Real-Time Characterisation of Silver Nanoparticles:

Development of a Compact Static Light Scattering Device for Size and Stability Analysis

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MATS02

Applications of Nanoparticles

Field	Medicine	Food Safety	Environmental Science
Icon	🩺 **(Pill or Syringe)**	🥫 **(Food Package)**	💧 **(Water Droplet or Filter)**
Application	**Targeted Drug Delivery**	**Antimicrobial Food Packaging**	**Water Purification & Pollution Control**
Why This Field Uses Nanoparticles	Nanoparticles can carry drugs directly to specific cells or tissues, enhancing treatment precision and minimising side effects.	Nanoparticles provide antimicrobial properties, helping prevent spoilage and extending the shelf life of food.	Nanoparticles react with contaminants, breaking them down or neutralising them to make water safer and reduce pollution.
Key Property of Nanoparticles	Small Size - Enables easy movement through body tissues and entry into specific cells, improving drug targeting.	High Surface Area - Increases interaction with bacteria, enhancing antimicrobial effects.	High Reactivity - Maximises contact with pollutants, making them more effective in water treatment.
Example	Cancer Treatment: Nanoparticles deliver chemotherapy drugs directly to tumor cells, reducing harm to healthy cells.	Food Packaging: Silver nanoparticles in packaging materials inhibit bacterial growth, keeping food fresh longer.	Water Filters: Silver and titanium dioxide nanoparticles neutralise harmful bacteria, viruses, and pollutants in water.
Importance of Accurate Characterization	Ensuring the correct size and stability of nanoparticles is essential. If they aggregate, they may not reach targeted cells, reducing drug effectiveness.	Stable nanoparticles are critical. If they lose stability, they may lose their antimicrobial effect or even leach into food, raising safety concerns.	Consistent size and stability ensure nanoparticles remain effective in neutralising pollutants. Aggregated particles lose reactivity, reducing purification efficiency.

Problem

The challenge in nanoparticle characterisation, particularly in real-time monitoring of size and aggregation, arises from the limitations of existing methods. Traditional Static Light Scattering (SLS) systems used for nanoparticle characterization are often expensive, batch-based, and not designed for continuous real-time tracking. Most commercial systems rely on fixed-angle detectors and only provide snapshot measurements, making it difficult to monitor dynamic changes in nanoparticle behavior over time.

This limitation is critical in applications such as drug formulation, nanomaterials, and biotechnology, where nanoparticles must remain stable and aggregation can lead to loss of functionality. A real-time, cost-effective alternative to commercial SLS is needed for continuous monitoring of nanoparticle size and stability.

Traditional Characterisation Methods

	Limitations
Transmission Electron Microscopy (TEM)	• **Expensive and time-consuming –** Requires vacuum conditions and extensive sample preparation. • **Not real-time –** Only provides a static image, not dynamic tracking. • **Requires thin samples –** Thick samples can cause artifacts. • **Low throughput –** Only a few particles are analyzed at a time.
Scanning Electron Microscopy (SEM)	• **Requires a conductive coating for non-conductive samples, which can alter the structure.** • **Cannot analyse particles in liquid – Requires a dried or frozen sample.** • **Not real-time – Provides only static images.**
Dynamic Light Scattering (DLS)	• **Sensitive to Impurities:** Minor impurities affect measurement accuracy. • **Limited Shape Information:** Provides only size data, not shape, limiting comprehensive analysis. • **No Real-Time Monitoring:** Cannot continuously monitor changes in nanoparticles, unsuitable for dynamic settings.

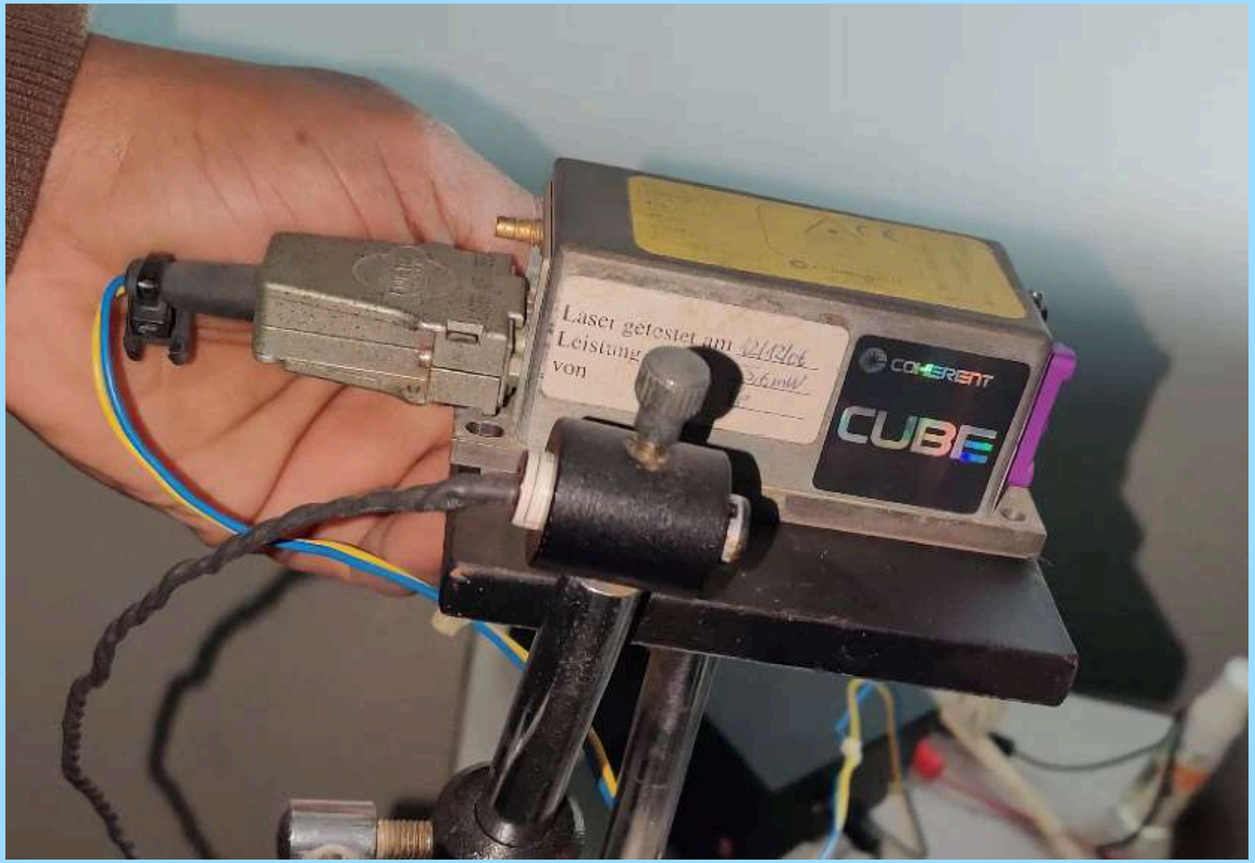
Goal

Design and develop a real-time, cost-effective Static Light Scattering (SLS) system that continuously monitors nanoparticle size, aggregation, and stability in liquid samples. Unlike commercial SLS instruments, this system will:

1. Enable continuous real-time tracking of nanoparticle behavior without requiring batch measurements.
2. Use two detectors with a stepper motor instead of multiple fixed detectors, reducing cost while maintaining multi-angle measurements.
3. Integrate a Picoscope (USB oscilloscope) for continuous data streaming, allowing instant visualization of nanoparticle size fluctuations.
4. Be adaptable and open-source, enabling researchers to modify and optimize the system for various applications.

The Device
-Zoomed In-

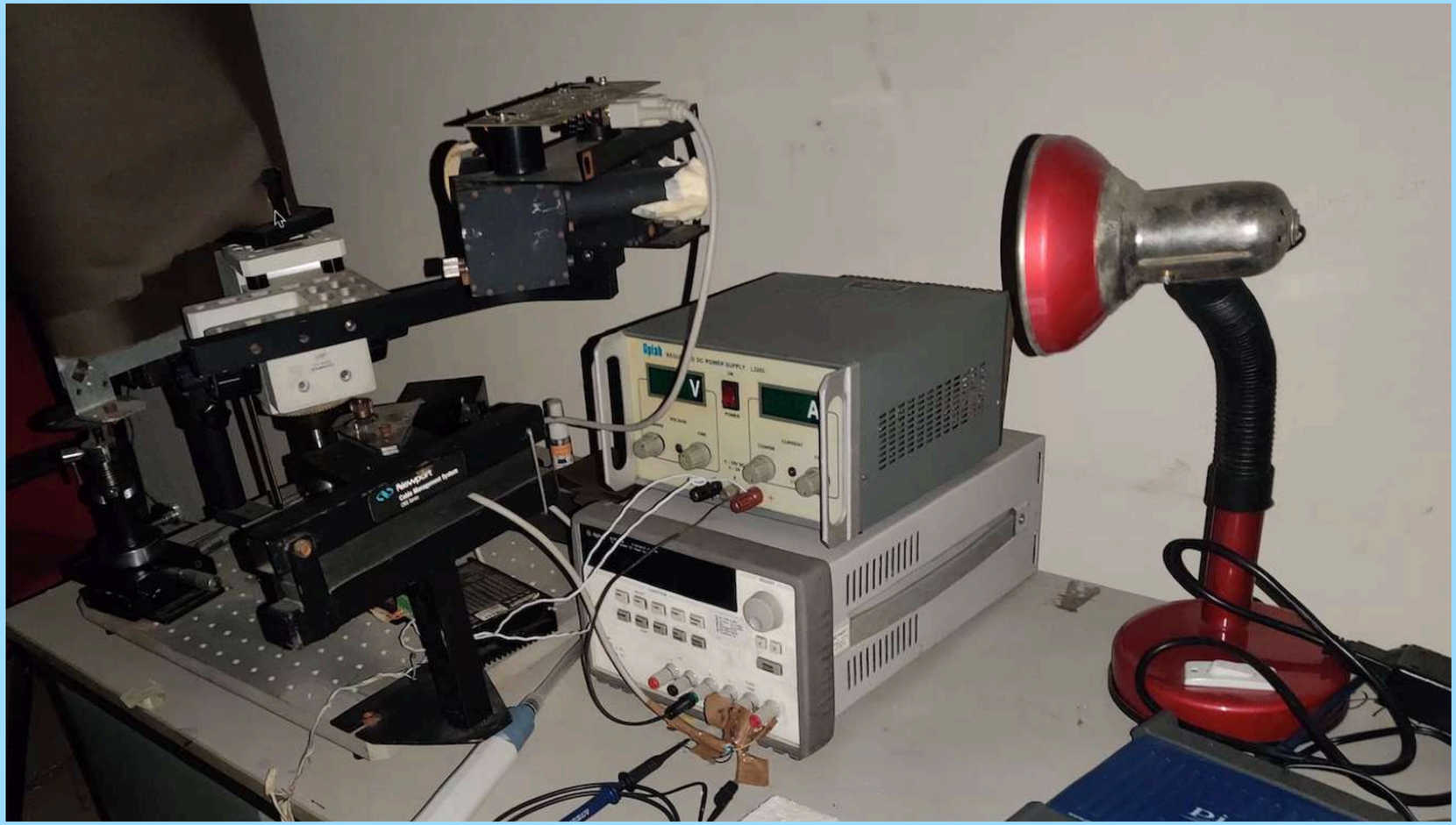
Individual Lasers



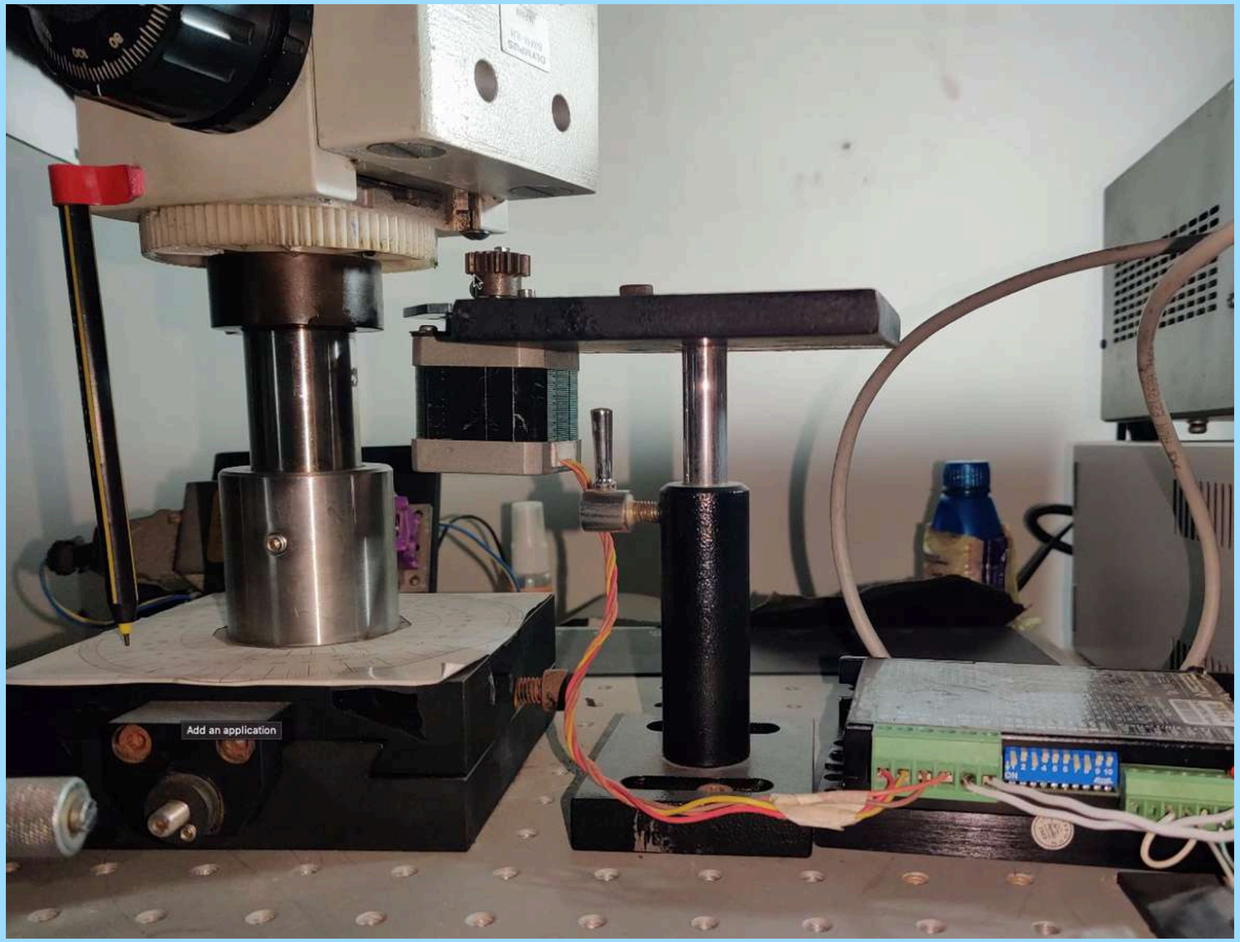
Cuvette Holder

Demonstration of how Light travels through the Cuvette

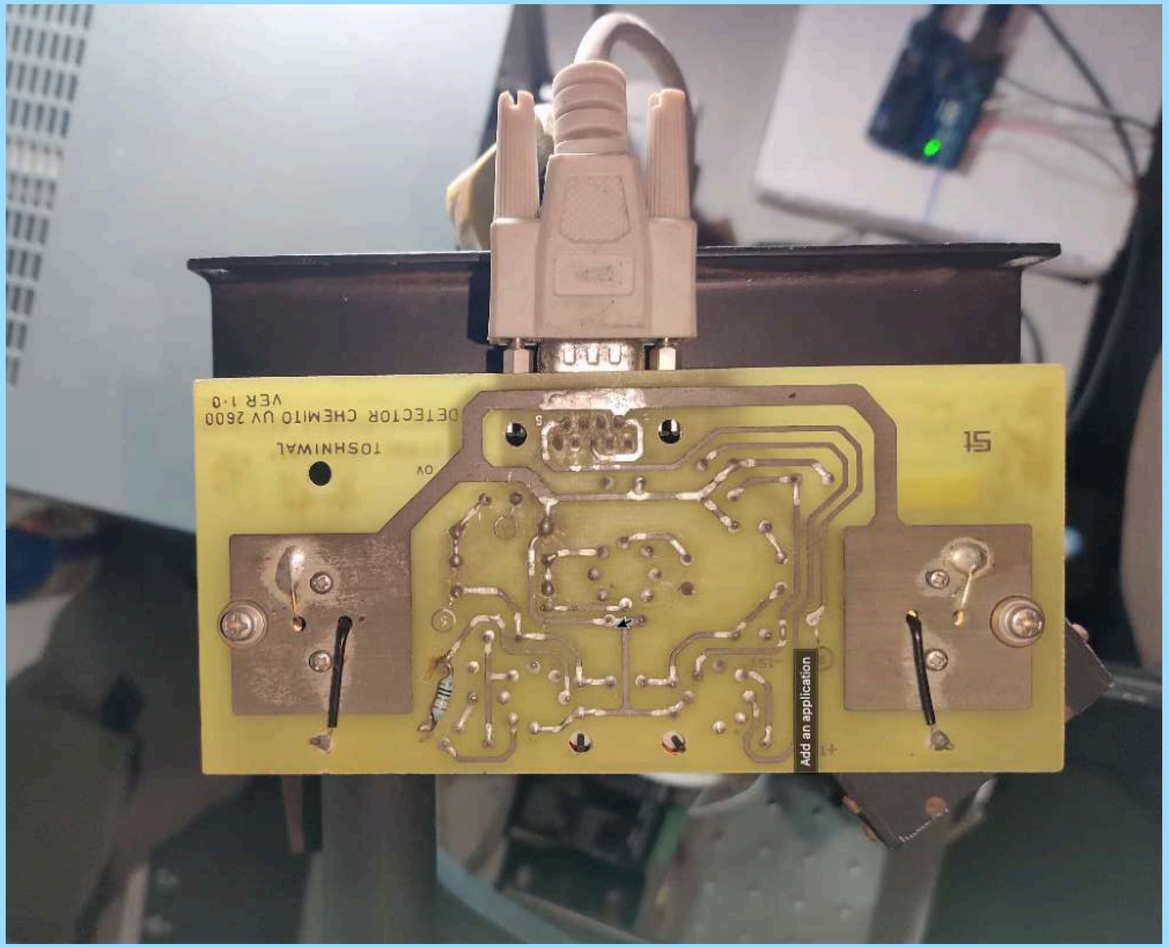
Entire Static Light Scattering Device



Stepper Motor and Driver



The 2 Detectors



Testing

Before running experimental tests, the device underwent calibration to ensure precise angular measurements and signal accuracy. The calibration process included:

Aligning the laser and detector to optimise scattering detection.
Setting angular increments to 1° using the stepper motor.
Verifying intensity response using a standard solution to confirm signal linearity.
After calibration, the system was ready to measure silver nanoparticle samples.

Testing

Step 1: Sample Preparation

- Silver nanoparticles were synthesised using the chemical reduction method (Silver Nitrate + Sodium Borohydride).
- The synthesized nanoparticles were dispersed in a colloidal solution and placed in the sample holder.
- A 633 nm laser illuminated the sample, and the scattered light was collected across different angles.

Step 2: Data Collection

- The stepper motor rotated the silicon detector from 0° to 180°, measuring scattered intensity at each angle.
- The Picoscope continuously recorded voltage signals from the detector, converting them into scattering intensity values.
- Data to prove changes in stability: (5 minutes, 15 minutes, 60 minutes, 24 hours, 10 days, 20 days) to observe stability changes.

Testing

The experimental data were analyzed using Guinier and Zimm methods to determine nanoparticle size, aggregation behavior, and stability over time.

A. Scattering Intensity vs. Angle Plot

- The scattering intensity data were plotted against scattering angles.
- Higher intensities at lower angles indicated the presence of larger aggregates.
- Over time, a shift in the scattering peak suggested nanoparticle aggregation.

B. Guinier Analysis (Size Estimation)

- Guinier analysis was applied to low-angle scattering data to determine the radius of gyration (Rg).
- A linear fit was performed on ln(I) vs. q^2 data, where q is the scattering vector.

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Testing

C. Zimm Analysis (Polydispersity and Molecular Weight)

- The Zimm method was used to evaluate molecular weight (Mw) and size distribution.
- A plot of $Kc/I(q)$ vs. $1/q^2$ was generated to determine Mw and polydispersity.
- Results:
  - Weight-average molecular weight (Mw) was around 60 kDa, consistent with expectations.
  - The Zimm plot confirmed a polydisperse sample, with size distributions ranging from 5 nm to 20 nm.

D. Time-Dependent Stability Analysis

- The scattering intensity data were collected at multiple time points (5 min, 15 min, 1 hour, 1 day, 10 days, 20 days).
- Trends Observed:
  - At 5 minutes: Slight increase in intensity, indicating minor aggregation.
  - At 1 hour: Noticeable peak shifts, suggesting nanoparticle growth.
  - At 10-20 days: Strong aggregation observed, with a significant increase in scattered intensity at lower angles.

TEM Results

To validate the size estimates from SLS, a subset of the samples was analyzed using Transmission Electron Microscopy (TEM).

- TEM images confirmed the presence of spherical nanoparticles in the 30-60 nm range, aligning with Guinier and Zimm analysis.
- TEM also showed increased clustering over time, supporting the SLS observations on aggregation.

Applications

The system can be directly integrated into pharmaceutical production lines by using a flow-based monitoring setup, where the drug solution continuously flows through the SLS detection chamber.

The silicon detector, controlled by a stepper motor, captures scattered light at multiple angles, while the Picoscope records and streams data in real time. If any increase in scattered intensity at lower angles is detected, it signals the formation of nanoparticle aggregates. This real-time feedback allows for immediate formulation adjustments, reducing drug wastage and ensuring product consistency.

Pharmaceutical companies can also automate data logging and integrate AI-based predictions to analyse trends in stability, providing early warnings for potential formulation failures. This system can be particularly useful for mRNA vaccines (such as COVID-19 vaccines), chemotherapy drugs, and monoclonal antibody treatments, where nanoparticle stability is critical.

References

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