DOI: 10.61782/fa.2025.0925

FORUM ACUSTICUM
EURONOISE 2025

ULTRASONIC IMAGING FOR QUANTIFYING MICROPLASTIC CONCENTRATIONS IN LIQUIDS

Óscar Martínez-Graullera[1*] **Paula Moreno**[1] **Carlos Pinillos Boralla**[1] **Jorge Huecas**[1]
Ruslan Shaporin[1] **Montserrat Parrilla**[1] **Luis Elvira**[1]
[1] Instituto de Tecnologías Físicas y de la Información (ITEFI), CSIC, Spain

ABSTRACT

In recent decades, the uncontrolled disposal of plastic waste into the environment has caused widespread contamination, infiltrating even the food chain. The issue of microplastics, particularly in oceans, poses significant challenges with negative implications for marine ecosystems, human health, and the economy. Furthermore, emerging contaminants and their interactions with climate change exacerbate these impacts. To address this problem, active monitoring programs are being developed to detect contaminants such as microplastics, antibiotics, and chemicals in coastal waters. Advancing technologies to implement these strategies effectively is essential. This study aims to develop an analytical procedure to quantify microplastic concentrations in liquids (5–50 microns), optimized for onboard instrumentation. A system has been designed to channel the flow through a 1 mm diameter pathway, utilizing high-frequency ultrasonic imaging (20–50 MHz). Ultrasonic image processing enables the measurement of reflected energy to estimate microplastic concentrations. This method is calibrated using controlled monodispersive polystyrene particle concentrations, establishing a relationship between reflected energy and particle concentration. The proposed approach provides a pathway for real-time, accurate microplastic detection, supporting environmental monitoring and mitigation efforts. This paper presents a preliminary study, employing a 20 MHz transducer and an experimental setup with monodispersive polystyrene particles in continuous flow.

*__Corresponding author__: oscar.martinez@csic.es.

Keywords: *microplastic, high frequncy ultrasonic, ultrasonic image*

1. INTRODUCTION

Nowadays, the presence of micro-scale contaminants in the food chain remains a significant uncertainty for human well-being. Studies have detected both chemical and physical pollutants at various points in the chain, with particular concern in the oceans, which serve as humanity's primary food reservoir [1,2]. To assess the severity of this issue, the European Union has launched research initiatives to establish monitoring protocols. These efforts are accompanied by technological developments that could be integrated into early warning systems in critical areas. This study is framed within that context.

Microplastic concentrations (5–50 microns) can be measured using various high-precision optical and spectroscopic methods [3–5]. However, ultrasound offers key advantages: it can detect particles in suspension, enables real-time marker-free detection, and allows for in situ application. These features are essential for developing an autonomous monitoring system. As a first step, this study proposes a measurement procedure using optical methods as a reference. The objective is to obtain an image of the sample—ultrasonic in this case—on which processing can be performed to quantify the number of particles.

Although this procedure does not allow for chemical identification and faces significant challenges, such as nanoparticle detection and the influence of factors like salinity, temperature, and turbidity on the ultrasonic signal, it is nonetheless more robust and applicable than other solutions. Additionally, since certain polymers absorb more ultrasonic energy, it offers some potential for discrimination.

2. EXPERIMENTAL SET-UP

2.1 Image Generation

Given the range of particle sizes to be detected, the decision was made to use high-frequency ultrasound and focused transducers (20 MHz, focal position at 13 mm, beam diameter of .1mm) operating in pulsed wave mode to generate the ultrasonic image. Due to the characteristics of the medium, a peristaltic pump (Watson-Marlow 120U/D1 pump 200rpm) and a 1 mm-section tube were used to create a closed circulating system for the sample. At a specific point, the transducer was integrated into a specially designed device that provides a flat interface with the sample flow. The transducer is positioned at an inclination angle of 30^o to increase the measurement area within the flow, as shown in Figure 1. However, the measurement section is limited to the beam section that covers only part of the tube (see Figure 1 right).

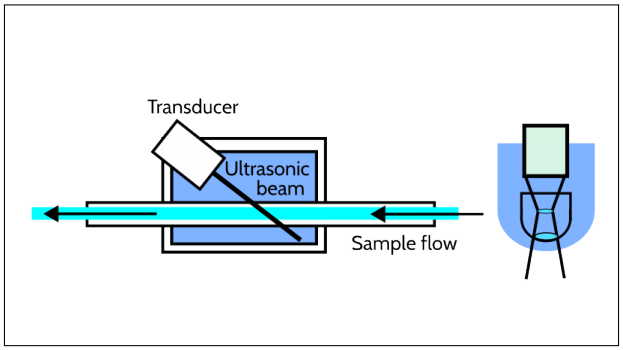

Figure 1. Transducer position in the measurement device.

In this setup, the image is composed by assembling a sequence of consecutive acquisitions. The image size is determined by the acquisition system's ability to maintain a constant data flow to the processing system. In this case, with a sampling rate of 80 MS/s, echoes are captured for 20 microseconds, and the analysis image consists of 5000 consecutive lines acquired every 500 milliseconds.

2.2 Sample Preparation

In order to develop an experimental system for the detection and quantification of particles in water samples, we have generated several calibrated samples based on spherical monodisperse polystyrene particles ranging from 2 to 12 microns in diameter. We calculated the concentrations by counting the particles in a Neubauer chamber under a microscope or using the ImageJ program. In Figure 2, we can see an optical image of the sample.

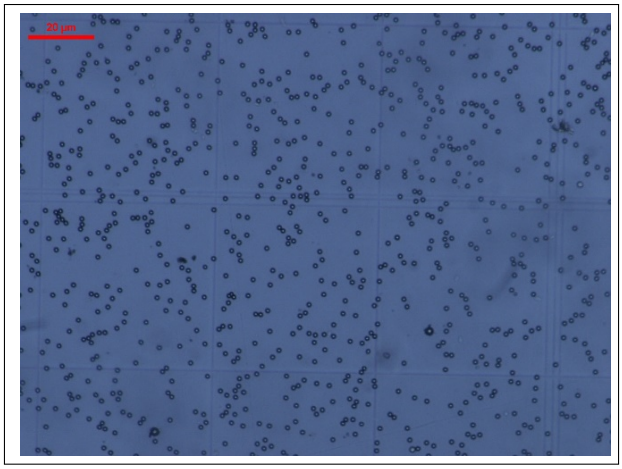

Figure 2. Spherical monodisperse polystyrene particles ranging 10 microns in diameter

To obtain polydisperse samples, with particles of different sizes and irregular shapes, we used polystyrene shavings. In these samples, we used the same methods to determine the concentration, but the irregular shape of the particles makes it difficult to distinguish whether we are observing large particles or several smaller particles agglomerated together (figure 3).

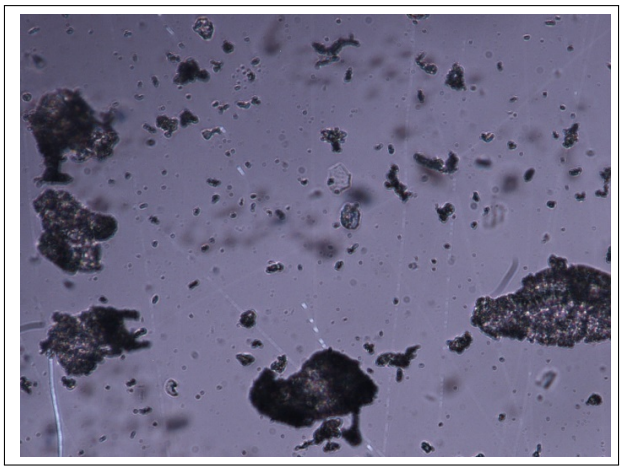

Figure 3. Polydisperse samples

2.3 Measurement Procedure

The measurement system is configured in two stages. The first, instrumental stage consists of the transducer, its support system, and an ultrasonic Difrascope system (DASEL Sistemas S.L.) responsible for signal acquisition. The second stage is a processing stage, at this moment developed in MATLAB, which handles signal preprocessing and reflector counting.

Ultrasonic imaging is composed of the assembly of consecutive A-scan lines (see figure 4). The image shows microplastic particles, artifacts due to multiple reflections in the measurement tube, and thermal noise. With a transducer frequency of 20 MHz, the preprocessing stage includes band-pass filtering and a spatial filter designed to eliminate the effect of multiple reflections within the tube. Once the structural elements are removed, image processing is performed. After applying a two-dimensional low-pass filter to reduce noise, dilation and erosion operations are used to differentiate reflectors from the background, eliminating spurious values. Then, a statistical analysis of the data is conducted to determine the threshold value that enables segmentation and reflector counting.

In the case of monodisperse spherical particles, the reflectors appear in a characteristic pattern as oblique lines following the flow direction (Figure 5). Other shapes, such as arcs and symmetrical forms, also appear, caused by flow variations induced by the peristaltic pump. The periodicity of these artifacts indicates their artificial nature.

Finally, it is important to note that the ultrasonic beam only covers a section of the tube, meaning that the measurement represents a sample-based estimate of the particle concentration. Calibration is necessary to adjust the measurement to the actual concentration value.

3. CALIBRATION

In order to assess the ability to distinguish between concentrations and calibrate the system, three concentration levels were used: 10 particles per μL, 26 particles per μL, and 50 particles per μL (sample composed by spherical monodisperse polystyrene particles ranging 10 microns in diameter). Each concentration was evaluated with the pump operating at different speeds: 4, 8, 12, and 16 rpm.

For each measurement, 3000 images were acquired, each consisting of 5000 lines. The number of circulating particles was counted in each image, and to eliminate outliers, the complete dataset was averaged using a sliding window of 32 samples. This value was empirically determined. Finally, the histogram is calculated to statistically characterize each distribution. Given the nature of the data—positive values with a significant mean—we have chosen the Rice distribution as the basis.

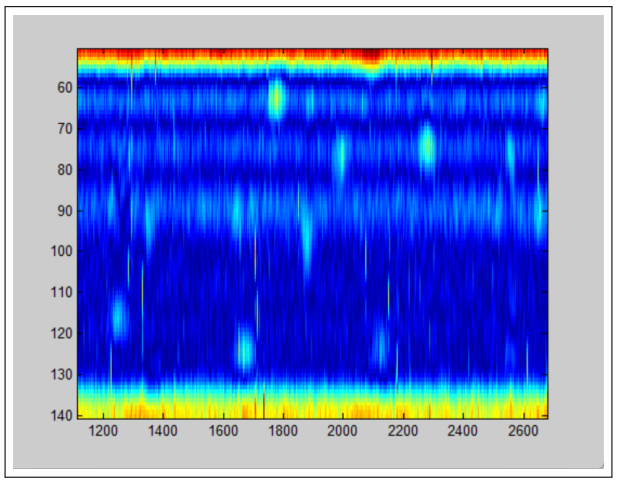

Figure 4. Ultrasonic image obtained at 20 MHz by assembling consecutive A-scan lines.

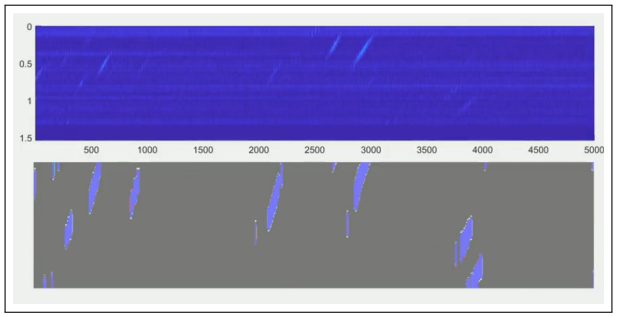

Figure 5. At the top, the ultrasonic image is presented after preprocessing. At the bottom, segmentation shows the reflectors.

To evaluate the results, the histograms of the three concentrations are compared at each speed, and Rice distribuions are estimated.

In Figure 6, we can see the result of circulating the liquid at the lowest speed. The number of detected particles is low, and the results are imprecise for all three concentrations, as the histograms overlap.

In Figure 7, we can see the result of circulating the liquid at speed 8rpm. The number of detected particles is higher, and the highest concentration becomes significant

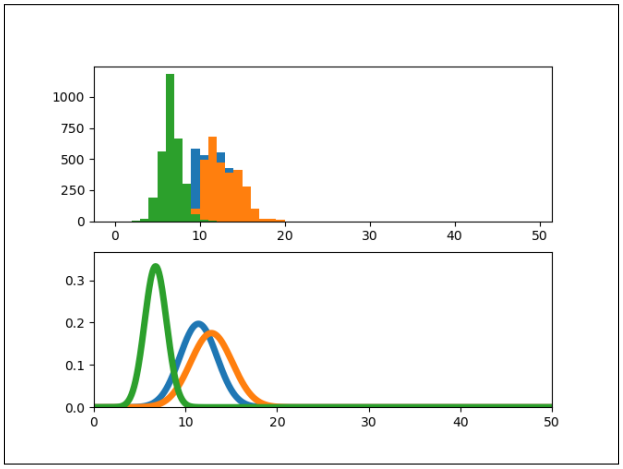

Figure 6. At the top, the histograms of the concentrations of 10 pp/μL (green), 26 pp/μL (blue), and 50 pp/μL (orange) at 4 rpm. At the bottom, the estimated Rice distributions (same color code).

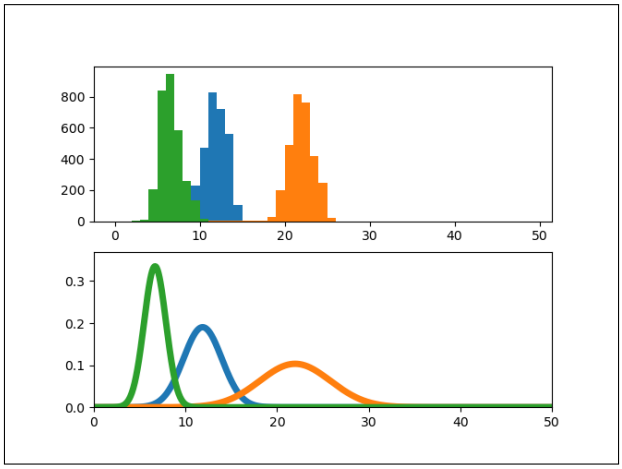

Figure 7. At the top, the histograms of the concentrations of 10 pp/μL (green), 26 pp/μL (blue), and 50 pp/μL (orange) at 8 rpm. At the bottom, the estimated Rice distributions (same color code).

and distinguishable from the other two. The 26 pp/μL and 10 pp/μL concentration remains consistent with the previous measurement.

In Figure 8, we can see the result of circulating the liquid at speed 12rpm. The concentrations can now be distinguished, and we can characterize them using the corresponding distribution functions. Although there is slight overlap between the 50 pp/μL and 26 pp/μL concentrations, the spread of the distributions allows for the calibration of intermediate concentrations.

In Figure 9, we can see the result of circulating the liquid at a speed of 16rpm. At this speed, the number of particles in the image increases, having opposite effects on the particle count. On one hand, the 26 pp/μL concentration increases in value and yields more consistent results, improving detection capability. On the other hand, the 50 pp/μL concentration decreases in value, contrary to expectations. This occurs because, as the number of particles under the beam increases, they cluster in such a way that, during the image binarization process, they may be counted as a single particle when, in reality, they could be two or more. In the case of 10 pp/μL, there is no substantial change in the mean. Despite the increase in speed, the particle density remains low, which means it cannot be ensured that the particles pass directly under the beam.

The results indicate that the pump exhibits an optimal operating speed at which measurement discrimination improves and histogram distributions become more concentrated. However, two key limitations were identified. At high concentrations, discrete particle counting is hindered by clustering effects, which compromise both the accuracy and precision of the measurements. This limitation necessitates the use of complementary descriptors to refine concentration assessment. Conversely, at low concentrations, it becomes essential to control the trajectory of microplastics to ensure their passage through the transducer beam, as their random motion can result in inconsistent or missed detections.

On a positive note, the measurement distributions can be statistically characterized using Rice distributions, which opens the possibility of developing a framework to manage measurement uncertainty based on the likelihood of belonging to a calibrated set of reference distributions.

4. CONCLUSIONS AND FUTURE WORK

This study has demonstrated the viability of using high-frequency ultrasound to quantify the concentration of microplastics in liquid media. The measurement protocol, while exhibiting a degree of flow dependence, has proven to be both reliable and reproducible and incorporates a defined margin to address uncertainty. Current research efforts are directed toward identifying the optimal flow velocity to enhance measurement resolution and extend the detection range toward lower concentrations. In parallel,

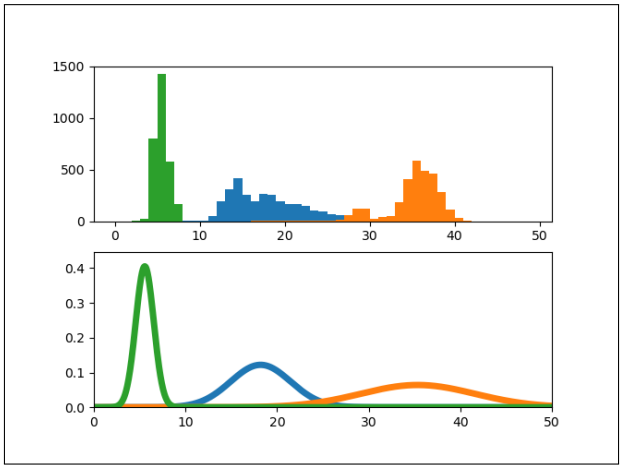

Figure 8. At the top, the histograms of the concentrations of 10 pp/μL (green), 26 pp/μL (blue), and 50 pp/μL (orange) at 12 rpm. At the bottom, the estimated Rice distributions (same color code).

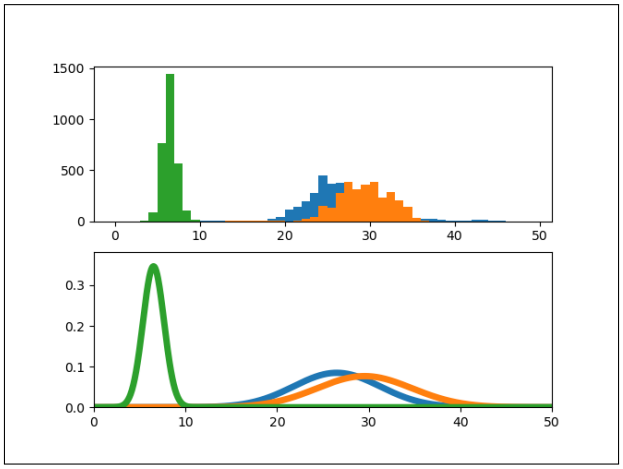

Figure 9. At the top, the histograms of the concentrations of 10 pp/μL (green), 26 pp/μL (blue), and 50 pp/μL (orange) at 16 rpm. At the bottom, the estimated Rice distributions (same color code).

alternative signal descriptors, such as energy density, are being evaluated to complement particle counting, with the aim of improving concentration estimation and resolving ambiguities that arise at elevated flow speeds.

Nonetheless, the methodology has thus far been validated only to a limited extent using polydisperse samples, and the potential impact of naturally occurring microorganisms in water has yet to be addressed. These considerations will introduce future refinements to the signal processing pipeline.

Despite these limitations, the results obtained thus far provide a solid foundation for the development of a next-generation measurement prototype, advancing the system toward eventual deployment on a lightweight computational platform.

5. ACKNOWLEDGMENTS

Carlos Pinillos, Staff hired under JAE-ICU, *Scholarships for starting a research career* cofunded by the Max-CSIC Program. ITEFI. CSIC.

Paula Moreno, Staff hired under PEJ-2021-AI/TIC-21647, AYUDAS PARA LA CONTRATACIÓN DE AYUDANTES DE INVESTIGACIÓN Y TÉCNICOS DE LABORATORIO (Orden 2839/2021, de 24 de septiembre, BOCM núm. 245, de 14 de octubre de 2021). Comunidad Autonoma de Madrid.

Jorge Huecas, Staff hired under the Generation D initiative, promoted by Red.es, an organisation attached to the Ministry for Digital Transformation and the Civil Service, for the attraction and retention of talent through grants and training contracts, financed by the Recovery, Transformation and Resilience Plan through the European Union's Next Generation funds.

This research work was funded by the European Commission – NextGenerationEU, through Momentum CSIC Programme: Develop Your Digital Talent

This work has been funded by the EU HORIZON-CL6-2023-ZEROPOLLUTION-01 project ONE-BLUE (Ref No. 101134929).

This work has been funded by the PID2022 - 138013OB -I00 /MCIN /AEI /10.13039/ 501100011033/ FEDER, UE

6. REFERENCES

[1] Mikaël KedzierskiMikaël KedzierskiDominique FrèreDominique FrèreGwénaël Le MaguerStéphane BruzaudStéphane Bruzaud. Why is there plastic packaging in the natural environment? Understanding the roots of our individual plastic waste management behaviours. The Science of The Total Environment 740:139985. DOI: 10.1016/j.scitotenv.2020.139985. June 2020

[2] Albert Vega-Herrera, Maria Garcia-Torné, Xavier Borrell-Diaz, Esteban Abad, Marta Llorca, Cristina M. Villanueva, Marinella Farré. Exposure to micro(nano)plastics polymers in water stored in single-use plastic bottles. Chemosphere (2023): doi.org/10.1016/j.chemosphere.2023.140106

[3] Renjith VishnuRadhanRenjith VishnuRadhanAnil LonappanAnil LonappanT.I. EldhoT.I. Eldho. A microwave-based technique as a feasible method to detect plastic pollutants in experimental samples. Journal of Hazardous Materials 428(5):128224. DOI: 10.1016/j.jhazmat.2022.128224. January 2022

[4] Tobias Kleinke and Finn-Frederik Stiewe and Tristan Winkel and Norman Geist and Ulrike Martens and Mihaela Delcea and Jakob Walowski and Markus Münzenberg. Identification and characterization of various plastics using THz-spectroscopy. arXiv. https://arxiv.org/abs/2212.04157. 2022

[5] Albert Vega-Herrera, Marta Llorca, Xavier Borrell-Diaz, Paula E. Redondo-Hasselerharm, Esteban Abad, Cristina M. Villanueva, Marinella Farré. Polymers of micro(nano) plastic in household tap water of the Barcelona Metropolitan Area. Water Research (2022): doi.org/10.1016/j.watres.2022.118645