Current practice of early leak detection methods for underground storage tanks

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Abstract. This article aims to provide general review on current practice of leak detection methods of underground storage tanks (UST). Fuel (i.e. gasoline and diesel oil) leakage from UST can contaminate groundwater and drinking water with various hydrocarbon contaminants. These leaks create ponds of fuel that spill into the land and aquifers, polluting and seriously destroying habitats. Numerous efforts have been focused on the development of leak detection to the tanks. However, without the opportunity to conduct fault intensity calibration and estimate a product's lifetime, there is a lack of information provided to consider the condition of previous underlying leakage. As a result, it is too late whether the harm has already been done. There are methods of detection that have been studied for the past ten years. Many approaches have been practised to detect leakage. Specific sensing devices will combine with additional applications that analyse and interpret the data to detect storage tank leaks. Various methods will provide different results depending on the feature chosen. Some approaches will use machine learning to analyse the provided data and provide the best leak detection result. This paper will explore the best leak detection techniques to improve underground tanks' structural integrity. At the end, this paper will give some overview on current practice early detection methods on underground storage tanks for future research.

1. Introduction

Leakage and spills from underground or aboveground storage tanks especially those storing hazardous fluids like petroleum, can impose risk to the environment [1-3], contaminate the soil and groundwater [4], and also cause health problems and catastrophic damage to humans [5]. Leakage is one of the most serious problem for the government and environmental agencies in monitoring and cleaning up polluted soil and groundwater [1, 6].

Leakage behaviour varies according to manufacture quality, installation handling, operational extremes, monitoring and inspection level, and the effects of wear over time [7]. Wilson, Zhang [8] stated that in March 2010, about 83 % of the total 590,000 active USTs confirmed leaks in 212,000 locations throughout the United States. These leaking underground storage tanks (LUSTs) affected almost half of the U.S. population and 99 percent of rural U.S. communities that depend on groundwater as their primary supply of drinking water [6, 8].

As evidenced by numerous publications, reported cases of groundwater contamination are both a global and local issue [9]. The main reason for the ground contamination is the leaking of underground storage tanks at petrol stations [10], and the challenge is when the leak is difficult to see from aboveground. This problem requires urgent attention since most service stations have been in operation for more than 25 years and must be monitored and remedied. Not only contamination but leakage can also lead to serious accidents.

Based on statistics in China from year 2013 to 2018, there were about 974 accident cases involving the petrochemical industry, including UST at petrol stations [11]. However, accidents cases at petrol stations in Malaysia are quite low in number. Monitoring and remediation actions must be considered for the early stage of leakage detection [5, 12]. There are many improvements in monitoring techniques from previous research. Sheng, Ngui [13] reported that, the percentage of action improvement on USTs, about 55 % used leakage detection technique followed by storage improvement 32 %, remediation 9 %, and prevention 4 %. Most of the research focused more on leaking detection rather than remediation. This was because the effectiveness of the remedy is still in question [13]. Often, the leak has not discovered until irreparable environmental harm has occurred. It also explains why so much effort has been expended over the many years to minimise the negative impact of buried fuel storage systems. In this respect, having an automated system capable of detecting leaks as soon as feasible is a major advancement in environmental safety [14]. Hence, the purpose of this paper is to present the general review of current practice of early leak detection methods for underground storage tanks nowadays.

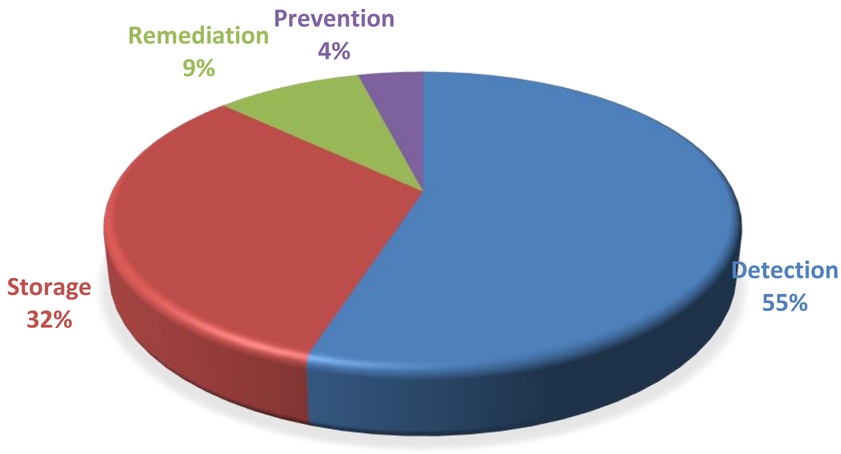

Figure 1. Percentage Improvement on UST Monitoring [13].

1.1. Underground Storage Tanks

Since the discovery of oil in 1859, storing volatile liquids has developed considerably, beginning with wooden barrels, and ultimately being superseded by welded steel storage tanks. In the first quarter of the twentieth century, the United States established codes to govern flammable liquids and guidelines for performance testing and design. Storage tanks were built underground for protection, comfort, and aesthetics as motorised cars became the most prevalent mode of transportation [15]. UST is a tank and any underground piping attached to it that has at least 10 % of its total volume underground [16]. It is commonly used for large oil resource storage, refuelling, and waste containment. The complex cylindrical-shaped tanks, generally located underneath gas stations, laundry outlets, and local homes, are invariably exposed to pollution, decay, and degradation during operating hours [13]. In the late

1970s, a robust environmental interest improved the technology used to store volatile liquids underground safely until today. Figure 2 below illustrates the general UST at the petrol filling station.

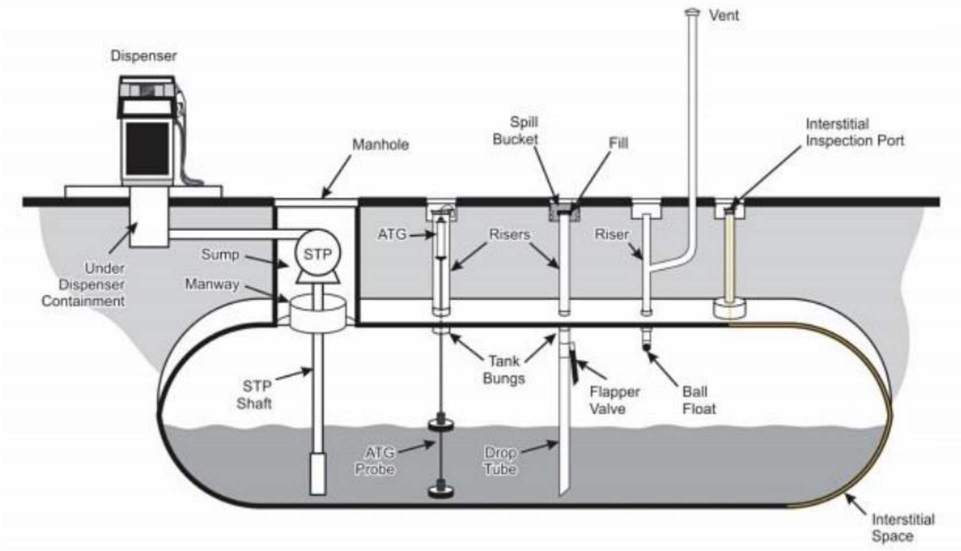

Figure 2. Overview on UST at Petrol Filling Station [13].

1.2. Groundwater as a Natural Resource

When rainwater falls and seeps deep into the soil, covering the cracks, crevices, and porous spaces of an aquifer (basically an underwater reservoir of water), it becomes groundwater, one of the least recognisable but most significant and important natural resources, especially in arid regions where rainfall is minimal and the surface water resources are scarce [17]. It is an essential part of the global water supply scheme, and humans have used it since ancient times. Groundwater may be less expensive than filtered surface water. Aside from the benefit of low turbidity, it also provides valuable nutrients to a person's health. Malaysia is a tropical country with lots of water on the surface. Most Malaysian states use surface water to satisfy different water demands. Groundwater has become a critical source of water supply due to global weather trends, rising demand, and extreme contamination of surface water. Figure 3 shows that groundwater is used to satisfy a variety of demands. The convergence of surface water and groundwater use is needed to ensure the long-term use of water supplies [18].

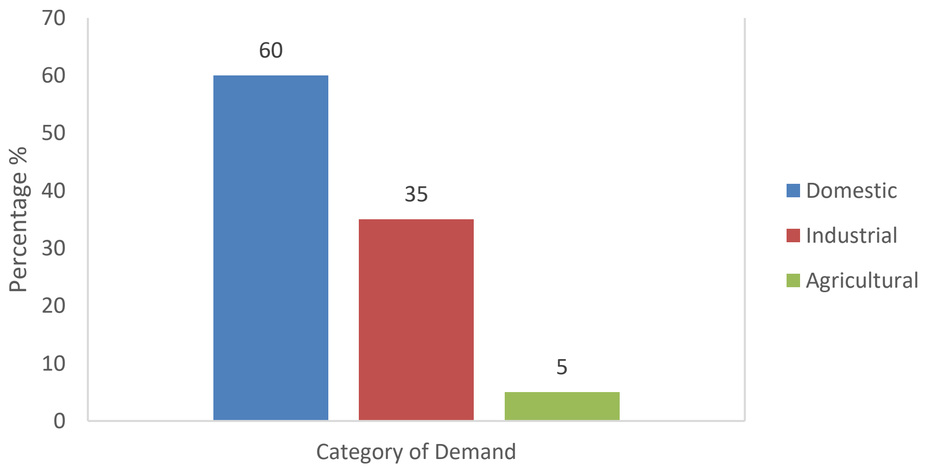

Figure 3. Various Demands for Exploited Groundwater in Peninsular Malaysia [18].

1.3. Leaking of Underground Storage Tanks

According to Sanneh [19], the majority of surface and groundwater contamination is caused by leaks from storage tanks (both underground and aboveground); the statement was also supported by others [1, 2, 12, 14]. Underground leaks are one of the most critical issues in gas stations with underground storage tanks (USTs). These leaks created ponds of fuel that spilled into the land and aquifers, polluting and seriously destroying habitats [12]. Leakage of fuel from USTs can contaminate groundwater and drinking water with a variety of hydrocarbon toxins, threatening human health and the environment [20]. Cracks, rust, valve breakdown, and inadequate maintenance are all factors that can cause leaking to the USTs [8, 21].

1.3.1 Impact of leaking UST. Petroleum contains substances that have a negative impact on human health and the development of plant growth. Solvents such as benzene, toluene, and xylene, as well as additives and organic lead compounds, are used in petroleum products [19]. More than 150 chemicals can be found in gasoline. Nonetheless, all of these compounds have unexplained or doubtful health consequences [22]. According to Clark [23], tertiary butyl alcohol (TBA) is a fuel oxygenate that is used to substitute tetra-ethyl lead as an anti-knock agent in gasoline alone or combination with methanol as a co-solvent. Limited amount of oxygenates added to gasoline will substitute a large amount of octane. Leaking UST sites are the most likely source of TBA pollution of groundwater and, possibly, drinking water sources [24]. Based on animal studies, McGregor [25] reported thyroid, kidney, and neurodevelopmental symptoms resulting from chronic oral exposure to TBA and decreased fetal viability and increased skeletal variations. Renal tumours in male rats and thyroid tumours in female mice have been linked to human carcinogenesis.

The release of petroleum hydrocarbon into the environment will cause public health and safety repercussions by contaminating drinking water, diminishing air and water quality, destroying habitats and food, and wasting non-renewable resources. It takes several years to recover once the soil is contaminated [10].

2. Leak Detection Techniques

Nowadays, various methods are used to identify generic gasoline leaks [12]. These methods can be classified into three categories such as internal, interstitial, and external methods. Internal technique is a method for monitoring product levels and inventory management that employs automated operations. A monitor is coupled to a probe permanently mounted in the tank, which provides information on product level and temperature. Automatic tank gauging systems, statistical inventory reconciliation, and continuous in-tank leak detection are examples of internal methods. The methods that detect leaks between the second barrier and UST is called interstitial methods, whereas external methods will include monitoring the groundwater and vapour [1]. For the effective remediation of soil and groundwater, monitoring techniques of underground storage tanks is an important issue. Various oil release detection methods have been studied, and regulations governing the installation and maintenance of a UST device have been developed by the United States Environmental Protection Agency [26].

Time-domain reflectometry (TDR) is one of the external detection methods used for monitoring physical properties in the unsaturated zone. However, there are only a few devices for detecting petroleum oil in soil that have been created. Through upgrading the traditional method of TDR, the hydraulic control system is added to the process [1]. The results show a sharp increase in detection of oil compared to TDR alone. Even though the result shows a positive output, this method can only be used after the leaking happened. This means, the soil must have been contaminated before the research begins.

According to Sacile [3], monitoring of UST systems are usually performed by taking the following approaches:

i. Electronic monitoring of the tank annular (interstitial) space or secondary containment vault on a continuous basis.
ii. An automatic tank gauging system is utilised to monitor a single-wall tank on a daily/nightly, weekly, and monthly basis.
iii. Manual Inventory Reconciliation (MIR) is done by using a book-keeping accounting system.
iv. Statistical Inventory Reconciliation (SIR) methods employ sophisticated statistical software to conduct computerised analysis. It can find leaks significantly smaller than the MIR method.
v. Tank tightness testing conducted annually or monthly.

Real-time monitoring and control of contamination by using soil venting systems is another approach of leak detection methods. This method includes five main modules to make up the system. First, the on-site technology setting uses sensors and programmable logic controller (PLC) to control the UST, communication software, Web interface, real-time database, and diagnostic module [3]. Based on the method, the system can positively detect the leakage and start to remediate it by the venting process. Even though the technique demonstrates the capacity to respond to small/medium leaks in everyday work, it is characterised as an expensive way. This is because the method will consume energy even less than 1kW.

Risk-Based Assessment (RBA) and Structure Health Monitoring (SHM) are also some of the leakage detection methods. Firstly, the process of RBA is to collect all the primary and secondary data from the service station. SHM systems, in general, are used to monitor the physical status of critical structural elements, as well as structural integrity, and typically consist of multiple sensors placed at this location [27]. The Long-Range Ultra Thickness (LRUTG) sensor is one of Non-Destructive Evaluation (NDE) equipment. LRUTG is used to capture the thickness of the wall of UST, the parameter including temperature, material, stress and strain, and detect the level of pressure of the material. Based on the results gained from this method, it is more inclined towards predicting the magnitude and severity of fire risk, not for detecting the leak of USTs. But the steps can be used to detect the leakage in future. Table 1 below shows the summary of detection techniques for UST's leakage. Based on the summary of detection techniques (Table 1), the author describes and discussed the previous paper and list the weakness of the paper's method.

Detecting generic fuel leakage is an issue that is being addressed in a variety of ways these days. One of the approaches involved implementing some sensing device to detect fuel leakage [28]. There is an alternative approach of leakage detection by applying pattern classification techniques to the early detection of fuel leaks in petrol stations. By the combination of inventory reconciliation with pattern classification theory, the results presented comply with the expectations. Based on the findings, the author believed there exist several aspects to improve [12].

Many previous studies conducted in-depth studies using quantitative or qualitative approaches widely debated in their respective research methods. However, engineering often looks for concise answers by using digits or numbers. As Holden and Lynch [29] said, conducting research is about the philosophy behind the study. In this paper, as discussed in Sigut, Alayón [12], the effective method was adopted to be discussed further. It provides a collection of two-class classifiers and a set of features that adequately represent the objects to be classified in their paper. These objects are the days when the fuel station is open, which are divided into two categories: "day without leak" and "day with leak".

Table 1. Summary of early leak detection techniques.

Method categories	Method	Tools/ instruments	Capability/ level of accuracy	Critical review	Author (year)
Internal method	Two possible categories: "day without leaks" and "day with leaks". With proper variables selection and applied to classifier.	-Classsifier: supervised and unsupervised - Manual Inventory Reconciliation (MIR)	Achieved EPA less than 5% error; the method can detect leak at the rate of more than 80 L/day.	Combined classifier tools and the rightly selected features group deliver consistent readings when the leak rate is more than 96 L/day. Limitation: this method will get higher error when the leak rate is lower than 80 L/day.	Sigut, et al., 2014
External method	Detect leaking in sandy soil by time domain reflectometry (TDR) and increase sensitivity by hydraulic control system.	-Hydraulic control systems - Time-domain reflectometry (TDR)	Increase the sensitivity of detecting oil release in unsaturated soils.	Limitation: the method of TDR has limited number of devices for petroleum oil. This method will cost more on remediation if leaking is detected.	Lee, Kwon, et al., 2019
Internal method	By using Risk Based Assessment (RBA) and SHM to detect the leakage of storage	-RBA -Long Range Ultra Thickness (LRUTG)	Can predict the magnitude and severity of risk.	Limitation: the method is only used for predicting the risk; not for leaking release. But LRUTG is good to be used for detecting the thickness, material, temperature, level of pressure of the storage.	Mohd Shamsuri Khalid, et al., 2017
Internal method	Using real-time monitoring to diagnose the leakage and remediate with specific venting process.	-Programmable logic controller (PLC) -Communication software -Web client -Real time database	Can diagnose small medium leakage in daily work.	Limitation: the system can only diagnose for leakage, but not the quantity of leakage. The system can only detect the leakage for 3 years.	Sacile, 2007.

For the leak detection to work correctly, the leak detection system must distinguish between changes in the inventory record caused by leakage and those produced by other causes such as evaporation, volume change due to temperature, and other reasons mentioned by Gorawski, Skrzewski [30]. The paper study used a pattern recognition method to distinguish between these two scenarios. For certain combinations of classifiers and feature sets, the study produced acceptable classification results for constant and variable leaks. To determine whether a classification result was satisfactory, they used the European EN 13160 set of standards [31] which defines a maximum time for identifying the leak with error less than a specific threshold.

Internal technique is a reliable method for monitoring product levels and inventory management that employs automated operations. The next section 2.1 to 2.3 will be discussing the steps of internal technique which include the inventories reconciliation method and the most relevant features selection aspects concerning the use of classification algorithms.

2.1. The inventory reconciliation method

In most cases, regular inventory logs are used in gas stations. These documents have inventory monitoring of the amounts sold, ordered, and stored in each tank, much as it does for any other commodity. These documents can be stored physically or electronically. Basic concepts in inventory reconciliation are applied as the following:

- Theoretical inventory (Ti): the amount of gasoline that should be in the tank at the ending of the day or shift It may be calculated using the following expression:

$$Ti = Initial\ inventory + Receipts - sales + Adj \tag{1}$$

Where:

Initial inventory: inventory at the start of the day or shift.
Receipts: delivery made to the service station by tanker-truck on the current day.
Sales: total amount sold at the service station's petrol pumps.
Adj: correction due to certain maintenance operations.

- Difference in inventory or variation defined as follows:

$$Var = Ti - Actual\ inventory \tag{2}$$

- Accumulated difference in inventory or accumulated variation: sum of the variations over a period time.

- Sales variation defined as below:

$$Variance = Var/Sales \tag{3}$$

- *Accumulated variance*

$$Accumulated\ variance = Accumulated\ Var/Accumulated\ Sales \tag{4}$$

By comparing the theoretical and actual inventory, this technique is utilised to identify abnormal service station functioning. The EN 13160 family of standards provides a limited time for recognising leaks with an error below a certain threshold. According to Sigut, Alayón [12], UNE [31], when considered appropriately for routine inspection, the device must be capable of detecting leaks of up to 96 L/day with an error (both in false positives and false negatives) of less than 5 %. The extract of daily inventory records is shown in Table 2. This is the actual petrol station data without leak provided by Repsol [12].

Table 2. Daily inventory records for a service station [12].

Tank: fuel	Date	Initial	(+) Receipts	(-) Sales	(+/-) Adjustments	(=) Theoretical inventory available	Current available
1: Diesel							
	22/1/07	21,214.00	0.00	0.00	0.00	21,214.00	21,214.00
	23/1/07	21,214.00	16,998.00	8,553.13	0.00	29,658.87	29,564.00
	24/1/07	29,564.00	10,002.00	12,119.26	0.00	27,446.74	27,448.00
	25/1/07	27,448.00	12,000.00	9,355.93	0.00	30,092.07	30,117.00
	26/1/07	30,117.00	0.00	10,810.98	0.00	19,306.02	19,269.00
	27/1/07	19,269.00	17,000.00	7,038.59	0.00	29,230.41	29,258.00
	28/1/07	29,258.00	0.00	1,589,27	0.00	27,668.73	27,217.00
	29/1/07	27,217.00	17,004.00	13,137.14	0.00	31,083.86	31,127.00
	30/1/07	31,127.00	9,984.00	11,523.93	20.00	29,607.07	29,379.00
	31/1/07	29,379.00	0.00	13,823.09	0.00	15,555.91	15,204.00
Subtotal		265,807.00	82,988.00	87,951.32	20.00	260,863.68	259,797.00

2: Diesel e+10							
	22/1/07	9,700.00	0.00	0.00	0.00	9,700.00	9,700.00
	23/1/07	9,700.00	4,999.00	298.21	0.00	14,400.79	14,504.00
	24/1/07	14,504.00	0.00	610.53	0.00	13,893.47	13,932.00
	25/1/07	13,932.00	0.00	750.13	0.00	13,181.87	13,164.00
	26/1/07	13,164.00	0.00	612.04	0.00	12,551.96	12,532.00
	27/1/07	12,532.00	0.00	872.07	0.00	11,659.93	11,619.00
	28/1/07	11,619.00	0.00	405.71	0.00	11,213.29	11,158.00
	29/1/07	11,158.00	5,004.00	686.24	0.00	15,475.76	15,537.00
	30/1/07	15,537.00	0.00	595.37	20.00	14,961.63	14,977.00
	31/1/07	14,977.00	0.00	921.00	0.00	14,056.00	14,106.00
Subtotal		126,823.00	10,003.00	5,751.30	20.00	131,094.70	131,229.00

2.2. Detection of Petrol Leaks

The author uses a general classification problem to achieve the main goal of the research, which is to demonstrate the classification methods for detecting petrol leaks. The classification problem consists of N objects and M classes. Where N is classified as days, whereas M is defined as possible classes, “day with leaks” and “day without leaks”. The classifier systems will then assign each object to a certain class after analysing. The process is shown in Figure 4.

Figure 4. Classification process [12].

2.3. Features Selection

Feature collection is a critical step in the classification process. A good feature selection will greatly increase the classifier's performance. In these steps, certain features used are to be selected. The features that the author selected are as follows:

- Feature group 1 (FG1) – one feature: Var
- Feature group 2 (FG2) – one feature: sales variation
- Feature group 3 (FG3) – one feature: Ti
- Feature group 4 (FG4) – one feature: Var/actual volume
- Feature group 5 (FG5) – two features: daily sales and Var
- Feature group 6 (FG6) – two features: daily sales and sales variation

After grouping the features, the author applied four well-known classifiers to solve the fuel leak detection problem. Classification is predetermined using supervised algorithms. These classifications may be assigned to a specific section of data (training set). The role of the classifier is to look for patterns and build mathematical models by analysing data from the training set. Two different supervised methods are used to evaluate the new labelled after the training step is finished. Linear Discriminant Analysis (LDA) and K-Nearest Neighbour algorithm (K-NN) consist as follows:

- In any given set of data, LDA maximises the ratio of between-class variance to within-class variance, ensuring maximum separability.
- K-NN is a well-known method for classifying objects based on the closest training.

Unsupervised classifiers are not given labelled data. These algorithms look for similarities between pieces of unlabelled data to see whether they can be classified as part of a category (cluster). K-means and Fuzzy c-means (FCM) are two different unsupervised methods that were used and described as follows:

- K-means is an algorithm for clustering, demonstrated by Kanungo, Mount [32].

- FCM is a fuzzy clustering system that requires objects to belong to more than one cluster, with each object having a unique set of membership levels. As demonstrated in Bezdek [33].

The detection of petrol leaks is presented in Figure 5, where the input is an operating day (represented with feature set), the classifier systems consist of four classifications procedure, and the output is a class label that indicates “day with leaks” or “day without leaks”.

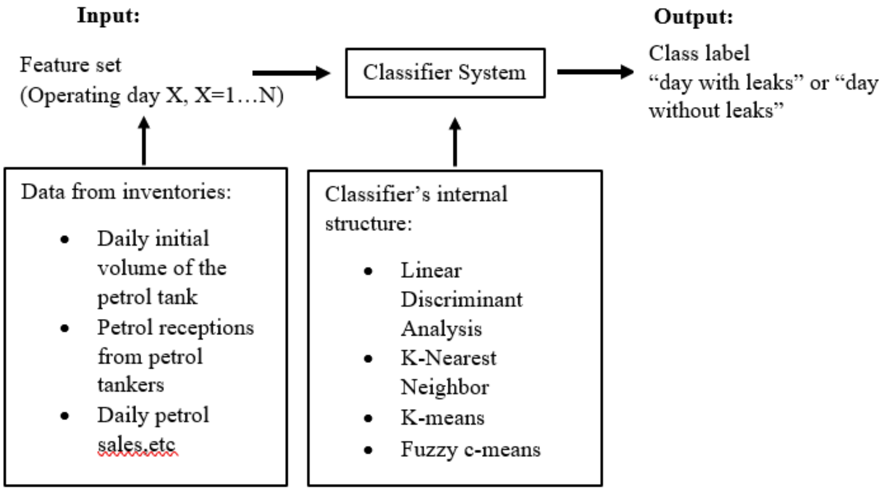

Figure 5. Classification process [12].

By the classification process flow chart (figure 5), the experiments were carried out by two different leaks situation. The tests are split into two groups: experiments with data set 1 (simulating a constant petrol leak) (table 3) and experiments with data set 2 (Simulating a variable petrol leak) (table 4).

Table 3. Results on constant leak (set 1) [12].

FG2	10		20		30		40		50		60		70		80		90		100	
LDA	65	**0**	85	**0**	80	**0**	80	**0**	65	**0**	55	**0**	40	**0**	5	**0**	15	**0**	5	**0**
K-NN	25	**0**	30	**35**	20	**0**	15	**5**	10	**25**	5	**0**	5	**0**	5	**0**	5	**0**	5	**0**
K-means	85	**0**	55	**0**	35	**0**	20	**0**	15	**0**	5	**25**	5	**0**	5	**0**	0	**0**	0	**0**
FCM	55	**0**	55	**0**	30	**0**	15	**0**	15	**0**	5	**0**	5	**0**	0	**0**	0	**0**	0	**0**
FG3	10		20		30		40		50		60		70		80		90		100	
LDA	85	**0**	90	**0**	90	**0**	90	**0**	90	**0**	90	**0**	90	**0**	90	**0**	90	**0**	60	**0**
K-NN	30	**35**	30	**45**	25	**10**	10	**20**	10	**30**	10	**20**	10	**20**	10	**20**	10	**15**	10	**20**
K-means	90	**25**	35	**25**	10	**25**	5	**25**	5	**25**	0	**25**	0	**25**	0	**25**	0	**25**	0	**25**
FCM	45	**25**	35	**25**	10	**30**	5	**30**	5	**30**	0	**30**	0	**30**	0	**30**	0	**30**	0	**30**
FG4	10		20		30		40		50		60		70		80		90		100	
LDA	75	**0**	80	**0**	80	**0**	85	**0**	90	**0**	95	**0**	100	**100**	95	**0**	40	**100**	100	**100**
K-NN	30	**15**	25	**20**	15	**10**	5	**15**	5	**10**	10	**10**	5	**0**	5	**0**	0	**5**	5	**5**
K-means	85	**0**	55	**0**	30	**0**	10	**0**	10	**0**	5	**0**	5	**0**	5	**0**	5	**0**	5	**0**
FCM	55	**0**	45	**0**	10	**0**	10	**0**	5	**0**	5	**0**	5	**0**	5	**0**	5	**0**	5	**0**
FG6	10		20		30		40		50		60		70		80		90		100	
LDA	45	**0**	30	**0**	25	**0**	20	**0**	20	**0**	10	**0**	10	**0**	5	**0**	5	**0**	5	**0**
K-NN	35	**65**	35	**65**	35	**65**	35	**65**	35	**65**	35	**65**	35	**65**	35	**65**	35	**65**	35	**65**
K-means	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**
FCM	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**

Based on the data set 1, constant leak (table 3), the error percentages for a day without leaks (on the left) and error percentages for a day with leaks (on the right with bold) are shown in the data set. In set 1, the feature groups that selected in this experiment is all consist of constant values, except two feature group, feature groups 1 (FG1) and feature groups 5 (FG5) because both use the variable "variation" which is not constant.

Table 4. Results on variable petrol leak (set 2) [12].

FG1	0.2		0.3		0.4		0.5		0.6		0.7		0.8		0.9		1.0		1.1	
LDA	65	**0**	65	**0**	60	**0**	55	**0**	55	**0**	50	**0**	45	**0**	30	**0**	30	**0**	25	**0**
K-NN	30	**20**	15	**0**	10	**5**	10	**0**	10	**0**	15	**5**	10	**5**	10	**0**	5	**0**	5	**0**
K-means	50	**0**	30	**0**	15	**5**	15	**5**	5	**5**	5	**5**	5	**5**	5	**5**	5	**5**	5	**5**
FCM	55	**0**	25	**0**	15	**5**	15	**5**	5	**5**	5	**5**	5	**5**	5	**5**	5	**5**	5	**5**
FG2	0.2		0.3		0.4		0.5		0.6		0.7		0.8		0.9		1.0		1.1	
LDA	85	**0**	85	**0**	85	**0**	85	**0**	85	**0**	85	**0**	80	**0**	50	**0**	25	**0**	5	**0**
K-NN	40	**20**	30	**15**	20	**25**	20	**0**	20	**5**	15	**0**	15	**0**	15	**0**	15	**0**	15	**0**
K-means	55	**0**	15	**30**	5	**35**	5	**35**	0	**55**	0	**40**	0	**30**	0	**40**	0	**40**	0	**30**
FCM	35	**15**	20	**20**	15	**20**	5	**25**	5	**25**	0	**30**	0	**30**	0	**30**	0	**30**	0	**25**
FG3	0.2		0.3		0.4		0.5		0.6		0.7		0.8		0.9		1.0		1.1	
LDA	95	**0**	95	**0**	95	**0**	95	**0**	95	**0**	90	**0**	90	**0**	80	**0**	40	**5**	5	**20**
K-NN	50	**20**	50	**40**	35	**25**	20	**25**	15	**20**	10	**20**	15	**20**	25	**20**	25	**20**	10	**20**
K-means	30	**30**	5	**45**	0	**50**	0	**50**	0	**20**	0	**50**	0	**50**	0	**40**	0	**40**	0	**50**
FCM	30	**30**	5	**40**	0	**45**	0	**45**	0	**45**	0	**45**	0	**45**	0	**45**	0	**40**	0	**40**
FG4	0.2		0.3		0.4		0.5		0.6		0.7		0.8		0.9		1.0		1.1	
LDA	50	**0**	50	**0**	45	**0**	45	**0**	50	**0**	65	**0**	85	**50**	0	**100**	0	**100**	95	**0**
K-NN	25	**20**	15	**20**	15	**20**	5	**15**	5	**5**	0	**10**	0	**10**	5	**0**	5	**0**	5	**0**
K-means	55	**0**	30	**0**	10	**5**	5	**5**	5	**5**	5	**5**	5	**5**	5	**5**	5	**5**	5	**5**
FCM	30	**10**	20	**5**	10	**5**	5	**10**	5	**5**	5	**5**	5	**5**	5	**5**	5	**10**	0	**10**
FG5	0.2		0.3		0.4		0.5		0.6		0.7		0.8		0.9		1.0		1.1	
LDA	60	**0**	55	**0**	55	**0**	50	**0**	50	**0**	45	**0**	40	**0**	35	**0**	25	**0**	25	**0**
K-NN	30	**45**	25	**40**	25	**40**	35	**50**	25	**40**	15	**35**	15	**40**	15	**40**	15	**35**	15	**35**
K-means	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**
FCM	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**	45	**50**

Table 4 present the results data on variable petrol leaks for experiment 2. In the set of data, the error percentages of day without leaks (on the left) and error percentages for day with leaks (on right with bold) are shown. FG1, FG2, FG3, FG4, and FG5 are selected in the experiment. FG6 is not selected because it provides similar information that contained in the FG1, FG2 and FG5.

3. Discussion

According to Environment Protection Agency (EPA), the system of daily inspection is considered acceptable with 5 % error and leakage detection up to 96 L/day. In fact, Sigut, Alayón [12] focused on the daily inspection in order to detect leakage, however, it is incapable of detecting the minimal quantity of leaking tanks. The following will discuss on the findings of the best classifier and features used.

3.1. Experiment 1: Simulation of constant leaks

In this section, the error was studied separately: false positive (day without leaks) and false negative (day with leaks). The feature groups used in Experiment 1 is FG2, FG3, FG4 and FG6. Table 5 shows the classification error for the first 10 subsets. The error days without leaks is in the left cells, while day with leaks is in the right cells with the number in red bold.

Table 5. Optimum Results for constant leaks (Experiment 1) [12].

FG4	10		20		30		40		50		60		70		80		90		100	
LDA	75	**0**	80	**0**	80	**0**	85	**0**	90	**0**	95	**0**	100	**100**	95	**0**	40	**100**	100	**100**
K-NN	30	**15**	25	**20**	15	**10**	5	**15**	5	**10**	10	**10**	5	**0**	5	**0**	0	**5**	5	**5**
K-means	85	**0**	55	**0**	30	**0**	10	**0**	10	**0**	5	**0**	5	**0**	5	**0**	5	**0**	5	**0**
FCM	55	**0**	45	**0**	10	**0**	10	**0**	5	**0**	5	**0**	5	**0**	5	**0**	5	**0**	5	**0**

Based on the optimum results of constant leaks, shows that feature group 4 (FG4), except for LDA, the other three classifiers perform well with errors of 0 – 15 % with leak rates from 40 L/day and above.

The combination of FG4 with K-NN, K-means or FCM provided the best results that are fully compliant with the rules contained in the UNE-EN 131601-5 Standard.

3.2. Experiment 2: Simulation of variable leaks

In Experiment 2, the selected feature groups are FG1, FG2, FG3, FG4, and FG5. Table 6 shows the optimum results of Experiment 2. FG4 is still the best feature to combine with K-NN, K-mean or FCM. LDA algorithm is inefficient.

Table 6. Optimum Results for variable leaks (Experiment 2) [12].

FG4	0.2		0.3		0.4		0.5		0.6		0.7		0.8		0.9		1.0		1.1	
LDA	50	**0**	50	**0**	45	**0**	45	**0**	50	**0**	65	**0**	85	**50**	0	**100**	0	**100**	95	**0**
K-NN	25	**20**	15	**20**	15	**20**	5	**15**	5	**5**	0	**10**	0	**10**	5	**0**	5	**0**	5	**0**
K-means	55	**0**	30	**0**	10	**5**	5	**5**	5	**5**	5	**5**	5	**5**	5	**5**	5	**5**	5	**5**
FCM	30	**10**	20	**5**	10	**5**	5	**10**	5	**5**	5	**5**	5	**5**	5	**5**	5	**10**	0	**10**

These findings suggest that the best combination of FG4 with K-NN, K-means or FCM yields adequate results, which are fully compliant with the rule as in UNE-EN 13160-5 Standard. The author suggests that any of these combinations (K-NN with FG4, K-means with FG4 or FCM with FG4) as a classification solution for new methods of detecting the fuel leakage in service station.

4. Conclusion

This paper presents a current practice of early leak detection methods for leaking underground storage tanks and the impact of leaking USTs to underground water. There are a number of available references shows that monitoring of the leaking UST is one of the techniques to reduce the impact on underground water. Based on the method review, the method is focused on the detection of leaking underground storage tanks by using computer-based software. According to UNE-EN 13160-5 Standard, the system must be able to detect leaks up to 96 L/day with an error lower than 5 %. The method achieved complies with the standard with certain combination of "classifier + feature group".

Unfortunately, the technique used only detects the leaking after it happens with respect to the UST but not the causes of leaking and also the small leaks rate which is difficult to detect. There are many causes of leaking, such as cracks, rust, valve breakdown, and inadequate maintenance, which are all factors that can cause leaking of the UST. In the future, several possible improvements can be studied on the causes of leaking. Also, further development on computer-based software such as machine learning can be explored. Lastly, hope this paper will give some ideas on current practice early detection methods on underground storage tanks for further research.

Acknowledgements

The paper is financially supported by the Universiti Teknologi Malaysia (Malaysia) [grant number: Q.K130000.2456.09G41 and Q.K130000.2456.09G36] and the Ministry of Higher Education Malaysia [grant number: R.K130000.7856.5F248 and R.K130000.7856.5F021], which is gratefully acknowledged.

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