Mobile system to detect plastic particles in critical scenarios: potential approach for attachment in UAVs

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Abstract. This study aims to develop an efficient and cost-effective system for detecting small particles, with the potential for integration with unmanned aerial vehicles (UAVs). The research is divided into two main components: simulation and practical experimentation. The findings demonstrate that the system is capable of detecting particles with widths up to 400 µm. Additionally, it was established that the signal response could be modulated following a sigmoid function. These results confirm the functionality of the system; however, the simulation component indicates potential areas for improvement. Moreover, there is significant potential for the system to be adapted for UAV attachment.

1 Introduction

Year after year the problem with small sized plastic particles imposes an increasing danger to human society. First it was found in the sea, after that in the atmosphere [1]. With the passage of time, we started to find it in animals [2] implying that this hazard has entered the food chain in almost all maritime habitats. More recently studies have shown that this calamity is already present in the human body [3]. The production of plastics is expected to increase in the next years. **Fig. 1** was taken from a Nature article and shows exactly that predicted increase [4].

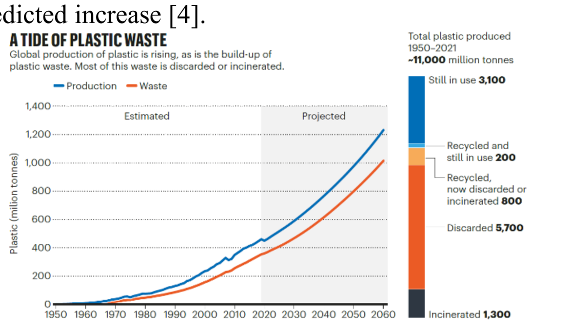


Fig. 1. Estimated and projected production and waste of plastic in the world from 1950 to 2060.

Considering this, several systems for detecting microplastics have been developed, ranging from visual identification to FTIR and Raman spectroscopy [5]. However, these methods necessitate sampling and advanced treatment processes, which are costly and time-consuming.

This study represents an initial effort to develop a cost-effective and efficient system for detecting plastic particles. The goal is to create a real-time detection system that provides immediate data, enabling on-the-spot analysis. Additionally, the system is designed with the intention of being attachable to UAVs. To achieve these objectives, the research is divided into two phases. The first phase involves simulating the projected system's performance, while the second phase consists of experimental trials to validate the hypothesis.

2 Methodology

The initial phase of this study involved simulating the system's detection capabilities and particle flow using MATLAB and SolidWorks. The subsequent phase consisted of experimental trials aimed at validating or refuting the prior simulations, with the intent to either confirm the simulations' accuracy or enhance their quality.

The system's operating principle is straightforward. It comprises a light-emitting diode (LED) and a phototransistor (PT). The phototransistor is configured inversely, such that the presence of light results in a low potential measurement, whereas the obstruction of light causes an increase in the measured value. It is crucial to avoid saturating the phototransistor during this process.

Given this configuration, the system leverages the potential spike induced by light obstruction to detect the passage of particles. A schematic representation of the system's working principle is illustrated in **Fig. 2**.

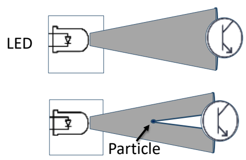


Fig. 2. Schematic of the working principle of the system.

Additionally, we conducted particle flow simulations using SolidWorks to analyze their behavior within our designed prototype (see **Fig. 3a**). MATLAB simulations were also performed to study the expected signal when an object obstructs the path between the LED and the phototransistor (PT). Based on the initial conclusions drawn from these simulations, we proceeded to experimental trials. The prototype utilized in these trials is depicted in **Fig. 3b**.

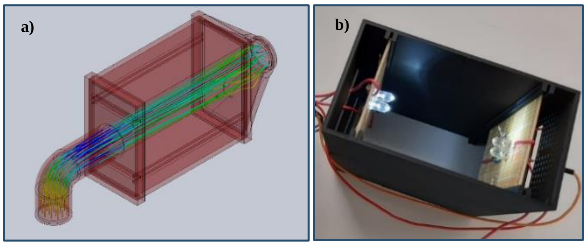


Fig. 3. a) Simulation of the flow of the particles through the prototype and **b)** prototype used to measure the signal in face of an obstruction.

The prototype was designed to facilitate obstruction experiments. Instead of particles, metal bars with a fixed width were used to create a more controlled and manageable obstruction of the PTs. This approach allows for a comparison of the two photodetectors' results and enables the study of alignment impact.

Data from the PTs was collected using an Arduino Uno R3. A MATLAB program with a graphical user interface (GUI) was employed to retrieve the data and display the system's real-time status.

3 Simulation

The first step of the simulation involved theorizing the system's operation and determining an accurate modulation method. To achieve this, we sought the most appropriate equation to describe the experiment.

Considering the system's constraints, we identified certain characteristics that the function must possess:

1. When $x \to 0 \Longrightarrow V \longrightarrow \mathrm{V_{min}}$;
2. When $x \to \infty \Longrightarrow V \longrightarrow \mathrm{V_{max}}$;
3. The curve must vary depending on the particle's distance to the phototransistor.

With x being the samples' width and V the signal.

Considering these properties, we concluded that the best function to describe this behavior is the sigmoid function which in this case is given by:

$$V = \frac{\mathrm{V_{min}} - \mathrm{V_{max}}}{1+(x/\mathrm{x_0})^{\mathrm{p}}} + \mathrm{V_{max}} \tag{1}$$

Where $\mathrm{V_{min}}$ and $\mathrm{V_{max}}$ are the minimum and maximum potential the PT can have, respectively, $\mathrm{x_0}$ and p are constants that depend on the system.

Lacking direct knowledge of these constants' values, we decided to estimate them based on our system's initial results and predictions. We hypothesized $x_0=1400-0.5\times1100\times d$, indicating that x_0 depends only on the distance to the detector (d) and not on the particle size. The negative signal was inferred from initial results, and we also assumed p=2**.**

4 Results and Analysis

4.1 System response time

Firstly, we must analyze the response of our electronic devices. The initial step involves examining the Arduino to determine the optimal BaudRate for communication within the context of our experiment.

To achieve this objective, we studied the intervals between data for various BaudRates and plotted the results in **Fig. 4**.

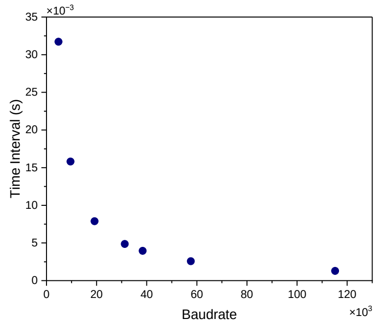


Fig. 4. Time intervals between the retrieved data in function of the BaudRate chosen in the Arduino IDE.

As observed, higher BaudRates result in smaller time intervals between data transmissions. However, this decrease reaches a limit, as depicted in the graph. We conclude that the time interval varies inversely with the BaudRate until a specific threshold, beyond which further increases in BaudRate do not affect the time interval between data.

The next step is to analyze the response time of the system. Using a signal generator and an oscilloscope, we sent a sinusoidal signal to the system and found how the system responded to the frequency applied. **Fig. 5** shows the results obtained.

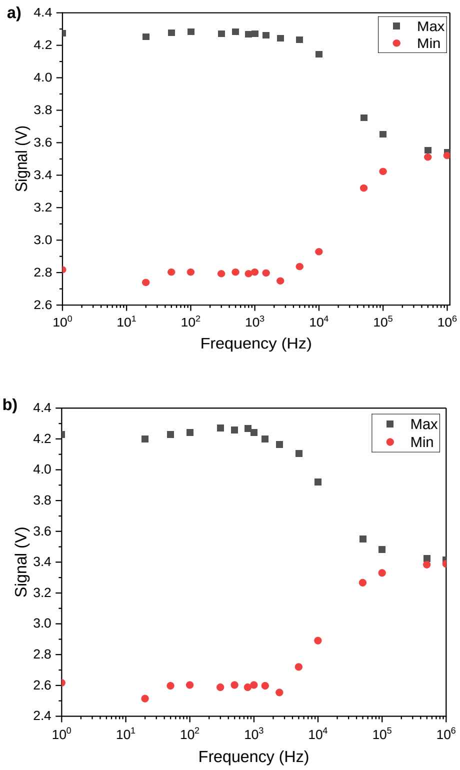


Fig. 5. Signal response for the PT used in function of the signal frequency applied to both, in **a)** PT1 and **b)** PT2.

From the graphics we can observe that the frequence of response is reasonable up to at least 10^4Hz, corresponding to time response of 0.1ms. Beyond this threshold, the system's response time fails to synchronize with the frequency of the input signal. Consequently, the system exhibits a diminished amplitude response, eventually stabilizing at zero amplitude, remaining fixed at the mean value.

It is important to consider that in this experiment, the signal is applied to the LED, so this frequency limit might not be attributed to the phototransistor (PT) but rather to the LED used. Despite this potential limitation, the value obtained is sufficient for our analysis, and thus, the possible constraint imposed by the LED does not pose a problem.

4.2 Size of the particle effect

The second part involves studying how particle size affects the value observed in the phototransistor (PT) signal. We begin by presenting the simulation results, as shown in **Fig. 6**.

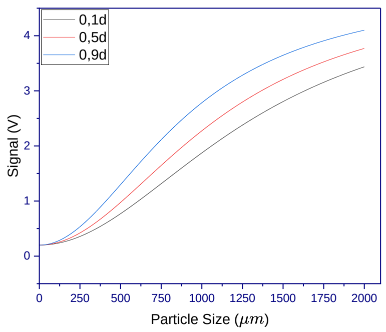
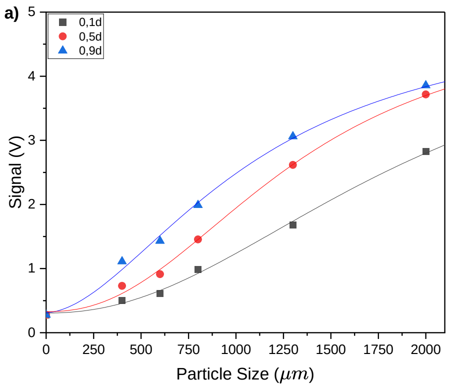


Fig. 6. Results of the simulation used to describe the signal detection in function of the sample size for some distances to the detector.

Considering the previous considerations, we can see that a 0 µm particle should not affect the system, and therefore, no alterations should be observed. Nevertheless, we can observe differences in the curves for varying distances to the detector. It is important to note that despite these differences, the rate of increase remains consistent because the p value is fixed.

Doing some trials, we get the results represented in **Fig. 7**



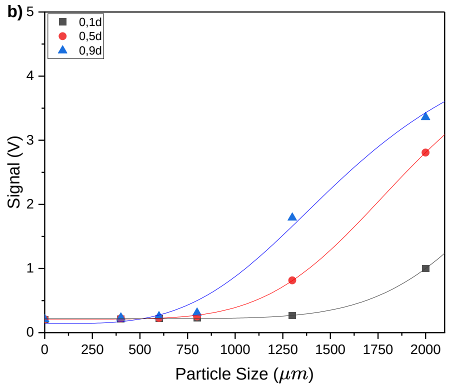


Fig. 7. Experimental results obtained for several particles along with a sigmoid fitting, in **a)** PT1 and **b)** PT2.

From our observations, the predicted evolution of the curve is noticeable confirming the simulation results. However, the differences between the curves are not as hypothesized before, leading us to conclude that the simulation could be more accurate. The oversimplification of the values of x_0 and p is inadequate to describe this system according to the experimental data.

4.3 Distance to the detector effect

To further study the distance-dependent response of the system, we conducted a MATLAB simulation using the same sigmoid function as previously described and the same assumptions for the constant values. The obtained results are represented in **Fig. 8**.

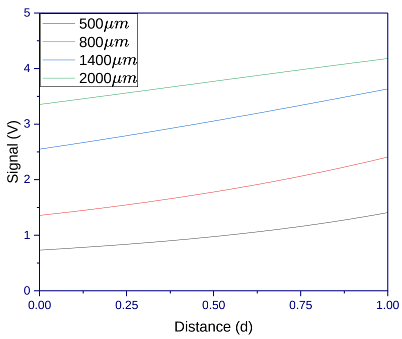


Fig. 8. Simulation of the signal in function of the distance to the detector for several sample sizes.

After some experiments of passage for particles with different width we obtained the results represented in **Fig. 9**.

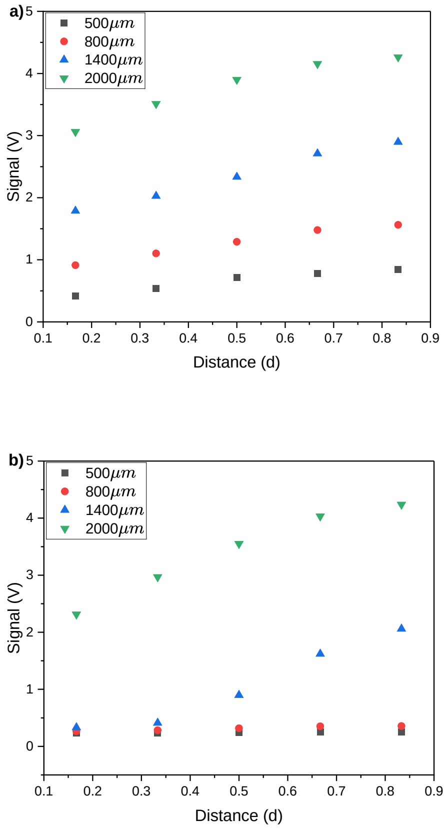


Fig. 9. Experimental results obtained for several distances to the detector, in **a)** PT1 and **b)** PT2.

These results do not appear to be neither linear nor quadratic nor any easy fit.

Considering that the initial considerations for the value of x_0 are not accurate and considering that we supposed that its value is influenced by d but also considering that the value of the constant p can also be affected by the distance we cannot determine an equation that is able to describe this behavior without getting the actual dependence of this constants on d.

5 Cost and Attachment to UAVs

Considering two of the main objectives, make this a cheap and accurate detector system and attach it to UAVs, we can consider the cost of the prototype and the cost of the material involved.

To make the prototype we invested around 30 euros. The real system would be more expensive considering the need for a smaller Arduino, a system of communication UAV-ground and a larger number of LEDs and PTs. On the other hand, we also must consider the material of the box that enclosures all those components.

To attach this system to UAVs there are some things we must consider. First, the electronics of the system must be stable to avoid any misreading and consequently misdetections. Another one is that since we have a sensible system, and the velocity of detection is limited, we must guarantee some conformity in the flow velocity.

Last, we must consider that this system is not perfect and has a limitation to the detection of plastic particles, for example smaller particles might not be detected and demand a greater investment and a greater precision that this system does not provide.

6 Conclusions

With these considerations in mind, we conclude that integrating this system with a UAV is feasible, albeit requiring significant effort to enhance its practicality.

Moreover, the system demonstrated promising results in detection. The amplitude-to-base signal ratio extended the detection range, thereby improving the system's usefulness and effectiveness.

This system proves to be simple and cost-effective. For more accurate real-time data reading, it must be complemented by software capable of self-analyzing the provided data and identifying the passage of plastic particles autonomously.

Future work should focus on accurately determining the correlations between the distance to the detector and the constants x_0 and p. Once these relationships are established, a more precise system can be simulated, facilitating the development of software and the integration of the system with UAVs.

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