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A Novel Deep Learning Method for Water leakage Detection Using Acoustic Features

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Conservation of water is one of the major objectives for any country around the world. Water management plays a very important role in a society, as it is one of the basic needs for the mankind. Water leak detection is an important task for ensuring the safety and efficiency of water systems. Deep learning techniques, combined with real-time sensor data, can greatly enhance the accuracy and efficiency of water leak detection. Water leak detection plays a crucial role in maintaining the safety, efficiency, and sustainability of water systems. This paper presents an investigation of the capacity of deep learning methods (DL) to localize leakage in water distribution systems (WDS). Progress in real-time monitoring of WDS and DL has inspired towards new opportunities to develop data-based methods for water leak localization. However, the handlers of WDS need recommendations for the selection of the optimal DL methods as well their practical use for leakage localization. This paper contributes to this issue through an investigation of the capacity of DL methods to localize leakage in WDS. Water leak detection is crucial in conversation of water, cost saving, infrastructure protection prevention of water damage and operation efficiency. This paper shows a proposal for a system based on a wireless sensor network designed to monitor water distribution systems, such as hotel industry, irrigation systems, which, with the help of an autonomous learning algorithm, allows for precise location of water leaks. Autoencoder neural network (AE), an unsupervised DL model, is further developed to detect leak with unbalanced data.

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The results show AE-DL model achieved high accuracy when leaks occur in pipes inside the sensor monitoring area, while the accuracy is compromised otherwise. This observation will provide guidelines to deploy monitoring sensors to cover the desired monitoring area. A novel strategy is proposed based on multiple independent detection attempts to further increase the reliability of leak detection by the AE-DL and is found to significantly reduce the probability of false alarm.

Keywords: Water leakage detection; deep learning; machine learning; water conservation.

1. INTRODUCTION

Water leak detection is a proactive approach that benefits both water utilities and consumers. By implementing effective leak detection strategies and leveraging technologies like machine learning and real-time sensor data, water systems can be better monitored, maintained, and protected, ensuring the safety, efficiency, and sustainability of our water resources.

Sensor Data Collection: Install sensors at various points in the water distribution system to collect real-time data. These sensors can measure parameters such as flow rate, pressure, temperature, and acoustic patterns.

Data Pre-processing: Pre-process the collected sensor data to remove noise, handle missing values, and normalize the data for further analysis. This step is crucial to ensure the accuracy of the machine learning models. Technology such as ground penetrating radar can localize leak around pipe but requires heavy human intervention in signal analysis [1-3].

Feature Engineering: Extract relevant features from the pre-processed sensor data. These features can include statistical measures such as mean, standard deviation, and variance, as well as frequency-based features and time-based features.

Labelling: Generate labelled data by introducing artificial leaks or using historical data that indicates the presence or absence of leaks. The labelled data will be used to train the machine learning models.
Model Training: Train machine learning models using the labelled data. Various algorithms can be applied, such as decision trees, random forests, support vector machines (SVM), or neural networks. The choice of algorithm depends on the specific requirements and characteristics of the data.

Model Evaluation: Evaluate the trained models using appropriate evaluation metrics such as accuracy, precision, recall, and F1-score. This step helps in selecting the best-performing model.

Real-Time Monitoring: Deploy the trained model in a real-time monitoring system that continuously receives sensor data from the water distribution system. The model analyses the incoming data and makes predictions about the presence or absence of leaks.

Leak Detection and Alert Generation: Based on the predictions from the model, the system can detect water leaks and generate alerts. The alerts can be sent to maintenance personnel, facility managers, or an automated system that can take appropriate actions, such as shutting off valves or initiating repairs.

Model Updates: Continuously monitor the performance of the machine learning algorithms in the real-world environment. If the performance deteriorates or new patterns emerge, retrain the models with updated data to ensure accurate leak detection.

1.1 Related Work

Sithole et al. [4] have demonstrated the technique for water leakage detection and their proposed method showed efficient way to resolve the underlying problem in smart manner. Daadoo and Daraghmi [5] have proposed techniques based on sensor nodes of wireless domain and then set up the technical architecture for the same. Proposed method of the author was satisfactory enough to resolve the issue of water leakage detection. Martini et al., [6,1,2] have demonstrated the technique to detect water leakage. They focused on drinking water supply and monitored the big pipelines leakage. The authors of [3,7] also focused on same techniques using thermal imaging. Multiple researchers used similar techniques like ANN to address the underlying issue. We are going to discuss dataset design, AI based techniques to detect water leakage in the upcoming sections followed by conclusion and underlying mathematics.

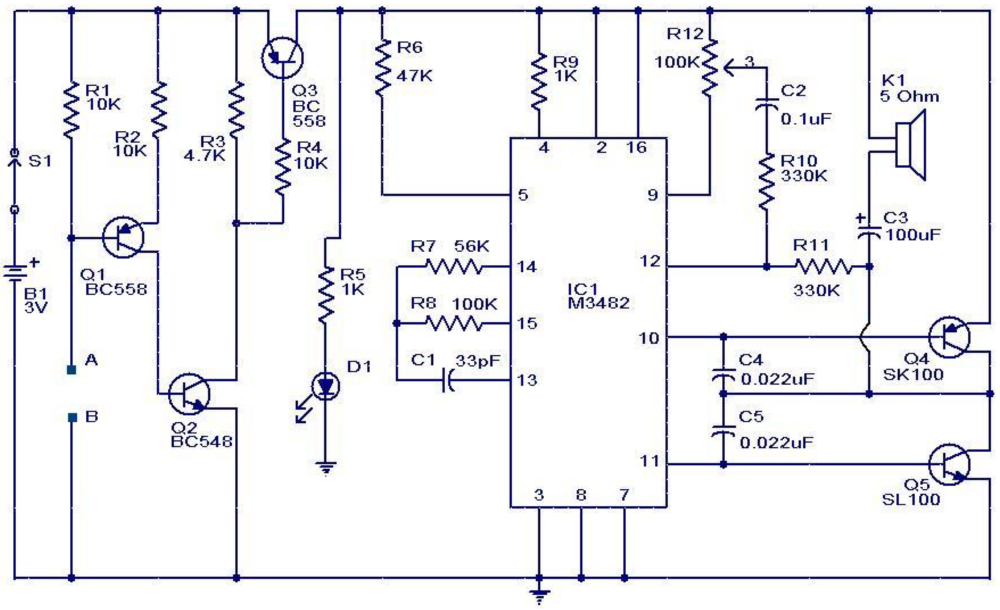

Fig. 1a. Circuit diagram of water sensor

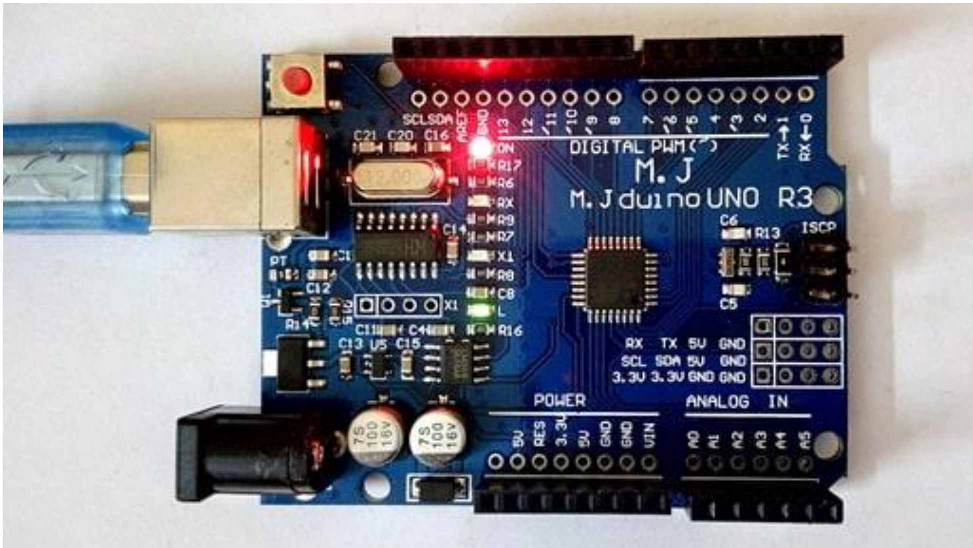

Fig. 1b. Hardware for water leakage detection

1.2 Dataset Design

Dataset generation is done using synthetic process as well as with the help of open-source database mixing. Synthetic process of dataset generation is shown in Fig. 2. We have utilized the open source process to extract the acoustic features for water leakage process. Relevant sources are listed below:

1. https://github.com/neelabhsinha/Leakage-Detection-in-Smart-Water-Distribution-Systems
2. https://github.com/atharwa-24/Water-Leakage-Detection-System
3. https://github.com/3springs/satellite_leak_detection
4. https://github.com/anirudhnag27/Leak-detection-and-Localisation
5. https://microsoft.github.io/techcasestudies/iot/2016/11/29/Powel.html
6. https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29WR.1943-5452.0001317?src=recsys
7. https://www.hackster.io/taifur/smart-water-leak-detector-for-home-ml-inside-f0dcae

8. https://docs.edgeimpulse.com/experts/prototype-and-concept-projects/fluid-leak-detection-with-flowmeter-and-ai
9. https://www.crowdsupply.com/microphonon/aquaping
10. https://www.crowdsupply.com/microphonon/aquaping
11. https://esphome.io/cookbook/leak-detector-m5stickc
12. https://www.altexsoft.com/blog/audio-analysis/

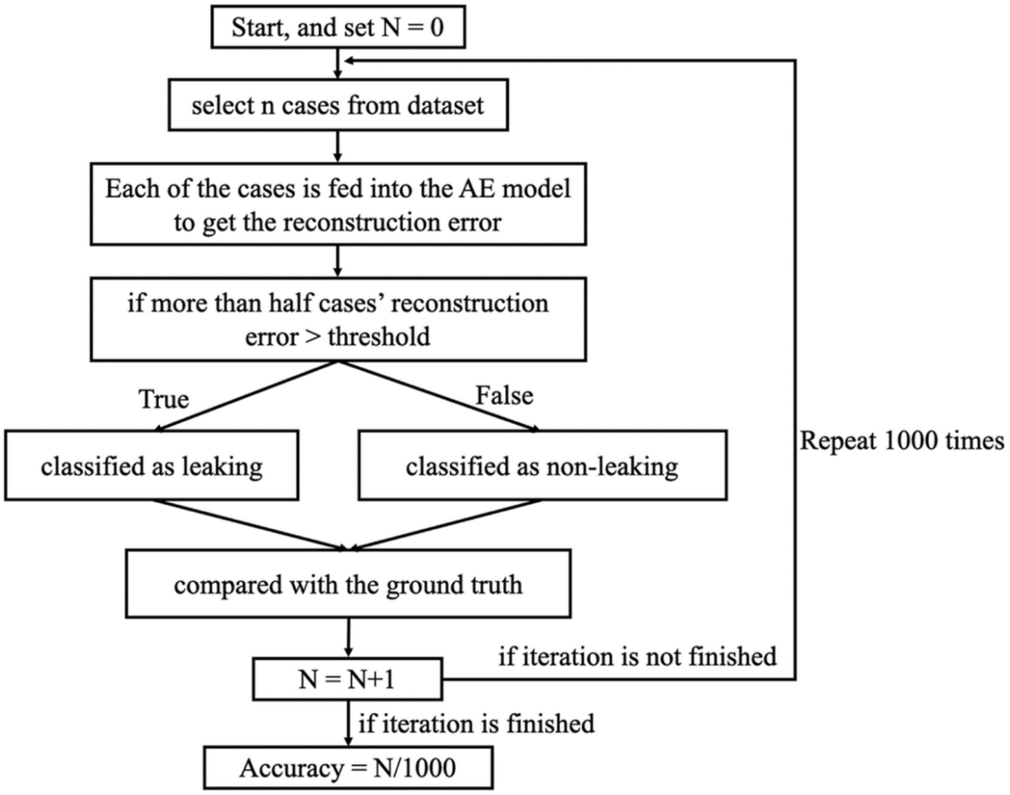

Fig. 2. Data generation process

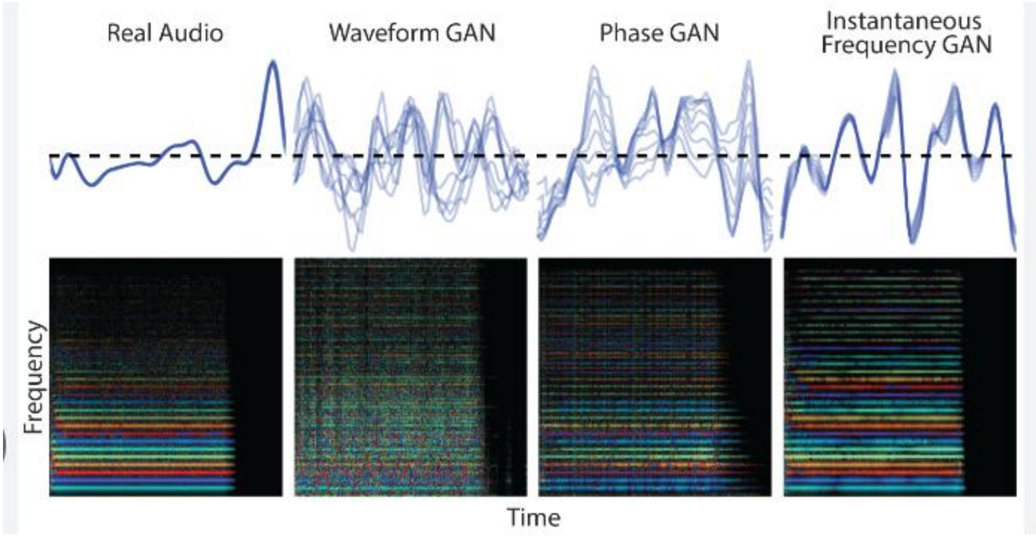

Fig. 3. Data generation using GAN

We also utilized the capabilities of GAN to generate data points as shown in Fig. 3.

2. METHODS AND MATERIALS

This research used EPANET [8,9] software for water leakage simulations and analysis at different level. Synthetic data is generated as mentioned in previous section. Different machine learning algorithms and deep learning algorithms are used on the top of dataset. Next section describes the details of machine learning algorithms and deep learning algorithms.

3. RESULTS AND DISCUSSION

3.1 Use of Artificial Intelligence Techniques for Water Leakage Detection

Artificial intelligence involves various techniques and models to absorb data and draw inference. Artificial neural network [10-15] are very much popular that involves data feature processing and mapping weights according to the same. Thresholding is used at the end to define classes. Following equations are used to utilize the data points mapping. Feature selection is also important, and we used optimization methods for the same.

$$P = \frac{1}{1+e^{-(a+bX)}}$$

$$\begin{aligned} Q(\mathrm{PC}_{(j)}, \mathrm{PC}_{(k)}) &\propto (\mathbf{X}\mathbf{w}_{(j)})^\mathsf{T}(\mathbf{X}\mathbf{w}_{(k)}) \\ &= \mathbf{w}_{(j)}^\mathsf{T}\mathbf{X}^\mathsf{T}\mathbf{X}\mathbf{w}_{(k)} \\ &= \mathbf{w}_{(j)}^\mathsf{T}\lambda_{(k)}\mathbf{w}_{(k)} \\ &= \lambda_{(k)}\mathbf{w}_{(j)}^\mathsf{T}\mathbf{w}_{(k)} \end{aligned}$$

The decision tree is another basic method that is being used in our process for initial method and comparative analysis. Following equation is being used to analyse the inputs.

$$Gini = 1 - \sum_{i=1}^{C} (p_i)^2$$

Ultrasonic sensors are commonly used in applications where non-contact detection is required, or when the object being detected is in motion or difficult to access. They are primarily used in various industries for tasks such as distance measurement, object detection, level sensing in tanks or containers, and liquid flow monitoring.

It's important to note that the performance of ultrasonic sensors can be affected by factors such as temperature, humidity, and the presence of obstacles or other reflective surfaces. Careful consideration of these factors and appropriate calibration of the sensor are necessary for accurate water detection using ultrasonic sensors.

Fig. 4 shows the process where our architecture is defined. We use different sites and sensors are installed. The purpose of sensor is to take acoustic data and analyse the features out of it. Data from multiple sites are sent to server where decision making can be done. AI algorithms are installed at server to decide the water leakage pattern.

Autoencoder architecture [16] is used with Neural network at the aggregation node to determine the results. Autoencoder network is merged with UNET and we are calling it AE-DL model. Autoencoder Architecture is as follows IN Fig. 5.

Location coordinates and segmentation is also critical part so in order to manage this situation, we are using U-NET [17] for image segmentation for our use case.

We used various metric like accuracy, precision, recall and sensitivity at the end of pipeline. This process produced 98% accuracy.

$$\text{Accuracy} = \frac{(\text{TP} + \text{TN})}{(\text{TP} + \text{FP} + \text{TN} + \text{FN})}$$

$$\text{Precision} = \frac{TP}{TP+FP}$$

$$\text{Recall} = \frac{TP}{TP+FN}$$

$$\textbf{Sensitivity} = \frac{\textbf{True Positives}}{\textbf{True Positives} + \textbf{False Negatives}}$$

$$\textbf{Specificity} = \frac{\textbf{True Negatives}}{\textbf{True Negatives} + \textbf{False Positives}}$$

$$\begin{aligned} \text{F1 Score} &= \frac{2}{\frac{1}{\text{Precision}} + \frac{1}{\text{Recall}}} \\ &= \frac{2 \times \text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}} \end{aligned}$$

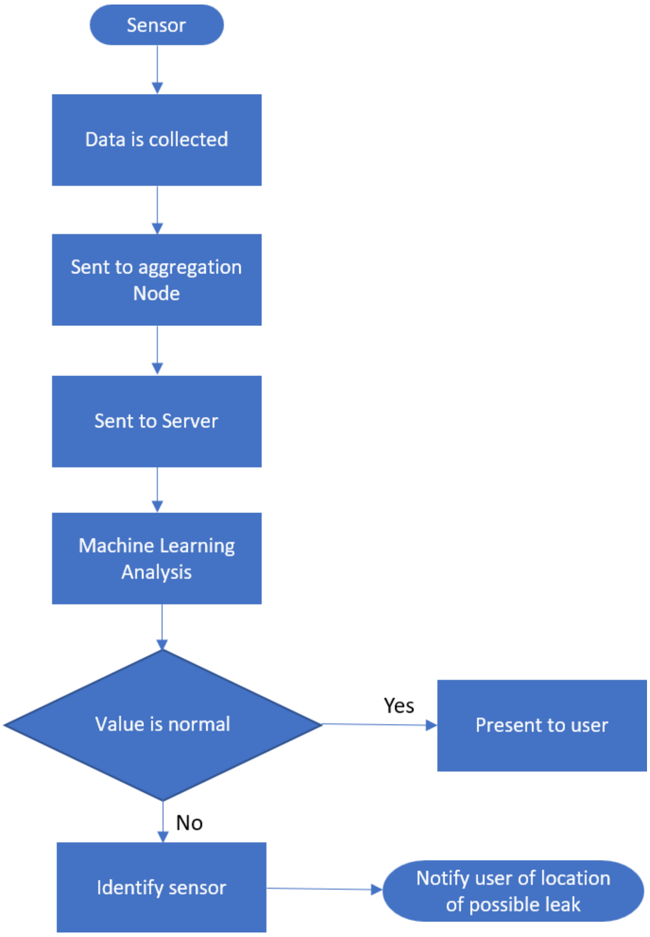

Fig. 4. Generation of monitoring dataset in the water supply network

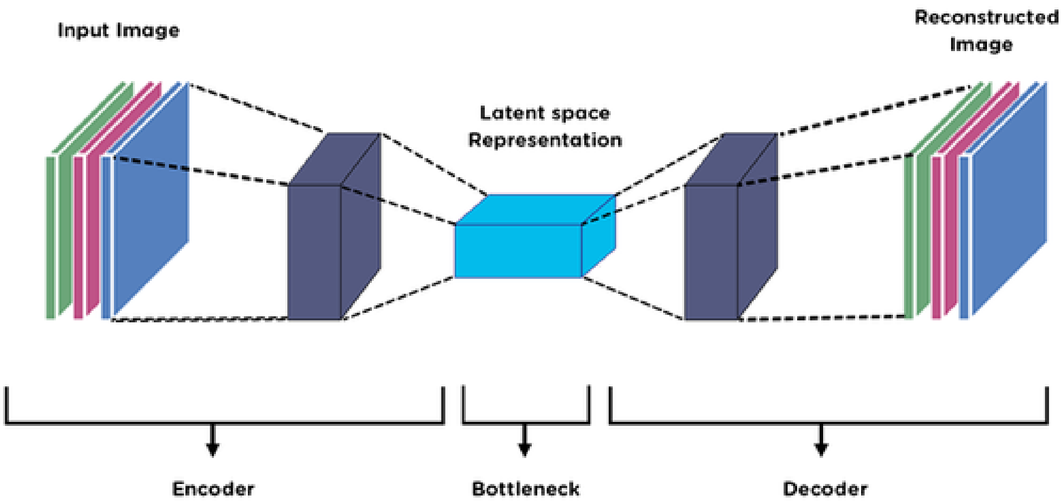

Fig. 5. Autoencoder Architecture

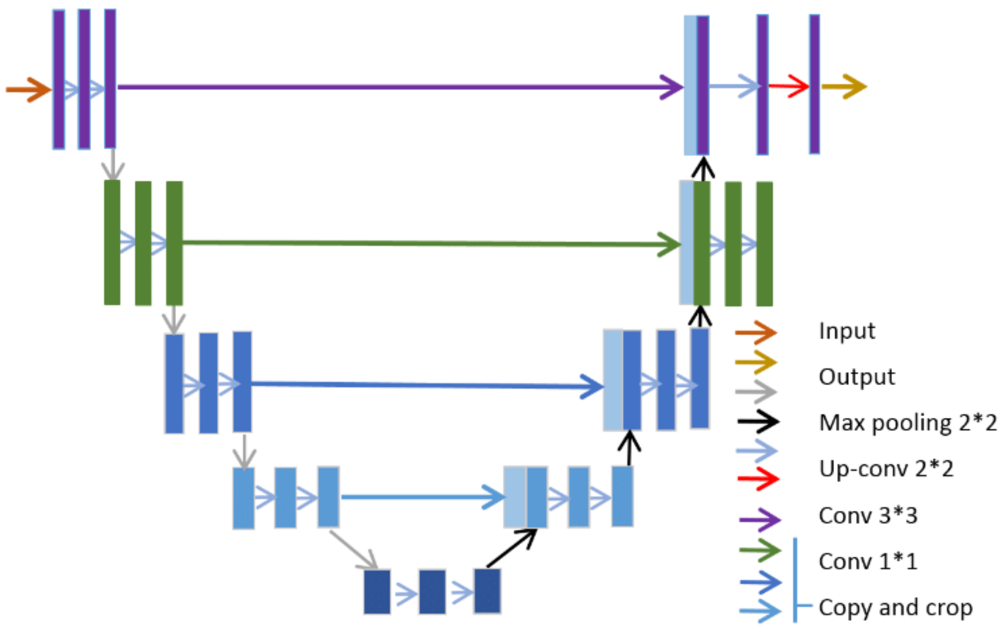

Fig. 6. U-NET architecture

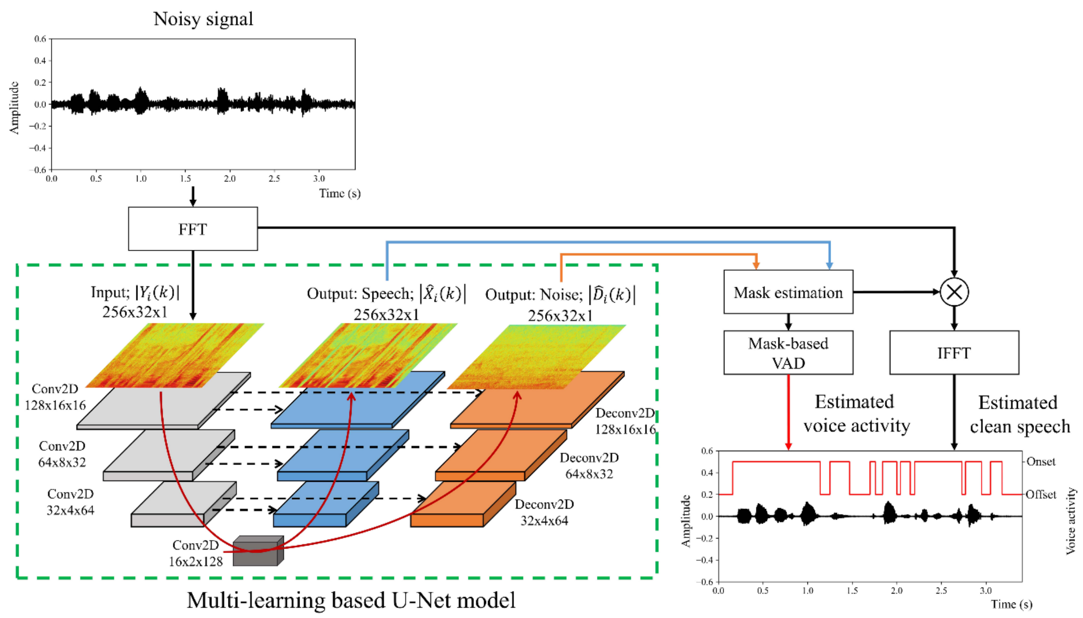

Fig. 7. UNET for voice analysis [18]

4. CONCLUSIONS

This paper showed the process of water leakage detection and localization using deep learning method. We did data collection using deep learning based synthetic data generation and then public domain data sources are also used. We used multiple deep learning and machine learning method to develop models on the top of collected data. We found that AE-DL method is outperformed. This method is the combination of Autoencoder and UNET method. Water leakage classification and localization is done here. We are further enhancing data quality and modelling. This research will be helpful for those who are working in water conservation and artificial intelligence areas.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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