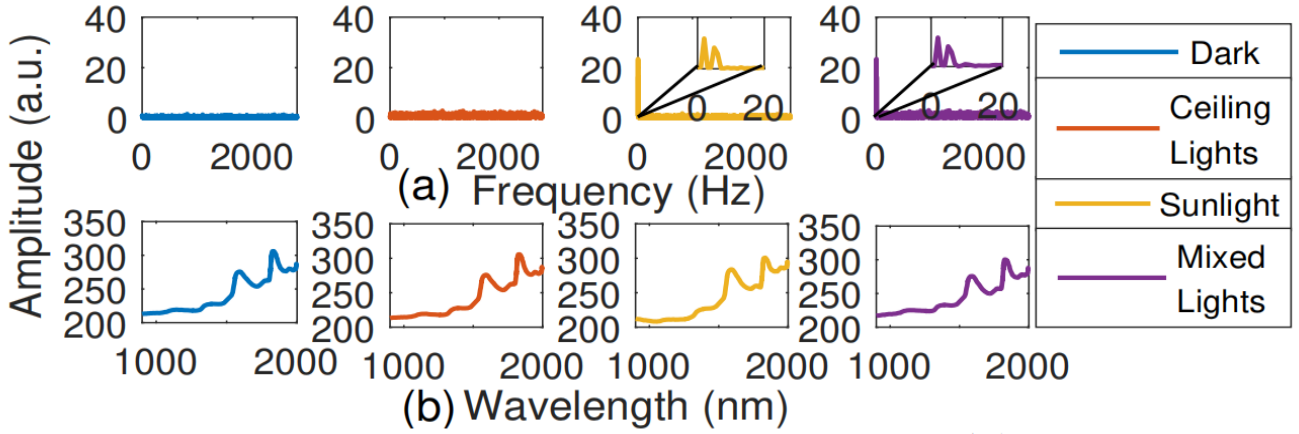


$Hygiene++ (0 - 10^2$ units)
$Hygiene+ (10^2 - 10^3$ units)
$Hygiene- (10^3 - 10^4$ units)
$Unhygienic$ (greater than 10^4 units)



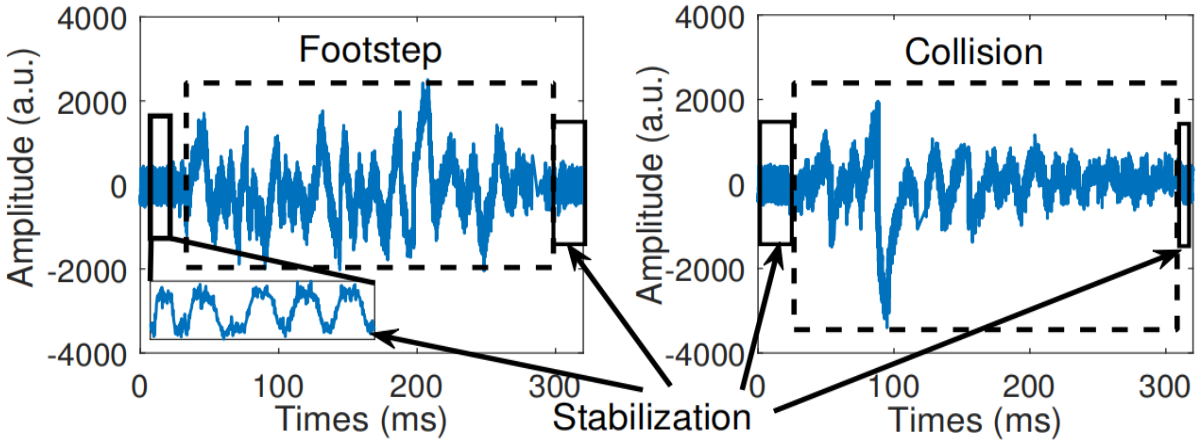
System Design

Eliminate Ambient light Noise.



Subtracts the ambient light amplitude-frequency curve to eliminate ambient light noise.

Reducing Interference from Sloshing



Average amplitude

$$\bar{A} = \frac{1}{T}\sum_{t=0}^{T} I_t$$

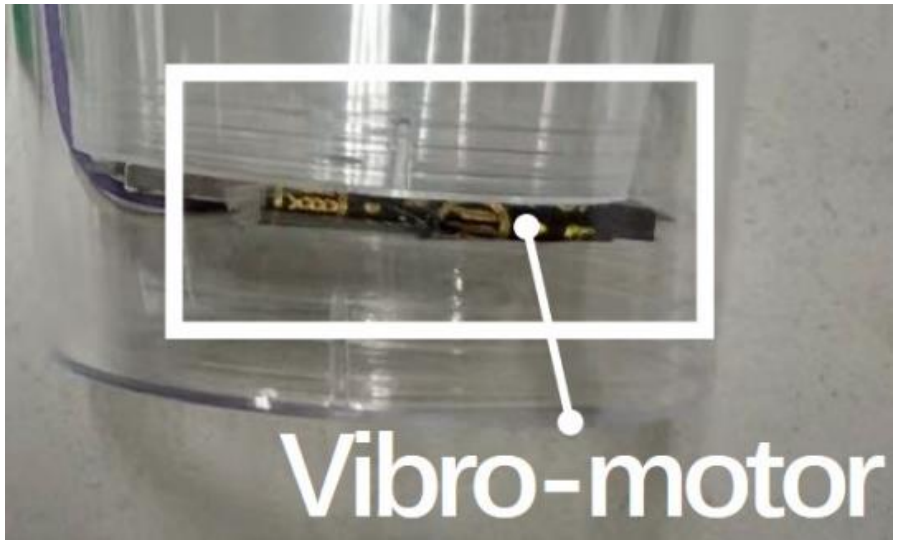
Amplitude sum

$$S = \sum_{t=(n-1)T}^{nT} \left| I_t - \bar{A} \right|$$

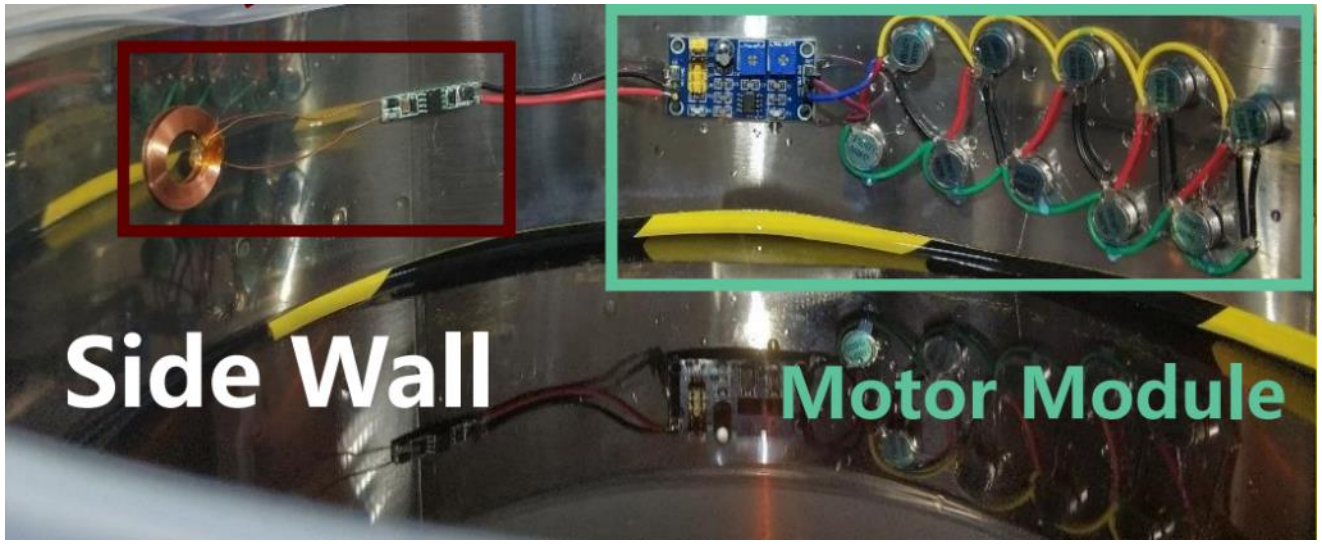
When the amplitude sum exceeds the threshold, Suspend the measurement for 30 s.

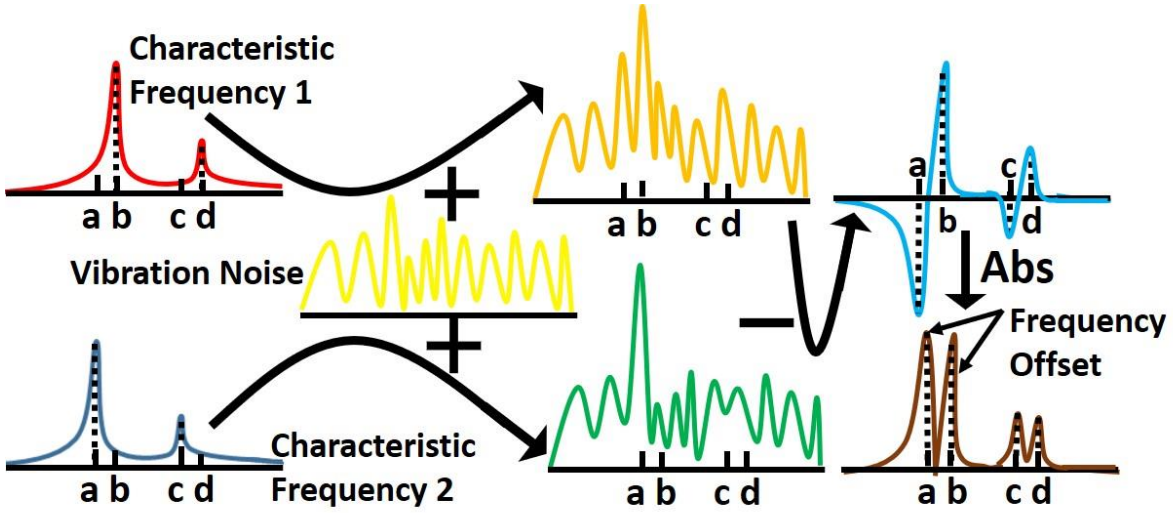
System Design

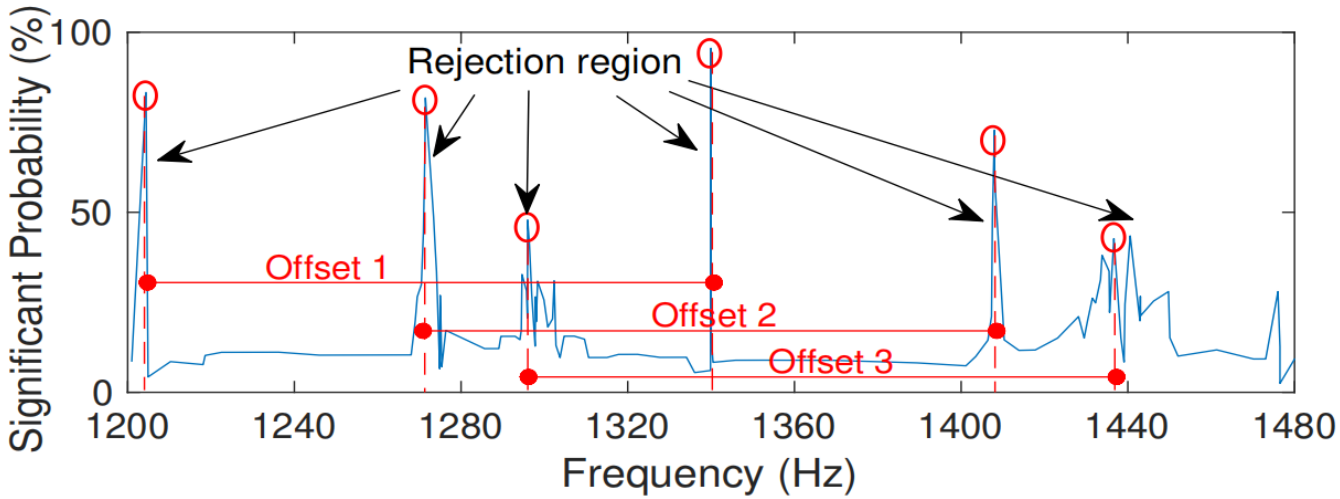
Double-layered 3D-printed cup



Real brewing equipment

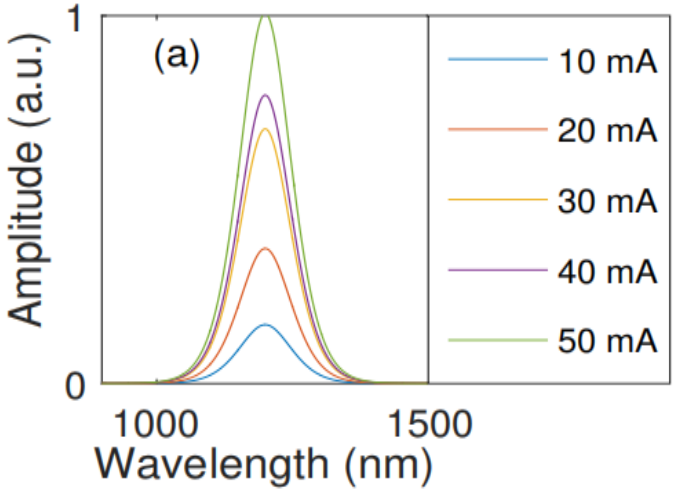




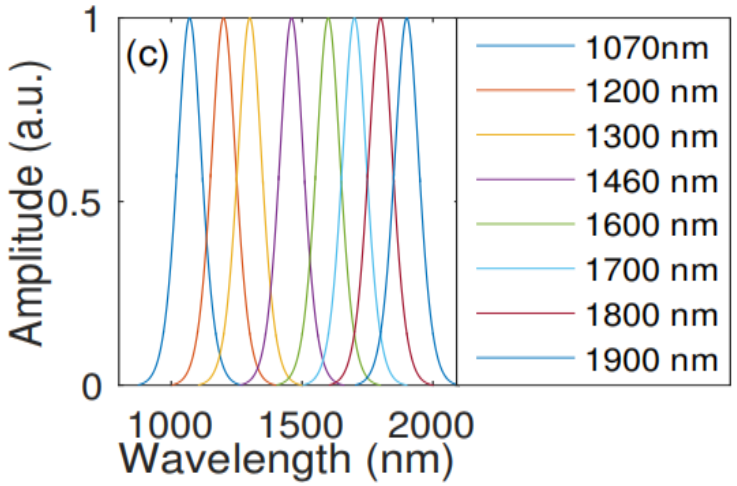


System Design

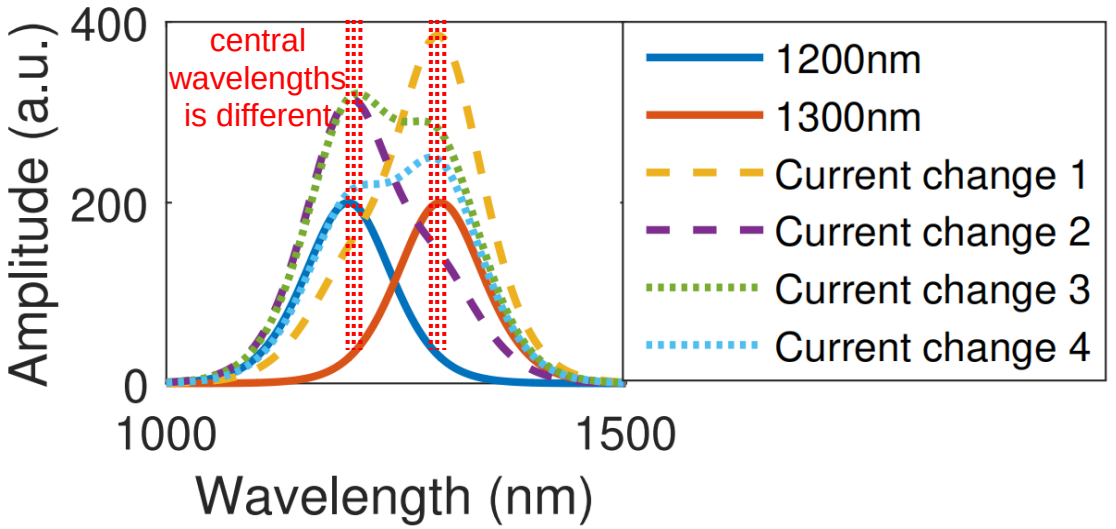
As the current increased, the FWHM of the LED spectrum gradually expanded



The spectral distribution of Lili's LEDs.



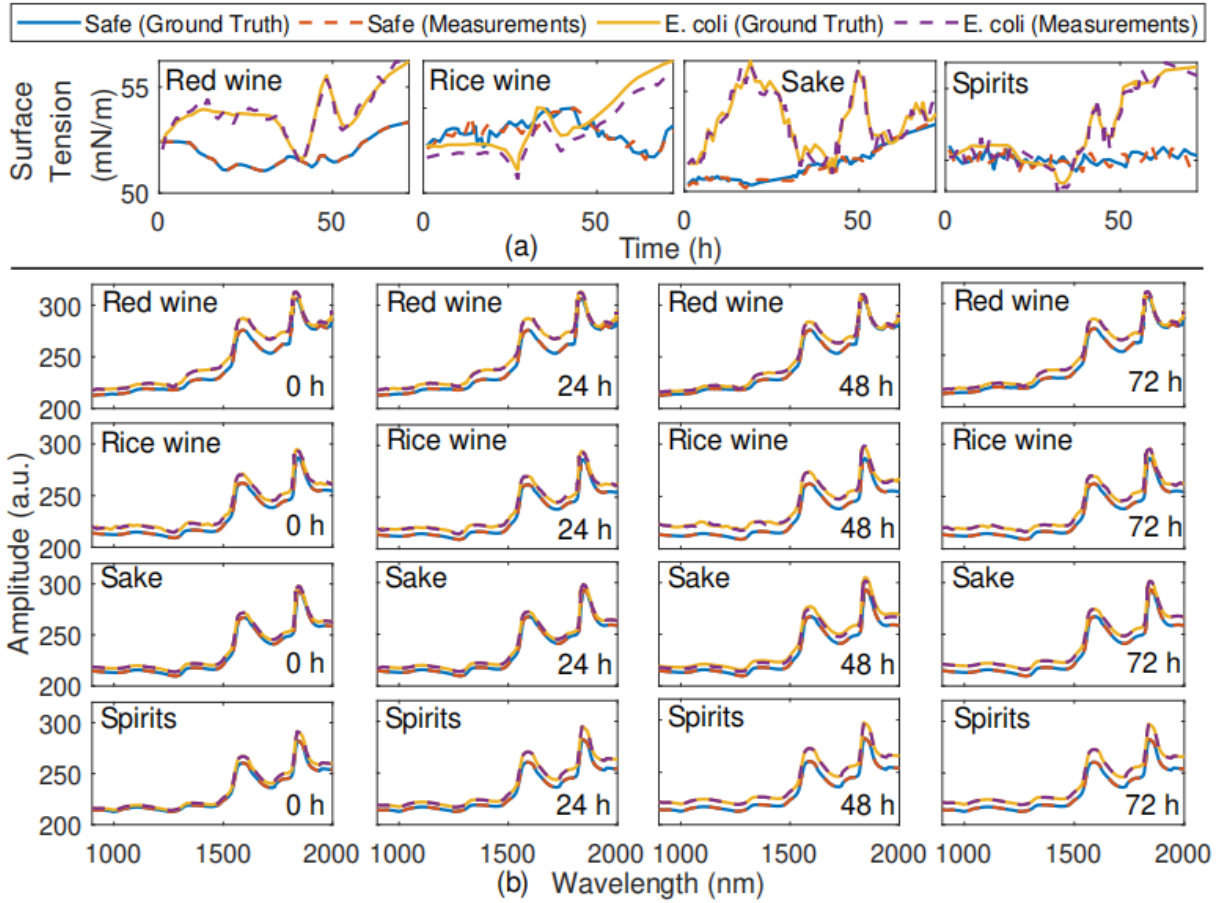
Different current combinations are adjusted to obtain spectra of different central wavelengths.



Evaluation

Liquor Monitoring Performance

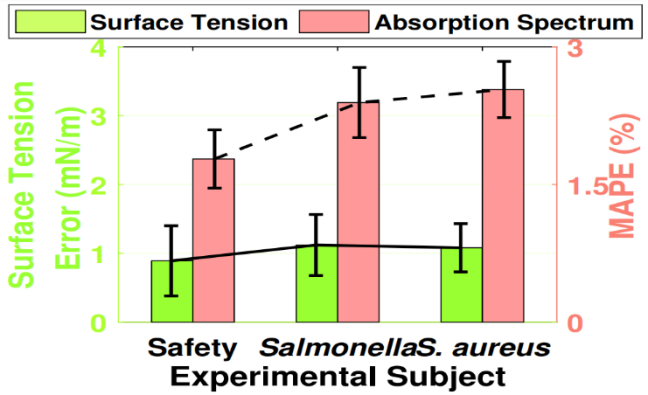
Measurement Accuracy for Different Liquors



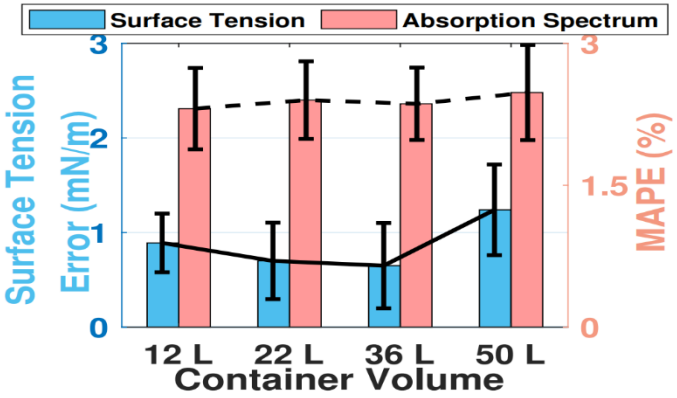
Safety group
surface tension error: 0.89 mN/m
absorption spectra MAPE 2.37%

***E. coli* group**
surface tension error: 1.16 mN/m
absorption spectra MAPE 3.04%

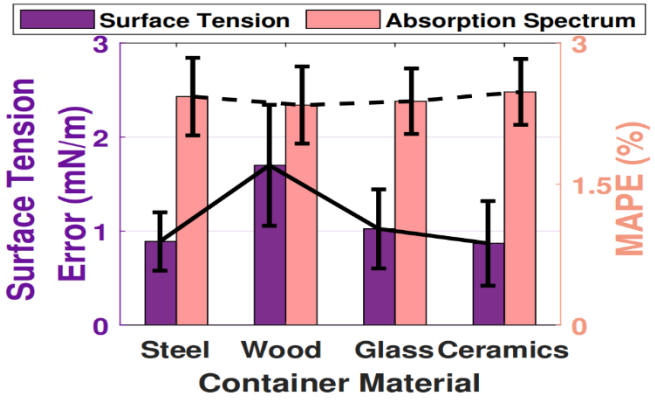
Different Pathogenic Bacteria



Different Container Volumes



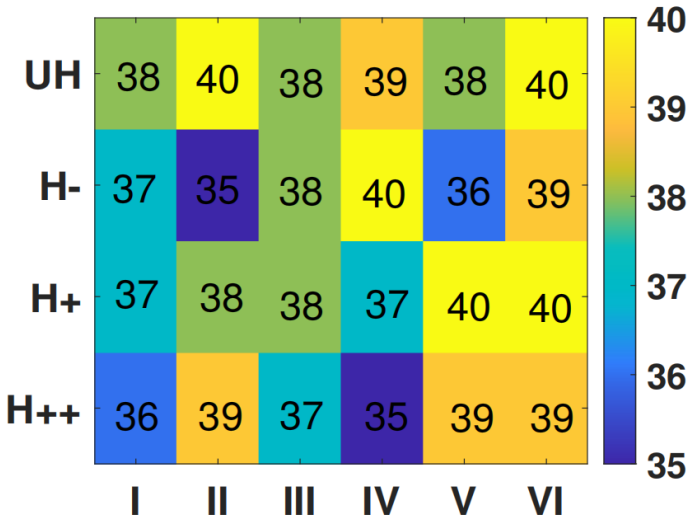
Different Container Materials



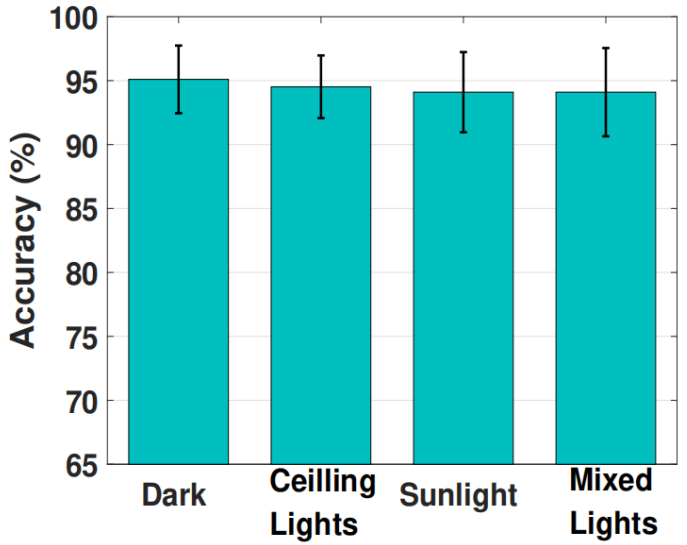
Evaluation

Liquors Quality Determination

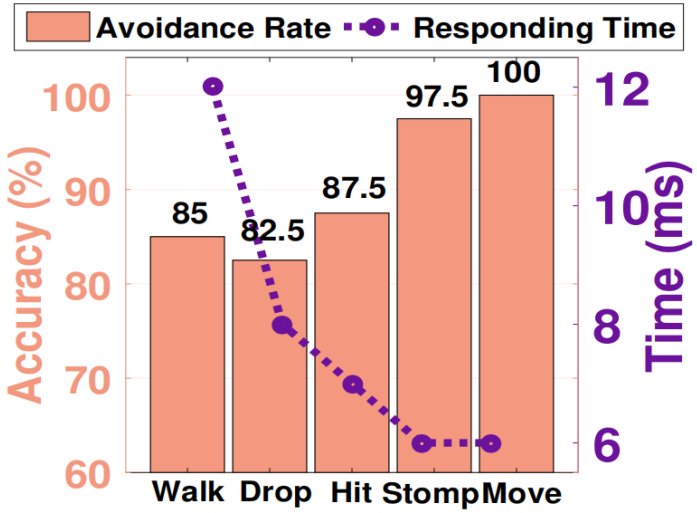
Baseline



Ambient light Interference



Interference from Liquor Sloshing



The accuracy of identifying categories that impact health was **97.5%**

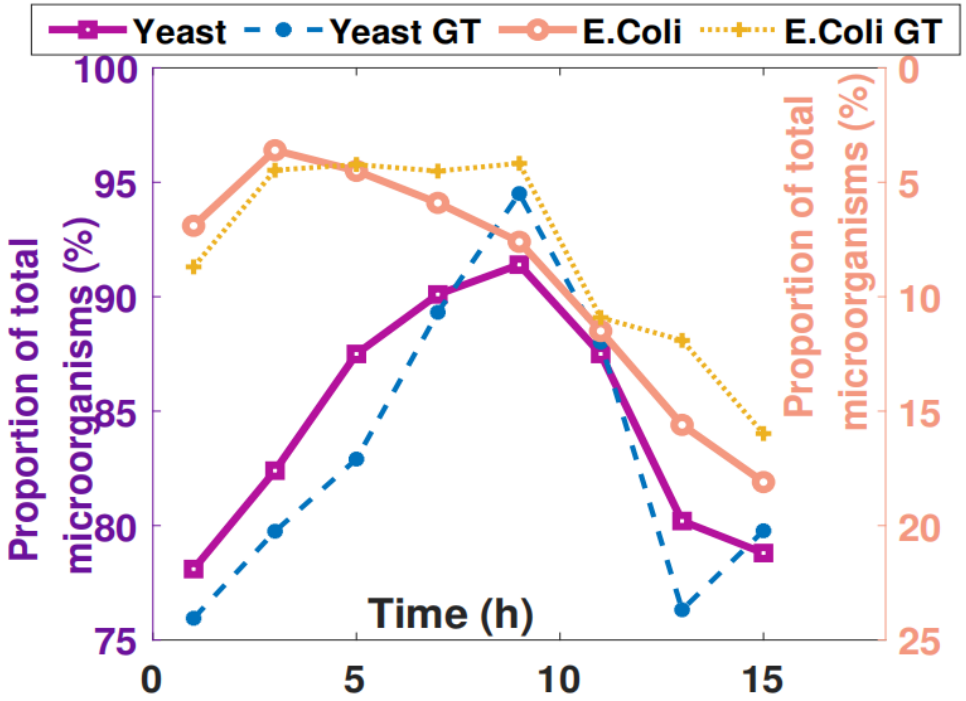
Lili could adapt to different types of ambient light with a mean accuracy of **94.6%**

Lili could also quickly distinguish sloshing interferences with a mean accuracy of **90.5%**, and response time of **7.8 ms**

Evaluation

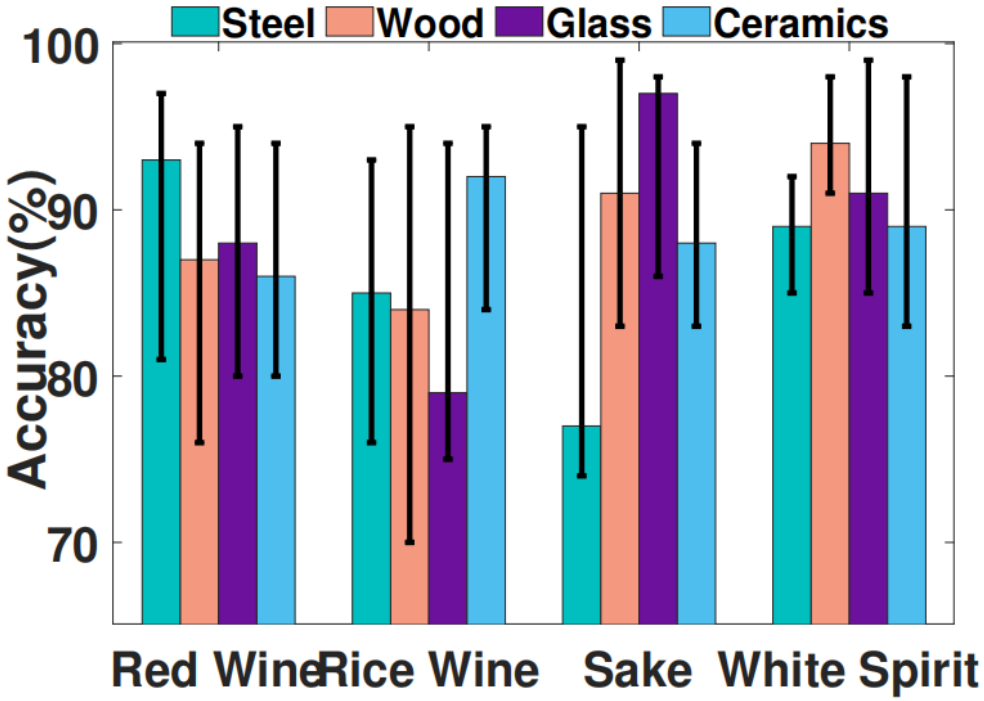
Concentration Determination

Microorganism Composition



The MAPE in identifying the yeast and E. coli was only **2.33%** and **1.77%**

Alcohol Concentration



The alcohol content identification accuracy was **88.13%**

Summary

- Lili can robustly and accurately detects the changes in surface tension and absorption spectrum caused by microbial metabolites and growth during deterioration.

- We proposed a Characteristic Offset Degree Measurement model to guide the photodiode to calculate the surface tension under the low signal-to-noise ratio condition.

- We also presented the Dimension Expansion of Coarse-grained Absorption Spectrum model to solve the subtle changes in substances that monochromatic LEDs cannot detect.

- In addition, we implemented countermeasures against ambient light noise and sloshing interference.


Thank you for your listening!
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