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## Les caméras spectrales sont-elles le futur de la surveillance de la pollution dans les réseaux d'assainissements?

### Are spectral cameras the future of urban drainage system pollution monitoring?

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#### RÉSUMÉ

L'imagerie hyper-spectrale (IHS) est une technique qui a le potentiel d'être utilisée pour mesurer de manière non intrusive la pollution des eaux usées dans les systèmes d'assainissement urbains. L'un des avantages de l'IHS est sa capacité à mesurer des données de réflectance détaillées sur une surface, ce qui permet d'utiliser simultanément des méthodes d'analyse spatiale et spectrale. Cependant, il y a encore relativement peu de recherches dans ce domaine. Pour évaluer l'efficacité de l'IHS pour mesurer la pollution des eaux usées, nous avons mené une expérience de laboratoire avec 144 échantillons. En utilisant un modèle de régression des moindres carrés (PLS), il est possible d'estimer avec une précision de 10% environ sept indicateurs de pollution courants (COD, turbidité, DOC, TN, PO4-P, SO4-S, NH4-N). De plus, en utilisant des méthodes spécifiques à l'IHS, comme la sélection de pixels et de longueurs d'onde, nous avons mesuré une amélioration de la performance du modèle de 50% par rapport à un modèle de référence, ce qui montre la supériorité de l'IHS par rapport à d'autres dispositifs spectraux. Pour pallier aux limitations de cette première expérience et obtenir des résultats plus généraux, nous prévoyons maintenant d'installer un système IHS au-dessus d'un canal ouvert afin de collecter des mesures de réflectance des eaux usées réelles sur une période plus longue.

#### ABSTRACT

Hyperspectral imaging (HSI) technology has the potential to be used for contactless monitoring of wastewater pollution in urban drainage systems, but there has been relatively little research in this area. One advantage of HSI is its capacity to measure detailed reflectance data over a surface, which allows for the simultaneous use of spatial and spectral analysis. In a proof-of-concept laboratory experiment, we tested HSI's effectiveness in measuring wastewater pollution using 144 samples and found that it could estimate seven common pollution indicators (COD, turbidity, DOC, TN, PO4-P, SO4-S, NH4-N) with an error rate of around 10%. The use of HSI-specific methods such as pixel and wavelength selection improved the model's performance by up to 50% compared to a simple baseline model, demonstrating the superiority of HSI over other spectral devices. To address the limitations of this initial experiment and produce more reliable results, we plan to install an HSI system over an open flume to collect reflectance measurements of real wastewater for an extended period of time. Our research suggests that HSI is very interesting for monitoring wastewater pollution in urban areas.

#### MOTS CLÉS

Camera hyperspectrale, mesure non-intrusive, mesure en continu

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## 1 INTRODUCTION: STATE OF THE KNOWLEDGE

The light reflected on the surface of an object can provide information about its chemical and physical properties. Hyperspectral imager (HSI) is a camera that can capture hundreds of wavelengths over a continuous spectrum in the visible-near infrared range (400-1000nm). It is already used in a variety of fields, such as environment monitoring [1], medical measurements [2] and industrial process control [3]. However, it received relatively little attention in the wastewater sector. In the past two decades, research groups have recognized the interest of developing non-contact wastewater pollution measurement, and studied the use of spectrometer to collect the light reflectance [4]–[6]. Although initial results were promising, there have been few real-world applications and further research due to limitations of spectrometers, which can only measure spectral reflectance from a limited field of view and are therefore sensitive to the selection of the region of interest [7].

Recently, Huang et al. (2022) used a HSI camera to monitor the organic content of industrial wastewater with a precision under 10% [8]. They used a wavelength selection method coupled with a random forest regression model. However, the main advantage HSI is to capture image with fully spectrally resolved pixels, enabling the use of classification methods to retrieve the spectral signature of the area of interest, while excluding bad pixels [9]. In summary, HSI technologies are potentially well suited for contactless and continuous monitoring of urban drainage systems due to their ability to combine spatial and spectral analysis. In this contribution, we present two series of experiments testing its use to monitor wastewater pollution.

## 2 OVERVIEW OF TWO RESEARCH PROJECTS WITH HYPERSPECTRAL CAMERA

### 2.1 Proof-of-concept: Hyperspectral camera to measure 7 pollution indicators

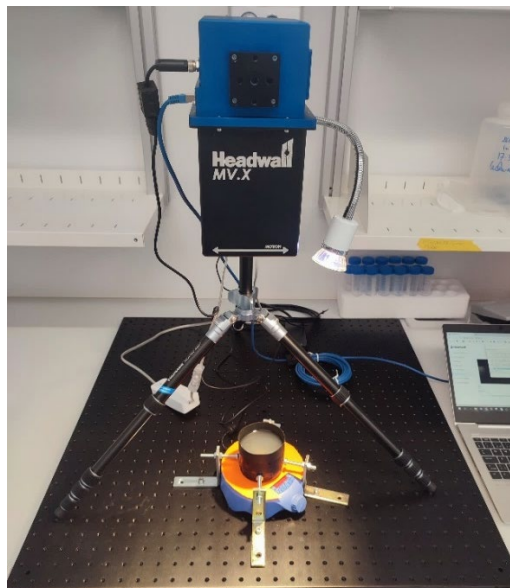


Figure 1: Picture of the experimental setup to capture the hyperspectral image of a sample placed in a cup

We designed a first laboratory experiment (Figure 1) to assess the potential of HSI to measure wastewater pollution. With the MV.X camera from Headwall Photonics, we acquired hyperspectral images of 144 samples with a 2nm spectral resolution between 400 and 1000 nm. The samples used were mixtures composed of combinations of raw sewage samples taken from a municipal sewer system near Eawag (Dübendorf, Switzerland), and formazine, a synthetic turbidity enhancer added in different proportions in a later phase of the experiment. Reference measurements for seven pollution indicators were measured in parallel in the laboratory: COD, turbidity, dissolved organic carbon (DOC), total nitrogen (TN), phosphate (PO<sub>4</sub>-P), sulphate (SO<sub>4</sub>-S) and ammonium NH<sub>4</sub>-N).

Before training a predictive partial-least-squared (PLS) regression model for each of the pollution indicator, we used a pixel classification and a wavelength selection to reduce the dimensionality of the data. Those two pre-processing steps enable by the unique structure of HSI data, made it possible to improve the pollution estimation up to 50%. The performance of each model measured with leave-one-out cross-validation are presented in Table 1. The results are very promising, with an estimation precision

of 5.9-13.1%, especially for turbidity, TN and ammonium. Therefore, we are planning a second experiment to test the HSI in a setup closer to drainage system conditions.

Table 1: Results of a modelling of the pollution with PLS regression

Parameter	Unit	Range		R <sup>2</sup>	RMSE	MAPE
		Min	Max			
<b>COD</b>	mg/L	91.2	379.0	0.88	23.7	9.6%
<b>Turbidity</b>	NTU	21.6	267.3	0.97	11.1	8.6%
<b>DOC</b>	mg/L	45.1	302.9	0.86	16.0	13.1%
<b>TN</b>	mg/L	13.5	44.6	0.94	1.9	5.9%
<b>PO4-P</b>	mg/L	0.8	5.0	0.91	0.2	8.6%
<b>SO4-S</b>	mg/L	27.8	74.7	0.84	5.5	8.9%
<b>NH4-N</b>	mg/L	5.4	26.6	0.93	1.4	7.5%

## 2.2 Next step: Installation of a hyperspectral camera in a flume

The first series of experiments had two main limitations. One limitation was the use of formazine, which altered the reflectance properties of the samples. Another limitation was that the experimental setup did not accurately reflect real-world measurement conditions. Specifically, the samples were filtered with a strainer and placed in a cup for HSI acquisition, resulting in a perfectly smooth water surface without any ripples. In contrast, in drainage systems, the wastewater is flowing in an open channel and may contain ripples and floating objects that can affect the measurement.

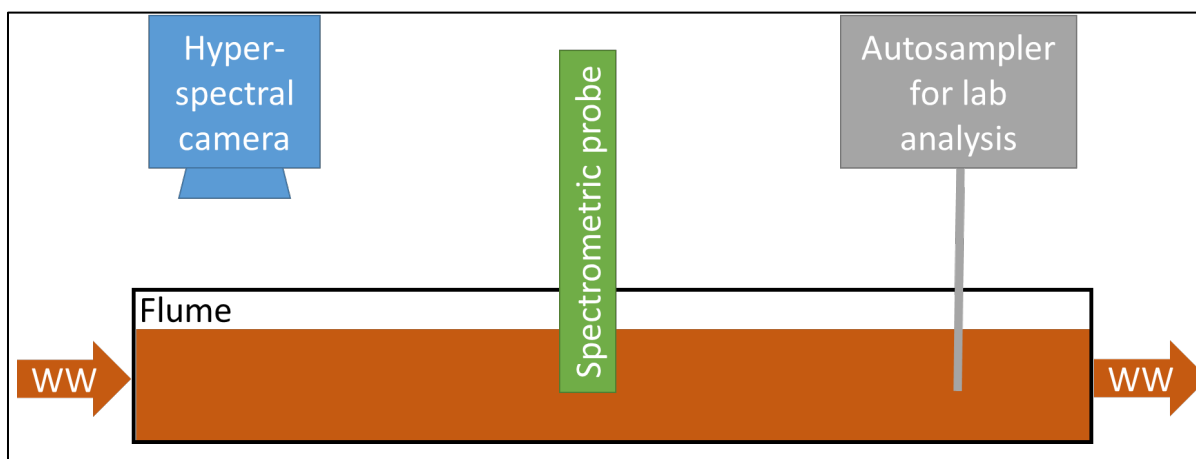


Figure 2: Setup for the monitoring campaign of sewer wastewater with a hyperspectral camera in a flume

Therefore, we want to assess HSI performance in a more realistic setup, and only with real wastewater. We will install the camera above a horizontal flume, in which real sewer wastewater will be circulated continuously (Figure 2). An additional spectrometric probe will be placed in the medium to measure wastewater absorbance spectra. Furthermore, a cooled automatic sampler will collect samples for reference laboratory analysis, in order to calibrate the HSI camera and the spectrophotometric probe and measure their performances. Finally, in addition to the automatic sampler, 50 grab samples will be collected in the first week of the experiment to be analysed directly in laboratory, to ensure a satisfactory calibration of the probe and the imaging system. We will take hourly HSI and absorbance measurement of the wastewater, and at least 200 laboratory reference measurement with the automatic sampler. The experiment will be carried out during about 6 month, starting in March 2023.

## 3 DISCUSSION FOR THE NOVATECH CONFERENCE

The advantages of HSI is not only to be potentially suited for reflectance measurement in a complex environment, but also to capture full spectral information that can be analysed afterwards. For example, in the case of turbidity, we found out that it is possible to estimate it with very good accuracy with only

three wavelengths corresponding to the sensitive colours of a regular RGB camera (Figure 3). This is interesting because it means that RGB camera might capture enough spectral information for turbidity measurements. HSI systems are still very expensive, and their substitution with multispectral or RGB camera has to be studied more in depth.

Despite promising results, the use of HSI also raises a number of practical issues. The optical calibration of the camera is challenging, because it needs to compensate for the site-specific lighting conditions that are daily and seasonally changing. Variations in the water flow and level might also perturb the measurement. Another challenge is the model calibration for pollution estimation. PLS model perform well with laboratory data, but the variability of real sewer wastewater is much higher. The second series of experiments will help answering part of those challenges.

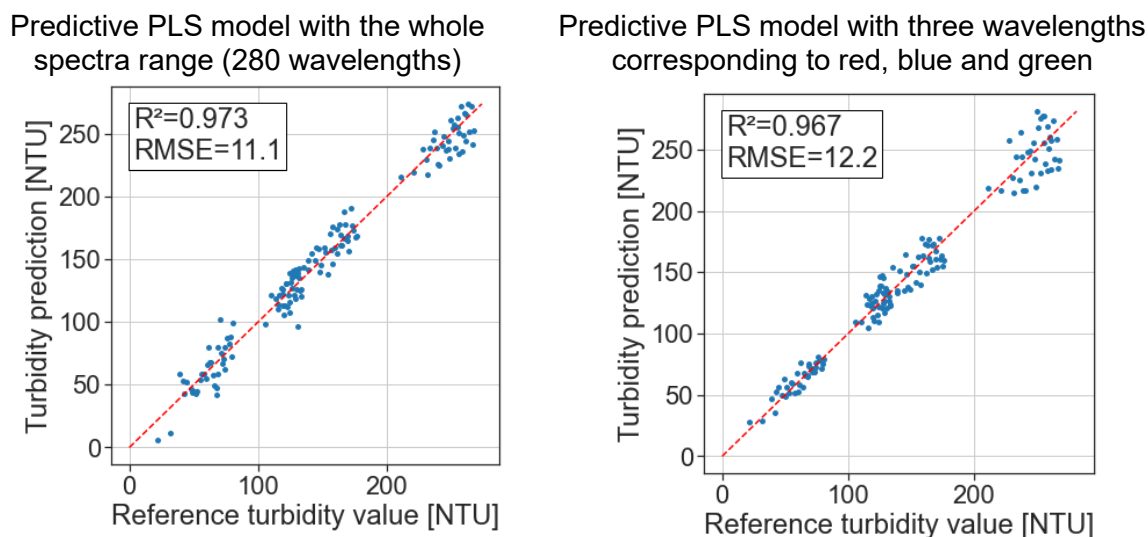


Figure 3: Comparison of a PLS model with full spectra versus only three wavelength

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