10.48047/jocaaa.2024.32.01.24

DETECTION OF WASTEWATER POLLUTION THROUGH NATURAL LANGUAGE GENERATION WITH LOW-COST SENSING PLATFORM

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ABSTRACT

The detection of contaminants in several environments (e.g., air, water, sewage systems) is of paramount importance to protect people and predict possible dangerous circumstances. Most works do this using classical Machine Learning tools that act on the acquired measurement data. This paper introduces two main elements: a low-cost platform to acquire, pre-process, and transmit data to classify contaminants in wastewater; and a novel classification approach to classify contaminants in wastewater, based on deep learning and the transformation of raw sensor data into natural language metadata. The proposed solution presents clear advantages against state-of-the-art systems in terms of higher effectiveness and reasonable efficiency. The main disadvantage of the proposed approach is that it relies on knowing the injection time, i.e., the instant in time when the contaminant is injected into the wastewater. For this reason, the developed system also includes a finite state machine tool able to infer the exact time instant when the substance is injected. The entire system is presented and discussed in detail. Furthermore, several variants of the proposed processing technique are also presented to assess the sensitivity to the number of used samples and the corresponding promptness/computational burden of the system. The lowest accuracy obtained by our technique is 91.4%, which is significantly higher than the 81.0% accuracy reached by the best baseline method.

INTRODUCTION

The task of accurate environmental monitoring is a pressing worldwide issue which is bound to become increasingly more important in the near future. There are many aspects that should be kept under control and concern the quality of the air, soil, and water [1, 2]. In fact, their continuous monitoring would allow targeted and timely actions aimed at restoring optimal conditions following dangerous events such as the appearance of pollutants. In this context,

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monitoring wastewater (WW) is particularly important [3]. WW is the water that has already been used for some purpose (civil or industrial uses) and must be subjected to purification before being returned to the natural cycle. To function at their best and effectively, the purification systems must know a priori the type of substances mixed with the water. It follows that a purification system for water for industrial use will be different from a purification plant for water for civil use. Hence, there is a strong need for protocols to promptly detect incompatible substances, to guarantee the correct and effective operation of purification plants[4]. Currently, this is solved by organizing periodic monitoring activities at particular points of the water path, which are carried out by the control institutes in charge using specialized laboratory instruments. Although this is an effective method, the quality of the water between two consecutive checks is unknown, and the checks may be not frequent enough to promptly identify problems.

The ideal solution would combine automated continuous and distributed early warning monitoring, alongside periodic manual checks carried out by the control institutes. To solve the problems of cost and installation of a distributed and continuous monitoring system, it is necessary to resort to low-cost and IoT-ready systems [5], which are able not only to collect environmental data but also to process them relying on centralized data collection and elaboration points. In this context, the data collected from the sensors need to be processed by an algorithm that is used to analyze and forecast the presence (or absence) of polluting substances in the WW. Current state-of-the-art systems for this task rely on machine learning algorithms such as decision trees [6, 7]. In this paper, we propose a novel system based on deep learning, and in particular on causal generative models developed for natural language tasks, for the detection and classification of pollutants in WW, starting from the data collected by a multisensory system based on SENSIPLUS (Sensichips srl, Pisa, Italy) [8]. Note that the present paper does not present the infrastructure necessary for data transport as any solution based, for example, on MQTT or message queuing protocols could be used for this purpose. The effectiveness of the proposed classifier is tested against a set of state-of-the-art baselines on a dataset created in collaboration with Sensichips s.r.l. and made available to the scientific community [9]. Results show that the proposed methodology outperforms the baseline methods and its

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effectiveness allows for practical usage of the developed methodology.

LITERATURE REVIEW

Long-Term Monitoring of Water and Air Quality at an Indoor Pool Facility during Modifications of Water Treatment

Previous research has shown that volatile disinfection byproducts (DBPs) can adversely affect the human respiratory system. As a result, swimming pool water treatment processes can play important roles in governing water and air quality. Thus, it was hypothesized that water and air quality in a swimming pool facility can be improved by renewing or enhancing one or more components of water treatment. This study is designed to identify and quantify changes in water and air quality that are associated with changes in water treatment at an indoor chlorinated swimming pool facility. Reductions in aqueous trichloramine (NCl_3) concentration were observed following the use of secondary oxidizer with its activator. This inclusion also resulted in significant decreases in the concentrations of cyanogen chloride (CNCl) in pool water. The concentration of urea, a compound that is common in swimming pools and that functions as an important precursor to NCl_3 formation, as well as a marker compound for the introduction of contaminants by swimmers, was also reduced after the addition of the activator. Concentrations of gas-phase NCl_3 did not decrease after the treatment processes were changed. The collection of long-term water and air quality measurements also allowed for an assessment of the effects of bather load on water and air quality. In general, the concentrations of urea (an NCl_3 precursor), liquid-phase NCl_3, and gas-phase NCl_3 all increased during periods of high swimmer number.

sand filter media to activated filter media, which was monitored for roughly four weeks; the

Development of low-cost indoor air quality monitoring devices: Recent advancements

The use of low-cost sensor technology to monitor air pollution has made remarkable strides in the last decade. The development of low-cost devices to monitor air quality in indoor environments can be used to understand the behaviour of indoor air pollutants and potentially impact on the reduction of related health impacts. These user-friendly devices are portable, require

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low-maintenance, and can enable near real-time, continuous monitoring. They can also contribute to citizen science projects and community-driven science. However, low-cost sensors have often been associated with design compromises that hamper data reliability. Moreover, with the rapidly increasing number of studies, projects, and grey literature based on low-cost sensors, information got scattered.

Intending to identify and review scientifically validated literature on this topic, this study critically summarizes the recent research pertinent to the development of indoor air quality monitoring devices using low-cost sensors. The method employed for this review was a thorough search of three scientific databases, namely: ScienceDirect, IEEE, and Scopus. A total of 891 titles published since 2012 were found and scanned for relevance. Finally, 41 research articles consisting of 35 unique device development projects were reviewed with a particular emphasis on device development: calibration and performance of sensors, the processor used, data storage and communication, and the availability of real-time remote access of sensor data. The most prominent finding of the study showed a lack of studies consisting of sensor performance as only 16 out of 35 projects performed calibration/validation of sensors. An even fewer number of studies conducted these tests with a reference instrument. Hence, a need for more studies with calibration, credible validation, and standardization of sensor performance and assessment is recommended for subsequent research.

Wastewater and public health: the potential of wastewater surveillance for monitoring COVID-19

Pathogenic viruses represent one of the greatest threats to human well-being. As evidenced by the COVID-19 global pandemic, however, halting the spread of highly contagious diseases is notoriously difficult. Successful control strategies therefore have to rely on effective surveillance. Here, we describe how monitoring wastewater from urban areas can be used to detect the arrival and subsequent decline of pathogens, such as SARS-CoV-2. As the amount of virus shed in faeces and urine varies largely from person to person, it is very difficult to quantitatively determine the number of people who are infected in the population. More research on the surveillance of viruses in wastewater using accurate and validated methods, as well as

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subsequent risk analysis and modelling is paramount in understanding the dynamics of viral outbreaks.

A methodology for assessing and monitoring risk in the industrial wastewater sector

The concept of sustainable risk assessment in industrial wastewater treatment is vital to determine the causes and consequences of plant failure. The potential wastewater-related risks that could hamper the operation of the entire manufacturing facility are currently inadequately defined and under researched. This work proposes a framework that includes the comparison of literature and experimental data to quantify the impact of the significant process parameters on the critical process outputs. From the business perspective, managing and minimising risks will be possible when the number of impact parameters is low and the relationships between different parameters are clearly understood. The results show that even only the evaluation of technical risks can provide an assessment platform template for other risk types. Also, the structured and statistically analyzed data sets applied might be further used in the design and development of machine learning platforms algorithms to inform sustainable process outcomes adjusted for various geographical locations and human factors which significantly affect the industrial water sector globally.

An Intelligent Modular Water Monitoring IoT System for Real-Time Quantitative and Qualitative Measurements

This study proposes a modular water monitoring IoT system that enables quantitative and qualitative measuring of water in terms of an upgraded version of the water infrastructure to sustain operational reliability. The proposed method could be used in urban and rural areas for consumption and quality monitoring, or eventually scaled up to a contemporary water infrastructure enabling water providers and/or decision makers (i.e., governmental authorities, global water organization, etc.) to supervise and drive optimal decisions in challenging times. The inherent resilience and agility that the proposed system presents, along with the maturity of IoT communications and infrastructure, can lay the foundation for a robust smart water metering solution. Introducing a modular system can also allow for optimal consumer profiling while

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alleviating the upfront adoption cost by providers, environmental stewardship and an optimal response to emergencies. The provided system addresses the urbanization and technological gap in the smart water metering domain by presenting a modular IoT architecture with consumption and quality meters, along with machine learning capabilities to facilitate smart billing and user profiling.

Drinking Water Quality Assessment Using a Fuzzy Inference System Method: A Case Study of Rome (Italy)

Drinking water quality assessment is a major issue today, as it is crucial to supply safe drinking water to ensure the well-being of society. Predicting drinking water quality helps strengthen water management and fight water pollution; technologies and practices for drinking water quality assessment are continuously improving; artificial intelligence methods prove their efficiency in this domain. This research effort seeks a hierarchical fuzzy model for predicting drinking water quality in Rome (Italy). The Mamdani fuzzy inference system is applied with different defuzzification methods. The proposed model includes three fuzzy intermediate models and one fuzzy final model. Each model consists of three input parameters and 27 fuzzy rules. A water quality assessment model is developed with a dataset that considers nine parameters (alkalinity, hardness, pH, Ca, Mg, fluoride, sulphate, nitrates, and iron). These nine parameters of drinking water are anticipated to be within the acceptable limits set to protect human health.

EXISTING SYSTEM

The monitoring of wastewater is a widely discussed topic in the scientific literature. In particular, several kinds of technologies contribute to developing sensors that discriminate and classify undesired substances to ensure an adequate water quality level. Some of the authors developed systems able to monitor both water and air thanks to the SENSIPLUS platform [10], [11], [12], [13]. The monitoring outputs can vary, ranging from a classification of the pollutants to a simple binary decision on the presence of contaminants in general. Precise solutions to specific problems are often preferred to the development of generic monitoring system that can work properly in very wide contexts. As an example, Lim [14]

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describes a system to detect pollutants in the WW framework, although the distinction between different substances is missing and the technologies appear outdated nowadays. A different approach is taken by Lepot et al. [15], where the presence of illegal connections in the sewage system is monitored using an infrared camera. Ji et al. [16] present an image processing system, intended to estimate the WW amount without taking care of the distinction among substances. The cameras adopted to acquire images do not suffer from sensors' corrosion problems but they require a high energy budget, thus making the system far from the low-cost condition. There are other cases where the classification accuracy is very high but the energy/cost constraints are not taken into account. This is the case of Pisa et al. [17], who developed a system to detect ammonium and total nitrogen based on another one that is more broadly designed to detect all components derived from nitrogen.

Drenoyanis et al. [18] propose an interesting portable device to monitor sewer pumping station pumps in order to generate alarms whenever anomalies are detected. The system is surely of great interest, but it does not include any pollutant classification stage. In terms of processing techniques, to the best of our knowledge, this is the first work leveraging natural language processing techniques, and in particular causal models developed for natural language generation, for the task of detecting WW pollution. Nevertheless, in literature we can find examples of the usage of natural language processing techniques and language models for non-canonical tasks. Language models have been used in the medical domain after the application of a ''reverse encoding'' (i.e., translating codes back to their description) for the classification of diagnostic tests [19], [20], [21] and for diagnostic rule encoding [22]. Furthermore, they have been used with a similar technique for the task of human mobility forecasting [23], [24]. More in general, transformer based models originally designed for NLP tasks have demonstrated successful applications in a wide variety of non-NLP tasks [25], including: images [26], [27], [28], videos [29], [30], [31], speech and audio recognition [32], [33], conversational systems [34], [35], recommender systems [36], [37], reinforcement learning [38], [39], graphs [40], [41], protein structure predictions [42], [43], autonomous driving

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[44], [45], and anomaly detection problems [46], [47].

Disadvantages

• The complexity of data: Most of the existing machine learning models must be able to accurately interpret large and complex datasets for Detection of Wastewater Pollution.

• Data availability: Most machine learning models require large amounts of data to create accurate predictions. If data is unavailable in sufficient quantities, then model accuracy may suffer.

• Incorrect labeling: The existing machine learning models are only as accurate as the data trained using the input dataset. If the data has been incorrectly labeled, the model cannot make accurate predictions.

Proposed System

In the proposed system, the system proposes a novel system based on deep learning, and in particular on causal generative models developed for natural language tasks, for the detection and classification of pollutants in WW, starting from the data collected by a multisensory system based on SENSIPLUS (Sensichips srl, Pisa, Italy). Note that the present paper does not present the infrastructure necessary for data transport as any solution based, for example, on MQTT or message queuing protocols could be used for this purpose.

Advantages

- Baseline extraction: a baseline signal is extracted to normalize raw data.
- Forwarding decision: for each sample, the FSM decides whether to forward it to the classifier, also providing the injection time.
- The proposed classification module is based on deep learning for natural language processing, and in particular on Transformer-based models.
- The proposed system is end-to-end and contains hardware and software components in **MODULES**

Service Provider

In this module, the Service Provider has to login by using valid user name and password. After login successful he can do some operations such as Browse Data

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Sets and Train & Test, View Trained and Tested Accuracy in Bar Chart, View Trained and Tested Accuracy Results, View Prediction Of Water Pollution Type, View Water Pollution Type Ratio, Download Predicted Data Sets, View Water Pollution Type Ratio Results, View All Remote Users.

View and Authorize Users

In this module, the admin can view the list of users who all registered. In this, the admin can view the user's details such as, user name, email, address and admin authorizes the users.

Remote User

In this module, there are n numbers of users are present. User should register before doing any operations. Once user registers, their details will be stored to the database. After registration successful, he has to login by using authorized user name and password. Once Login is successful user will do some operations like REGISTER AND LOGIN, PREDICT WATER POLLUTION TYPE, VIEW YOUR PROFILE.

ALGORITHMS

DECISION TREE CLASSIFICATION ALGORITHM

- Decision Tree is a **Supervised learning technique** that can be used for both classification and Regression problems, but mostly it is preferred for solving Classification problems. It is a tree-structured classifier, where **internal nodes represent the features of a dataset, branches represent the decision rules** and **each leaf node represents the outcome.**
- In a Decision tree, there are two nodes, which are the **Decision Node** and **Leaf Node.** Decision nodes are used to make any decision and have multiple branches, whereas Leaf nodes are the output of those decisions and do not contain any further branches.
- The decisions or the test are performed on the basis of features of the given dataset.
- ***It is a graphical representation for getting all the possible solutions to a problem/decision based on given conditions.***

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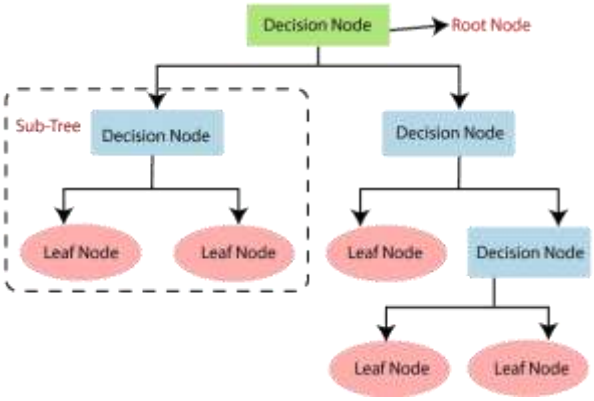

K-NEAREST NEIGHBOR(KNN) ALGORITHM FOR MACHINE LEARNING

- K-Nearest Neighbour is one of the simplest Machine Learning algorithms based on Supervised Learning technique.
- K-NN algorithm assumes the similarity between the new case/data and available cases and put the new case into the category that is most similar to the available categories.
- K-NN algorithm stores all the available data and classifies a new data point based on the similarity. This means when new data appears then it can be easily classified into a well suite category by using K- NN algorithm.
- K-NN algorithm can be used for Regression as well as for Classification but mostly it is used for the Classification problems.
- K-NN is a **non-parametric algorithm**, which means it does not make any assumption on underlying data.
- It is also called a **lazy learner algorithm** because it does not learn from the training set immediately instead it stores the dataset and at the time of classification, it performs an action on the dataset.
- KNN algorithm at the training phase just stores the dataset and when it gets new data, then it classifies that data into a category that is much similar to the new data.
- **Example:** Suppose, we have an image of a creature that looks similar to cat and dog, but we want to know either it is a cat or dog. So for this identification, we can use the KNN algorithm, as it works on a similarity measure. Our KNN model will find the similar features of the new data set to the cats and dogs images and based on the most similar features it will put it in either cat or dog category.

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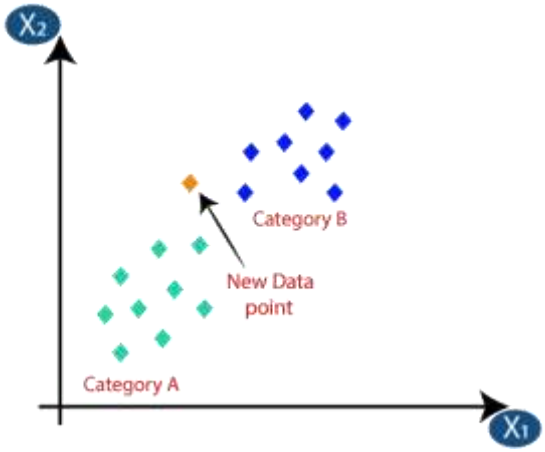

- Firstly, we will choose the number of neighbors, so we will choose the k=5.
- Next, we will calculate the **Euclidean distance** between the data points. The Euclidean distance is the distance between two points, which we have already studied in geometry. It can be calculated as:

CONCLUSION

In this paper we studied the capabilities of natural language processing models, especially generative causal models and more in detail T5, for the task of detecting the presence of polluting substances in wastewater. To this end, differently from state-of-the-art machine learning models, we applied a transformation of the input features called textification in order to translate them into a textual form and be able to feed them into a generative natural language model. The latter is trained to classify each sample based on whether it contains or not a polluting substance, and to identify it if present. We experimentally evaluated the proposed methodology testing its effectiveness against a set of state-of-the-art baselines, and we measured its efficiency. Experimental results show that the proposed methodology outperforms the baseline methods, and its efficiency and effectiveness allow for its deployment and for practical use.

Given that the purposed approach is non-conventional, and it might seem strange or counter-intuitive at first sight, in the following we discuss why such approach makes sense and works in practice. Recent work demonstrated the vast ability of transformers and attention based models to generalize on a large variety of tasks, including those where the model has not been trained on [60, 61, 62, 63], or even to tasks not directly related to or not naturally expressed using natural language processing, such as for example images [26, 27], videos [29], reinforcement learning [39], and graphs [40].

The ability of transformer-based models for generalization comes from the attention mechanism, and from the almost task-

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agnostic training procedure. In fact it consists, in its base form, in reconstructing part of the input item, being it masked or perturbed using domain-specific techniques or topredict the continuation of the input (if the masked part is thelast part of the input). Combined together, these techniques allow the model to learn meaningful and -most importantly-general latent relationships in input sequences, and the ability to relate those to the network's output. For example, networks applied to texts show the ability to reconstruct missing text orgenerate it from a prompt, for images and videos the ability to reconstruct corrupted or missing images and frames, for

graphs to learn complex graph sub-structures (i.e., arrange- ments of set of nodes and edges), and so on. Besides those specific abilities, network based on transformers and trained with masking or causal objectives (i.e., predict masked parts or predict the continuation of the input) show high gener-alization abilities across tasks and domains. For the same reason, we believe that the textual description gathered fromthe sensors which we use to train our neural network allows for accurate forecasting predictions for the possible pollutingsubstances present in wastewater.

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