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A Novel Technique for Detecting Underground Water Pipeline Leakage Using the Internet of Things

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Abstract: Water-pipeline leakage is one of the most common problems that depletes water supplies. Countries like Jordan, which are really experiencing a water deficit, are particularly concerned about this issue. The lack of monitoring tools makes the underground water-pipeline leakage a challenge since the pipelines are invisible. Besides, reducing the amount of time needed to precisely detect and locate the leak is another challenge. If not reduced, the aforementioned element has an effect on cost. A small broken water distribution line costs $64,000 per year. In Jordan, water leakage costs $1.7 million. This expense can be significantly decreased using an effective early water leak detection system. In this paper, we proposed an efficient internet of things system for detecting water-pipeline leakage based on a shielded pipeline, a NodeMCU, a soil moisture sensor, and the Firebase database. We created a baseline system, and then we tested and evaluated the proposed system when various types of soil are used. Furthermore, this paper compared several strategies offered for detecting water-pipeline leaking including the proposed system. The results showed that the proposed system reduced the time required for detecting water-pipeline leakage by 70% and the system hardware cost by 83% compared with the earlier work. It was difficult to compare the total cost of the proposed system with the total cost of previous works since the total cost is not calculated in their systems. Besides, in this paper, we proposed an IoT system for securing the underground water pipelines from adversaries.

Keywords: Internet of things, Underground-pipelines leakage detection, Water preservation, Shielded pipeline, Soil moisture sensor, NodeMCU, the Firebase database, Security
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1 Introduction

Water is a vital component of life in our world; it is essential to agriculture, industry, the creation of power, and human health. There are around one billion people without access to clean drinking water in the world. Underground pipelines are frequently used to transport urban water. Pipelines used for water transmission typically lose 20% to 30% of water that is transferred via them [El-Zahab, 19]. Network leakage has been a major issue all over the world, particularly in developing nations with limited water supplies. The study [Hassan, 18] sought to quantify the leakage's scope and constituent parts in Madaba, a Jordanian city. The study's conclusion was that a water leakage loss actually costs 1.7 million USD. The cost of water loss is proportional to the time it takes to notice a leak. The aim of this paper is to reduce the cost of water loss by proposing an efficient IoT system that is able to reduce the time it takes to notice a leak.

In fact, there are various reasons for water pipeline leakage, such as the material quality of which the pipeline is made, the temperature and pressure to which the pipeline is exposed, and human damage. One of the technologies being used to detect water pipeline leakage is the Internet of Things (IoT). The IEEE defines IoT as follows: IoT is a complicated network to which many things are interconnected and automatically configured and adaptive while connected to the Internet through the standard communication protocols [Liu, 16].

The IoT systems might offer many fresh solutions for the water leakage issue with the aid of sensors [Islam, 21]. Data collection is the primary goal of sensors [Moubayed, 21]. A variety of sensors, including soil moisture sensors and water flow sensors, can be employed to gather information about water leaks [Uddin, 19]. Artificial Intelligence (AI) and machine learning are further methods for detecting water leaks [Rojek, 19]. However, the two aforementioned fields are not the focus of this study. The research problem of this paper is how to efficiently reduce the cost and the time required for detecting water pipeline leakage using the IoT in a real-time environment while the pipeline is buried under the ground. The contribution of this paper is as follows:

- A novel IoT system for detecting underground water pipeline leakage.
- Compared with the state of the art, the proposed system outperforms the previous work in terms of cost and speed of detecting water pipeline leakage when various types of soil (e.g. black, yellow and brown (clay soil)) are used.
- A novel IoT system for securing water pipelines from adversaries using vibration and light sensors. If a person attempts to break a water pipeline then our system detects this activity and sends a message to the IoT system's manager as described later in section 7. Besides, our proposed system protects the data sent to the Firebase database using the Advanced Encryption Standard (AES) encryption algorithm.

The rest of this paper is organized as follows: Section 2 describes various techniques for detecting water pipeline leakage. In addition, a comparison of several articles (the state of the art) and the proposed system is held. Section 3 describes the research hypothesis and methodology of the proposed system. Section 4 describes the proposed system. Section 5 describes our experiments. Section 6 describes the evaluation of the proposed system. Section 7 describes security issues and finally, the paper's results and conclusions are described in section 8.

2 Related Work

The operational service of water utilities is severely hampered by water loss from leaking pipelines. Different IoT systems for detecting water leakage have been developed over the past few years because of growing concern over the financial loss and environmental pollution caused by leaking pipes [Adedeji, 17]. The IoT is used to reduce the financial loss caused by water pipeline leakage. The authors in [Che, 21], proposed an IOT system for detecting water leakage using Arduino microcontroller, water flow and water sensors. When water leakage is detected, an SMS message is sent to the user. In [Vijayakumar, 19] [Zhiyuan, 19] [Saravanan, 19] [Sadeghioon, 14] [Arjun, 17], the authors proposed an IoT system for monitoring water pipeline leakage by measuring and comparing water flow rate at both ends of the pipeline. However, the above techniques have the drawback of producing false positive results when flow rate fluctuations are large [Liu, 19]. In [Liu, 19], the authors proposed an intelligent system for detecting water leakage based on wireless sensor networks and machine learning. In [Choi, 17], the authors proposed an IoT system for detecting leakage and location based on vibration sensors. The IoT systems that use vibration or acoustic sensors have some disadvantages, including the high cost of sensors (about $500 for each sensor) and the high sensitivity of these sensors to the non-leak vibration noises. In [Martini, 17], water leakage is detected by monitoring the vibro-acoustic phenomena that is related to the leaking flow. In [Marmarokopos, 18], the authors suggested a technique for spotting leaks in plastic pipes by analyzing the surface vibration of the pipe using an accelerator with a high signal-to-noise ratio. In [Wan, 93], the authors proposed an intelligent IoT system for detecting water pipeline leakage based on the pipeline vibration frequency. The techniques in [Liu, 19] [Choi, 17] [Martini, 17] [Marmarokopos, 18] [Wan, 93] have the disadvantage of the high sensitivity of these sensors to non-leak vibration noises. The authors of [Bhende, 18] suggested an IoT system for detecting water leaks. The temperature, humidity, and moisture sensors were attached to the pipeline bends and joints. In their research, the pipeline was not buried under the ground. The shortcoming of this IoT system is that it can only identify pipeline-junction water leaks. In [Bhende, 18], the authors proposed an IoT system to solve the problem of underground water pipeline leakage. They planted a moisture sensor in the soil, and then they carried out a set of experiments in order to measure the time required for the soil to be saturated with water. After running a set of experiments, they concluded that using one moisture sensor is not enough for detecting water leakage since, in this scenario, the time necessary to discover water leaking is lengthy. This is because the majority of the detection time is spent on saturating the soil with water before water reaches the moisture sensor. Our proposed system, tackles this problem by using a shielded pipeline where water leak is isolated from soil, and this reduces the detection time and the cost as well, because this way we need fewer moisture sensors compared with [Elleuchi, 19]. In [Abusukhon, 21a], the authors proposed an IoT system for detecting water pipeline leakage based on a shielded pipeline. Their system consists of inner and outer pipes. In [Abusukhon, 21a], the authors defined the system conceptually; it was never tested or reviewed in a real-world environment. The authors of this paper, build the work proposed in [Abusukhon, 21a], alter the design, implement it, and thoroughly examine the communication module's software and hardware. Furthermore, the authors of this paper expand the system in [Abusukhon, 21a]. Besides, in [Abusukhon, 21a], the authors did not calculate the time and the cost of their proposed system, and they did not compare the time and the cost of their system with the previous work. However, in this paper, we calculate the time and the cost of the system proposed in [Abusukhon, 21a] and compare them with the stat of the art. Besides, in [Abusukhon, 21a] the authors did not address security issues, but we do.

Machine learning is not the focus of our study. However, some techniques use machine learning to detect a tank's overflow [Hatti, 21]. Our work differs from their work. The problem they addressed is focused on monitoring water overflow in tanks, bridges, etc. In our work, we are focusing on detecting water leakage from underground pipelines, making the task more difficult. In their work, they employed machine-learning techniques for detecting a tank's overflow. In our work, we use a set of sensors to detect water leaks. In their work, they use a simulator. In our work, we carried out a set of real-world experiments to examine our system. Besides, our work differs from that of the SCADA system [Water Resources Alliance-SCADA, 23] [Balsom, July 16, 21] as follows: SCADA is a general-purpose system (controlling and monitoring various devices), but our system is dedicated to water leakage detection only. SCADA used a water flowmeter, pressure sensors, and acoustic leak detectors to detect water leaks. In our system, we use shielded pipeline and soil moisture sensors to detect water leaks. In SCADA, the location of a water leak is identified when there is a difference in flow volume or a drop in pressure between two sites along the pipe. In our proposed system, the location of a water leak is identified when water leakage occurs and water drops inside the inner pipeline touch the moisture sensor and the value recorded by the moisture sensor reaches a threshold = 100%. In SCADA, water leakage detection is based on acoustic leak detectors, and thus, noisy environments may cause false alarms of water leakage detection. However, our proposed system is not effected by sounds from the surrounding environment, and thus, no false alarms are generated. In SCADA, when water leakage occurs, water moves out of the pipeline, where it becomes dirty water. This water is wasted water. However, in our system, when water leakage occurs, water is still running into an inner pipeline (it is clean water), and then it is pumped to an alternative tank(s). In other word, there is no wasted water. Satellite imaging of water supply networks is a new technology for detecting leaks in water supply distribution networks [Savic, 20]. In this technique, images of water leakage are captured using a radar sensor, and then these images are analyzed using an algorithm that is capable of removing noise from these images. This technology is applicable when there is no rain (≈ 0 mm of rainfall) [Agapioua, 16]. In other words, if there is rain and the ground becomes wet, this system may trigger a false alarm although there is no water leakage. Our work differs from satellite techniques in that it does not trigger false alarms during rainfall. This is because our system uses shielded pipelines in which the inner pipeline is isolated from rainfall. Techniques like satellite imaging are not the focus of our paper's research. Besides, unlike SCADA and satellite imaging, we propose an IoT system for securing water pipelines from adversaries. However, our proposed system is not an alternative to SCADA, but it is an efficient first step (data acquisition step) for the establishment of a further SCADA system that closes the control loop via intelligent multiagent-based solutions. The proposed system can be developed so that when water leakage is detected, the main tank is closed automatically.

In this paper, we compare our work with the most related papers, as described in Table 1. Table 1 compares various papers (the state of the art) with the proposed system based on various factors elicited from the previous work. These factors include the aim of the paper, the technique used in the surveyed paper, types of sensors, the total cost of the proposed system in Jordanian dinar per 100m, the water-leakage detection time in seconds and the pipeline type (single or double pipeline).

Paper Ref.	Aim	Technique	Sensors	Cost (JD/ 100m)	Detection time for a buried pipeline (Seconds)	Single/ Double pipe
[Zhiyuan, 19]	Detecting water pipeline leakage.	Monitoring and comparing water flow rate at both ends of the pipeline.	An ultrasonic flow meter	378.08	Not covered	Single
[Martini, 17]	Detecting water pipeline leakage in the service pipes of water distribution networks.	Water leakage is monitored based on the vibro-acoustic phenomena which is related to the leaking flow.	A hydrophone and two accelerometers.	357.22	Not covered	Single
[Thilagaraj, 20]	Developing an IoT system for detecting water pipeline leakage and measuring the water quality as well.	Develop wireless flow sensors and wireless solenoid valves.	Water flow sensor.	418.08	Not covered	Single
[Elleuchi, 19]	Detecting water pipeline leakage based on a moisture sensor.	Reaching the soil to its saturation point is an essential condition for detecting water leakage. The ultrasonic sensor is unable to sense water without achieving the above condition.	Ultrasonic sensor	390	405	Single
The proposed system	Detecting water pipeline leakage based on an ultrasonic sensor, a shielded pipeline, a pump and a capacitive moisture sensor.	Reaching the soil to its saturation point is not an essential condition for detecting water leakage. Detecting water leakage is done based on a shielded pipeline.	Ultrasonic sensor	56	119	Double

Table 1: Various IoT techniques for detecting water pipeline leakage.

In this study, most of the surveyed papers did not calculate the time required for detecting water leakage. Calculating this time is very important issue and reducing it is a challenge. It is difficult to draw a comparison with many of the publications evaluated in this study due to the dearth of studies measuring the time of detection of water leaking and the total cost of the IoT system. Thus, in Table 1, we calculate the total cost of the surveyed IoT systems by finding the price for each part of the hardware (e.g. sensors, microcontrollers, etc.) used in the surveyed papers. Besides, we compare between our work and the work proposed in [Elleuchi, 19] since [Elleuchi, 19] is the only work among the surveyed papers in which the time of detection of water leakage is calculated.

3 The Research Hypothesis and Methodology

Our research hypothesis is as follows: using a shielded pipeline may reduce the time required for detecting water pipeline leakage. If a shielded pipeline is used, then when water leakage occurs, water moves in the outer pipeline of the shielded pipeline instead of moving into the soil. This way, water moves faster toward the soil moisture sensor than running into the soil. In [Elleuchi, 19] when the moisture sensor is planted in the ground, it takes 52.13 minutes to detect water pipeline leakage. Note that this time is increased as long as the distance between the water-leak position and the moisture sensor is increased. To tackle this problem, we propose using a shielded pipeline in order to isolate water leakage from soil, and thus, reduce the water-leakage detection time. We compared our work with the work carried out in [Elleuchi, 19]. We first build the baseline system as described in [Elleuchi, 19]. In the baseline system, we use a single pipeline, and we monitor the time required for detecting water pipeline leakage as described in [Elleuchi, 19]. In the baseline experiment, we use the parameters described later in this paper in sub-section 6.2, Table 4. On the other hand, we calculate the time of water pipeline leakage when the proposed system is used (i.e., a shielded pipeline is used). In this experiment, we use the same parameters as described later in sub-section 6.2, Table 4. Finally, we compared the time resulted from the proposed system with the time resulted from the state of the art [Elleuchi, 19]. Besides, we compared the cost of the proposed system with the cost of the system proposed in [Elleuchi, 19]. Since the cost of the systems proposed in the previous work is not calculated, we calculate this cost based on the hardware used in these systems. In addition, unlike [Elleuchi, 19], we calculate the time required for detecting water pipeline leakage when various types of soil or mixtures of them are used.

4 The Proposed IOT System

In this section, we describe the proposed IoT system for detecting water pipeline leakage. The proposed system is described in Fig. 1. As described in Fig. 1 although the proposed system is buried in the ground, it is completely isolated from soil. It consists of a shielded plastic pipeline where an inner pipeline is shielded by an outer pipeline. In addition, at the bottom of the outer pipeline, there is a mini water-storage tank. This tank is used for collecting water leaks from the inner pipeline. The ultrasonic sensor, which is affixed inside this tank, is used for controlling a pump.

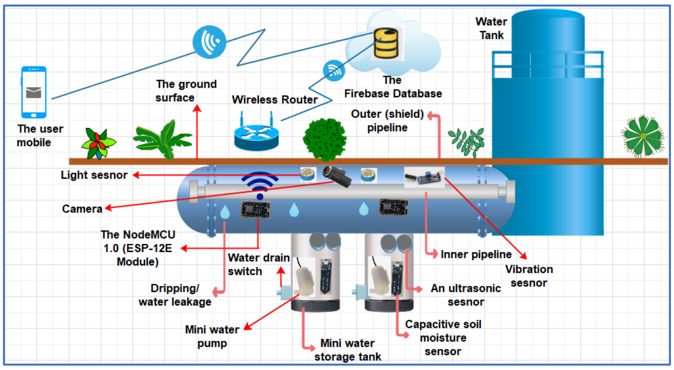

Figure 1: The proposed IoT system for detecting water pipeline leakage using a shielded pipeline and a wireless NodeMCU1.0 (ESP-12E Module) [Abusukhon, 21a]

The pump is used to move water outside the mini tank. The ultrasonic sensor measures the water level in the mini tank. If water in the mini tank reaches a specific level, then our Android application sends a command to the water pump in order to move water outside this tank. The proposed system is working as follows; when water leaks occur, because of a crack in the inner pipeline, then water moves into the mini tank. Then, at a specific water level, the Capacitive Soil Moisture Sensor (CSMS), which is affixed inside the mini tank, reads the value of moisture, and then, this value is stored in the cloud (i.e. in the Firebase database) associated with the NodeMCU's identifier. In the proposed system, we have more than one mini tank, which are distributed along the outer pipeline associated with their NodeMCUs as described in Fig. 1. Each NodeMCU has a unique identifier. When water leakage is detected, the NodeMCU's identifier is sent with the user message in order to help him to determine the position of water leakage in the pipeline. In the proposed system, suppose that we have three mini tanks, namely, t1, t2 and t3 distributed along the outer pipeline. Also, suppose that a crack occurs near t2 then if water fills t2 and then continues to fill t3, the proposed system will send a message telling the user that there are two cracks in the pipeline; one of them is near t2 and the other is near t3, but in fact, there is only one crack near t2. In this case, the user receives a false alarm about the location of water leakage since there is no crack near t3. To tackle this problem, we prohibit water from moving to the next mini tank (i.e. t3) using an ultrasonic sensor. When the current mini tank is filled with water and water reaches a specific level, the NodeMCU turns the pump "ON" using a relay, and water inside the mini tank is moved out until the tank becomes empty. Then, the pump is turned "OFF". Fig.1 also describes security issues where light sensors, and vibration sensors are affixed to the top of the inner pipeline while connected to the NodeMCU. When an adversary attempts to make a crack in the outer pipeline, he allows light to reach the light sensor(s), and allows the vibration sensor(s) to vibrate and record some signals (e.g. digging signals). In this case, an audio message is sent to the IoT system's manager associated with the NodeMCU's identifier. This message informs the system's manager that a water pipeline is hacked. The IoT system's manager, with the help of the NodeMCU's identifier, can determine the location of an adversary and make the right decision.

In this paper, the proposed system consists of four modules as follows: 1) the data-gathering module: in this module, the capacitive soil moisture sensor V1.2 is used for data gathering. 2) The communication module: in this module, the NodeMCU 1.0 (ESP-12E Module) is used as a Wi-Fi protocol. 3) The data storage module: in this module, we use the Firebase database for storing the collected data. To deal with Firebase, a Google account and a Firebase project are required. 4) The data retrieval and processing module: in this module, the Android Studio Arctic Fox 2020.3.1 Patch is used to process and analyze the collected data.

5 Experiments

In this section, we describe the experiments carried out in order to test the proposed system. In these experiments, the mini water-storage tank consists of the following components: horizontal mini submersible water pump 120 L/H DC3V-5V, the capacitive soil moisture sensor, the NodeMCU board, the HW-131 power supply module, an ultrasonic sensor, nine-volt batteries, relay, power bank 3 AA (1.5 V), water storage, and a USB cable. Fig. 2 describes the mini tank after packaging. We connect the NodeMCU module to an external battery (9 volt battery) using the HW-131 power supply module, and a USB cable. In addition, we connect the horizontal mini submersible water pump to an external power source (power bank 3AA 1.5 volt). When water leakage occurs (because of a crack in the inner pipeline), water moves inside the outer pipeline, and then it moves inside the mini water-storage tank. When water reaches a specific level in the mini tank, the capacitive soil moisture sensor senses the water, and then the NodeMCU WiFi module (which is connected to the Firebase database via a wireless router), stores the data read by the soil moisture sensor into the Firebase database.

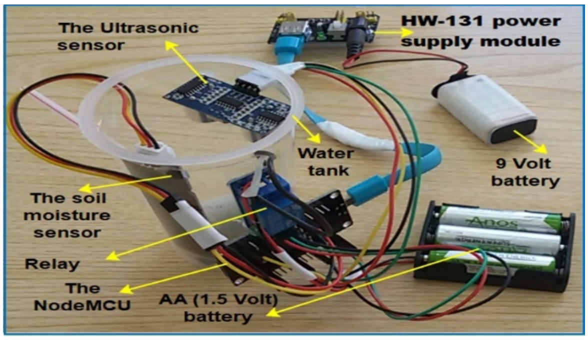

Figure 2: The mini tank components after packaging

To inform the user about water leakage, we develop an Android application, which is able to read the soil moisture value from the Firebase database, and if this value is 100%, then it sends a warning message (e.g. a text message or an alarm) to the user. The ultrasonic sensor monitors the water level in the mini tank, if water level is less than or equal to a specific threshold (e.g. 3.5cm), then the NodeMCU turns the water pump "ON" in order to move water out of the mini tank. This step must be carried out in order to prevent water from being moved to the other mini tanks, and thus avoiding false alarms. In our system, we assume that the distance between any two consecutive mini tanks is ≈ 100m, which is the range of the NodeMCU wireless board. To control the pump, we use a relay. The relay is connected to the NodeMCU board and to the external power bank as described in Fig. 2. When the distance between the ultrasonic sensor's edge and the water surface is less than 3.5cm, the water pump works. It moves water out of the mini tank. Fig. 3 describes the database structure of our proposed system. We create this database in the cloud using the Firebase database. The database consists of a root node, which we call the Water leakage System (WLS).

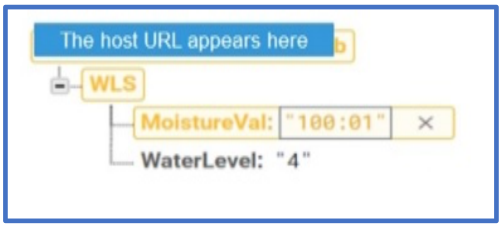

Figure 3: The moisture and ultrasonic sensor values as recorded in the Firebase database

The root node includes two sub nodes, namely, the "MoistureVal" and the "WaterLevel" sub nodes. Fig. 3 describes the Firebase database after a crack occurs in the inner pipeline and water fills the tank to a specific level. The values shown in Fig. 3 (the "MoistureVal" =100:01, and the WaterLevel = 4) resulted from an experiment which we carried out as described in Fig. 4.

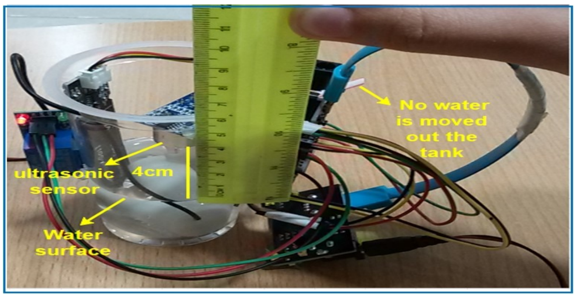

Figure 4: Water leakage – water level is greater than a threshold- Water is not moved out the mini tank

In Fig. 4, the distance between the ultrasonic sensor's edge and the water surface "WaterLevel" = 4cm and the moisture value "MoistureVal" =100%:01. The value 100%:01 is split into two values; the first value is the moisture value="100%" and the second value is the mini-tank's identifier="01". This means that water leakage occurs near the mini tank "01". The identifier of a mini tank (e.g. "01") helps the user to determine the crack position since we may have multi minitanks distributed along the outer pipeline. If the moisture reaches 100%, and the distance between the sensor's edge and the water surface is less than a threshold then an alarm is sent to the user's mobile phone (using our Android application) telling him about water leakage. In Fig. 4, water is not moved out of the mini tank since the distance between the ultrasonic sensor's edge and the water surface is greater than a threshold PT, where PT=3.5. In Fig. 5, after the user is informed about water leakage, the water pump moves water out of the mini tank because the distance between the water surface and the ultrasonic sensor's edge = 3 cm. (i.e. less than PT)

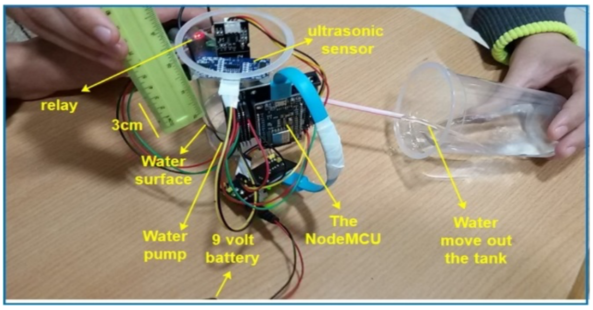

Figure 5: Water leakage– water level is less than a threshold- water is moved out of the mini tank

This is done in order to prevent water from moving to the other mini tanks, and therefore avoid sending false alarms to the users.

In Fig. 6 water moves from the main tank to the inner pipeline, then, it drips from the crack to the outer pipeline, and then, it moves to the mini tank. During this process, the moisture value "moistureVal" in the mini tank is measured and stored in the Firebase database. After that, our Android application, reads the "moistureVal" from the Firebase database. If the moisture reaches 100%, it sends a warning message to the user's mobile phone. Water continue moving inside the mini tank, and the ultrasonic sensor measures the distance ("waterLevel") between the water surface and the ultrasonic sensor's edge and then this value is stored in the Firebase database. When the "waterLevel" value, which is stored in the Firebase database, is changed, our Android application reads this value from the Firebase database, and if this value is less than or equal to PT, then our system turns the pump "ON" in order to get free from water inside the mini tank as described in Fig. 5. In Fig. 6, the outer pipeline's diameter is too large compare with the inner pipeline's diameter. However, the outer pipeline can be replaced with another one, which has smaller diameter.

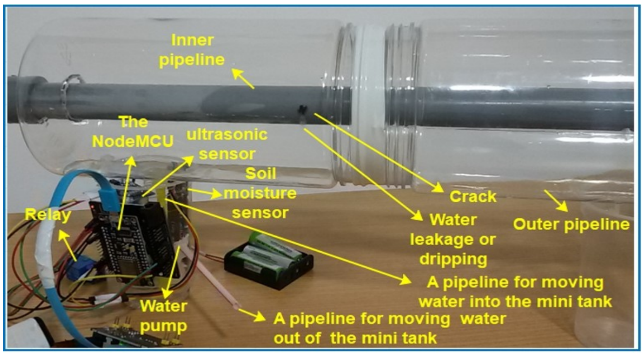

Figure 6: Water leakage path from the main tank to the mini tank

Next, we describe the Android application which we developed in order to enhance the proposed IoT system. Fig. 7 describes the Android application (the emulator Nexus 5X) and the Firebase database. As described in the emulator, data are as follows: the moisture value is 100%, the crack occurs in the inner pipeline near the mini tank number “01”, and water level in this tank (tank “01”) is 4 cm. Since the water level in this tank is greater than the required threshold (PT=3.5cm), the pump is turned “OFF”.

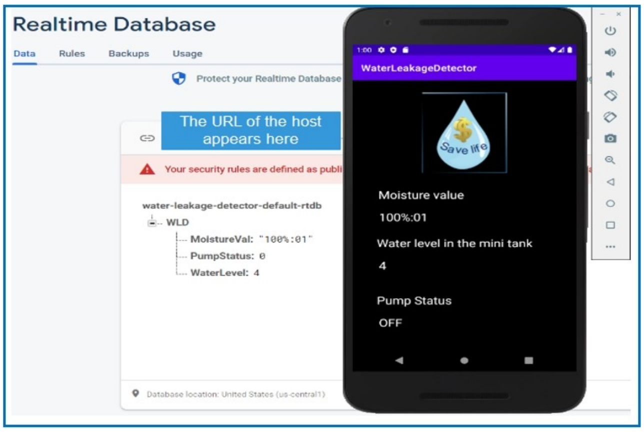

Figure 7: The Firebase database and the Android application–reading real-time data

6 The Evaluation of the Proposed System

6.1 Sensors evaluation

As we mentioned earlier in this section, we use the ultrasonic sensor and the capacitive soil moisture sensor in our experiments. We evaluate the sensors we use by calculating the Average Error Rate (AER) and the Accuracy (ACC) of the sensors as described in Eq.1 and Eq.2.

$$AER = |MD - AD| / (AD) \times 100 \quad (1)$$
$$ACC = 100 - AER \quad (2)$$

Where MD is the measured distance, AD is the actual distance, and | | is the absolute value. Table 2 describes the AER and the ACC values of the ultrasonic sensor when the actual distance between the water surface in the mini tank and the sensor's edge is 1, 2, 3, 4, and 5 cm. In Table 2, each value in the AER and the ACC columns is the average and or the accuracy of 20 trials. In Table 2, when the water surface is very close to the ultrasonic sensor (1 cm), the accuracy is very poor. This merit is one of the disadvantages of the ultrasonic sensor. For example, when the ultrasonic sensor touches the surface of a barrier (i.e. the distance between the ultrasonic sensor and the water surface is 0), then the value given by the ultrasonic sensor is not zero. Instead, it returns a value > 2000. However, in Table 2 when the distance > 1 cm, the accuracy is 100%. Thus, the ultrasonic sensor we use in our experiments is accurate. This means that the values we get to test the threshold PT is accurate by 100% (note that the PT value is between 3 cm and 4 cm. In Table 2, the ACC values corresponding to the distances 3 cm and 4 cm are 100%).

Distance in (cm)	AER	ACC
1	255%	-155%
2	0%	100%
3	0%	100%
4	0%	100%
5	0%	100%

Table 2: The AER and the ACC values of the ultrasonic sensor for various distances

Fig. 8 describes the actual and measured values read by an ultrasonic sensor.

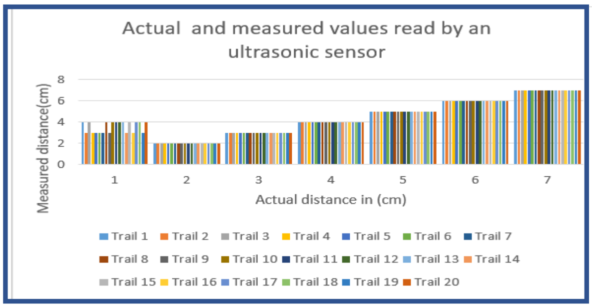

Figure 8: Actual and measured distance read by an ultrasonic sensor

Besides, we evaluate the moisture values measured by the capacitive soil moisture sensor for various levels of water inside the mini tank. Table 3 describes the average of 20 trails for measuring the moisture percentage with respect to water level inside the mini tank. In Table 3 when there is no water flow in the mini tank (i.e. water level =0), the moisture average is 52%. This is because of the environment moisture. When water flows in the mini tank, the moisture value increases.

Water level inside the mini tank in (cm)	**Moisture average**
0	52%
0.3	55%
0.8	62%
1.0	69%
1.2	83%
1.3	95%
1.4	99%
1.5	100%

Table 3: Moisture percentage with respect to water level inside the mini tank

6.2 System evaluation

Our work differs from other works [Che, 21][Vijayakumar, 19] [Zhiyuan, 19] [Saravanan, 19] [Sadeghioon, 14] [Arjun, 17] [Liu, 19] [Choi, 17] [Martini, 17] [Marmarokopos, 18] [Wan, 93] [Bhende, 18] [Elleuchi, 19] in that the other works used a single pipeline in their experiments. However, in our experiments, we use a shielded pipeline. Besides, our work differs from the work in [Elleuchi, 19] as follows: in [Elleuchi, 19], the authors used one pipeline, and thus, water leaks from a water pipeline and then it moves into the ground. When the soil is saturated with water, the moisture sensor detects water leakage. Therefore, the water-leakage detection time is high (e.g. 52.13 minutes as described in [Elleuchi, 19]). This is because the majority of the detection time is spent on saturating the soil with water before water reaches the moisture sensor. However, in our system, we use a shielded pipeline where water leaks move into an outer pipeline instead of moving into the ground. This way, there is no need to wait until the soil is saturated with water. This design has the advantage that water leaks move in the outer pipeline faster than moving into soil (this result is proved later as described in Table 5). The other thing is that in their work, water moves into the soil, and thus it is lost. However, in our system, water moves from the inner pipeline to the outer pipeline, and then it moves to a mini tank where a water pump pushes it to a storage area for further use. In addition, in [Elleuchi, 19], the authors proposed to speed up the performance of their system (i.e. reduce the time required for detecting water pipeline leakage) by increasing the number of moisture sensors (e.g. install a moisture sensor each 3 meters). This is because soil must be saturated with water before water reaches the moisture sensor. Using a moisture sensor each 3 meters raises the total cost of the system. However, in our system, since water moves inside the outer pipeline, we may install a moisture sensor every 100 meters (100 meters is the WiFi range). In addition, their system is unable to distingiuish between the rainfall and water pipeline leakage since the soil moisture sensor is not isolated from soil. However, our system is isolated from soil and thus the rainfall has no effect on the soil moisture sensor's value. Finally, in their work, they carried out a set of experiments in order to investigate how the performance of water leakage detection is affected by water propagation through soil using one type of soil. However, in our experiments, we investigate how the performance of water-leakage detection is affected by water propagation through various types of soil, such as brown soil (clay soil), yellow soil (sand), a mixture of brown and yellow soil (the mixture rate is one to one or 1:1), and a mixture of brown, black and yellow soil (the rate is 1:1:1). Fig. 9 describes various types of soil used in our experiments.

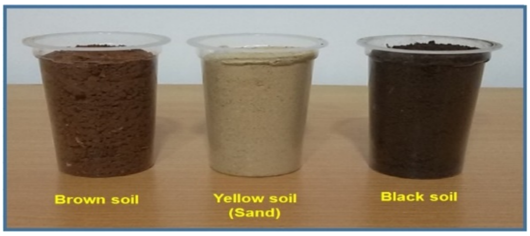

Figure 9: Various types of soil (brown (clay soil), yellow and black)

As we mentioned earlier in this paper, we compare our work with the work in [Elleuchi, 19] since this work is the only work in the surveyed papers in which the water-leakage detection time is calculated. To evaluate the proposed system, we first build the baseline system as described in [Elleuchi, 19], where a single pipeline (not a shielded pipeline) is used and then we calculate the time required for detecting the water pipeline leakage. Besides, we build the proposed system, which uses a shielded pipeline, and then we calculate the time required for detecting the water pipeline leakage. Unlike the work in [Elleuchi, 19], which calculated the time required for detecting the water pipeline leakage when only one type of soil is used, we calculate this time when various types of soil or mixtures of them are used (as described later in Table 5). Finally, we compare the time resulted from the proposed system with the time resulted from the state of the art [Elleuchi, 19]. To do so, we measure the following parameters before running the experiments: The distance (D_I) between the end of the inner pipeline and the crack, The diameter of the hole (crack) in the inner pipeline (D_H), The depth (height) of the soil layer (D_S) in which the moisture sensor is planted (e.g. 5 cm). Table 4, describes these parameters and their values.

The parameter symbol	**The value in centimeter (cm)**
D_I	21 cm
D_H	0.3 cm
D_S	5 cm

Table 4: The experiment's parameters

In addition, we define the Water Movement Time (WMT) as follows: the WMT is the time of water movement from the main tank to the mini tank passing through the inner pipeline's crack. In our experiment, we measure the WMT for two cases: in the first case, we measure the WMT using a shielded pipeline (i.e. we keep the inner pipeline inside the outer pipeline). In the second case, we measure the WMT while burying the inner pipeline in the soil as described in [Elleuchi, 19]. Bedsides, we measure the WMT when various types of soil are used. In Jordan, the most common types of soil are brown (clay soil) and yellow (sand) soil. The black soil has a limited use. For example, it is used indoor for home ornamental plants. Table 5, describes the results of our experiments. In Table 5, the depth (height) of the soil in the soil container is 5cm in all experiments. The container used in the experiments has a length (D_I) =21cm, and a width = 8 cm. As described in Table 5, the time required for detecting water leakage, when the proposed system is used, is 119 seconds. We measure this time by calculating the time taken by water to move from the main tank to the moisture sensor passing through a crack. This time (T_{TOTAL}) is composed of the following periods of time: the time taken by water to move from the main tank to the inner pipeline (T_{MI}), the time taken by water to move through the inner pipeline (T_I), and the time taken by water to move into the mini tank and touches the moisture sensor (T_{IS}). Thus,

$$T_{TOTAL} = (T_{MI}) + (T_I) + (T_{IS}) \quad (3)$$

We carry out five experiments as described in Table 5. In Table 5, the (*) symbol means "No soil, water moves in an outer pipeline.", (T_{TOTAL}) is the water-leakage detecting time in seconds as described in Eq. (3), %D: is the percentage decrease in water-pipeline detection time using our proposed system compared with other systems. For each experiment, we calculate the total time T_{TOTAL} using two timers, namely, T_S and T_E , which are implemented in the Arduino code on the NodeMCU board. The T_S timer is set at the beginning of each experiment (i.e. when water moves from the main tank toward the mini tank) while the T_E timer is set at the end of each experiment (i.e. when the moisture sensor value = 100%). Then, we calculate the ellapsed time (E_T) as follows:

$$(E_T) = (T_E) - (T_S) \quad (4)$$

The tested systems	**Soil type**	**Pure or mixed soil**	**The rate of the soil mixture**	T_{TOTAL}	**%D**
The proposed system (sheilded pipeline)	*	*	*	119	
[Elleuchi, 19] (single pipeline)	Brown (clay soil)	Pure	100%	405	70%
[Elleuchi, 19] (single pipeline)	Yellow (sand)	Pure	100%	175	32%
[Elleuchi, 19] (single pipeline)	Brown and yellow	Mixed	1:1	190	37%

[Elleuchi, 19] (single pipeline)	Brown, yellow and black	Mixed	1:1:1	316	62%

Table 5: A comparison between the proposed system and the state-of-the-art system [Elleuchi, 19] based on the time required for detecting water-pipeline leakage

The experiments described in Table 5, are carried out using the same parameters as described in Table 4). Unlike [Elleuchi, 19], we investigate the (E_T) value for various types of soil, and mixtures of them. For all of the above experiments, except for the experiment of the proposed system, the (E_T) is calculated when the soil is saturated with water [Elleuchi, 19], where the soil level in the container is 5cm. The main finding from these experiments is that the proposed system outperforms the system proposed in [Elleuchi, 19] in terms of the time required for detecting water leakage when various types of soil or mixtures of them are used. A secondary finding is that water propagates in the brown soil slower than other types. This is an indicator that the brown soil keeps water better than the other types of soil or mixtures of them. Besides, water propagates in sand (the yellow soil) faster than other types of soil or mixtures of them. In other words, the results from our proposed system show that the saturated hydraulic conductivity (K_s) of the sand soil is higher than the (K_s) of the clay soil (the brown soil). Soil's specification used in our experiment (as described in Fig. 9) are as follows: clay soil (brown soil) is basicly composed of silica, alumina, magnesium, water, iron, potassium, sodium, and calcium. The clay soil is made of very small brittle, homogeneous, and adjoining particles that are less than 0.002 mm in size. It does not contain roots or stones. The sand soil is made of weathered rock particles that are usually the result of the collapse or fragmentation of granite and quartz. The black soil is made of K2O (1.5-2.0%), P2O2 (1-1.5%), N (2-2.5%), PH (7-7.5%), CI (less than 0.9%), NA (less than 0.01%). [Suleiman,2001] developed a formula for measuring the tempospatial variability of saturated hydraulic conductivity (K_s) as follows:

$$K_s = 75\ (\theta_{er})^2\ (\text{cm d}^{-1}) \tag{5}$$

Where θ_{er} represents the relative effective porosity. Soil hydraulic properties such as hydraulic conductivity and water retention govern the soil's ability to capture and store precipitation or irrigation water. It is well known that soil texture has a greater influence on hydraulic properties because soil hydraulic conductivity is a function of pore size; thus, soil with large sized sand particles have relatively large pore spaces, resulting in higher saturated hydraulic conductivity (K_s) [Seema, 2019]. Soil texture has the greatest influence on soil saturation capacity, water holding capacity, and soil water characteristics [Saxton, 2006] [Ali, 2010]. [Reynolds, 2000] measured saturated hydraulic conductivity (K_s) for sand at 29 cm/h, loam at 4.1 cm/h, and clay loam soil at 0.091 cm/h. He concluded that the (K_s) of the sand soil (with a large sand fraction) was approximately 300 times greater than that of the clay loam (with a small sand fraction). Because of their large pore spaces, coarsetextured and wellaggregated soils are more conductive than clayey soils [Halfmann, 2005]. The results from our proposed IoT system confirms the above results from the previous work as described in Table 5. Besides, simulation results (using differential equation) showed that K_s (cm min−1) of clay soil = 0.0043; while the K_s (cm min−1) of sand = 0.0737 [Fan,22] . The results from our proposed IoT system confirms this result too, that is the (K_s) of the sand soil is higher than the (K_s) of the clay soil (the brown soil). Based on the results from Table 5, we conclude that θ_{er} is inversely proportional to the T_{TOTAL} or simply (T) as described in Eq. 6.

$$\theta\text{er} \propto \frac{1}{T} \tag{6}$$

thus,

$$\theta\text{er} = \mu \frac{1}{T} = \frac{\mu}{T} \tag{7}$$

where μ is a constatnt. Now substituting θ_{er} from Eq. (7) in Eq. (5) we have:

$$K_s = 75 \left(\frac{\mu}{T}\right)^2 \text{(cm d}^{-1}\text{)} \tag{8}$$
$$= 75 \frac{\mu^2}{T^2} \text{(cm d}^{-1}\text{)}$$

From Eq. 8, we conclude that the Ks (the saturated hydraulic conductivity) value has an inverse proportional relation with T (the soil saturating time). This theoretical result confirms what we have concluded previously from Table 5. In Table 5, for example, the sand soil recorded less time than the clay soil, thus the sand soil has greater K_s than the clay soil.

As described in Fig. 10, compared with the state of the art, using a shielded pipeline for detecting water leakage is faster than using one pipeline when both of them are buried in soil. Besides, our work differs from the work carried out in [Liu, 19] [Choi, 17] [Martini, 17] [Marmarokopos, 18] [Wan, 93]. The disadvantage of their work is that when noise (a vibration frequency which is equal to the water leakage frequency) from the surrounding environment arises, then, utilizing these techniques may result in erroneous results. Since our work is based on soil moisture sensors, it is not affected by vibrations or frequencies.

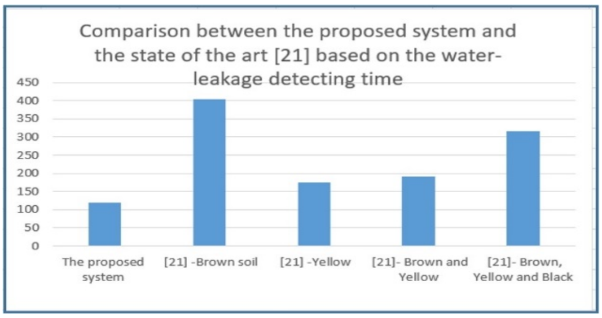

Figure 10: A comparison between the proposed system and the state-of-the-art [Elleuchi, 19] based on the time required for detecting water leakage.

Furthermore, the proposed system is compared with other works based on the system cost. In general, when calculating an IoT system cost, the following costs should be included in the cost model: the Cost of Establishing the necessary infrastructure for a specific IoT system (C_E), the Cost of Hardware (C_H), the Cost of Software (C_S), the Cost of Communication (C_C), the Cost of Maintenance (C_M), and the Cost of Securing the system (C_R) as described in Eq. 9.

$$\text{Total cost} = C_E + C_H + C_S + C_C + C_M + C_R \tag{9}$$

The cost of hardware includes, for example, the cost of sensors, microcontrollers, and cameras used in the IoT system. The cost of software includes, for example, mobile applications and security software. The communication cost includes, for example, hardware such as wireless routers, cloud computing rentals, and so on. The security cost includes, for example, the cost of software or hardware used for protecting water pipelines from being damaged by human and/or protecting data send/received via the Internet. Finally, the cost of maintenance includes the cost of repairing the water supply network if water leakage is detected. Unfortunately, the cost components mentioned in Eq. (9) are not included in the surveyed papers (not avialable), thus we focus on calculating the hardware cost (C_H) of our IoT system and compare it with the (C_H) of the other works carried out in [Elleuchi, 19] [Zhiyuan, 19] [Martini, 17] and [Thilagaraj, 20]. We choose to base the comparison between the previous system and our proposed system on (C_H) since calculating the (C_H) is possible by collecting information about the cost of each system from the websites that offer hardware at lower prices. In Jordan, the cost of the soil moisture sensor used in [Elleuchi, 19] is 10 Jordanian Dinar (JD) and the cost of the NodeMCU board is JD6. In addition, the cost of the horizontal mini submersible water pump is JD4. The authors in [Elleuchi, 19] found that using three soil moisture sensors is better than using one sensor when detecting water pipeline leakage. In one of their experiments, the distance between sensors was three meters. Thus, for 100 meters, their system requires $100/3 \approx 33$ soil moisture sensors and about 10 NodeMCU (since each three soil moisture sensors are connected to one NodeMCU). Thus, the Total Cost (TC) = the Total number of Sensors (TS) * Sensor's Price (SP) + the Total number of NodeMCU (TN) * NodeMCU's Price (NP) as described in Eq.10.

$$TC = TS * SP + TN * NP \tag{10}$$

Thus, for every 100 meters, the TC value is TC = 33 *10 + 10 * 6 = 390 JD. However, for our proposed system, the TC value is calculated by adding the cost of the Outer Pipeline (OP) to the total cost. The OP is calculated as described in Eq.11.

$$OP = (LP) * (PP) \tag{11}$$

Where, LP is the length of the pipeline and the PP is the price per meter. In our proposed system, we may use the 2-inch irrigation water High-Density PolyEthylene (HDPE) pipe. The cost of this pipe is $0.5 per meter. Thus, for 100 meters: OP = 100 *0.5 = $50 = 36JD. In addition, we use the horizontal mini submersible water pump (Flow rate: 80- 120L/H) in our system. The price of this pump (PU) is JD4 [Mikroelectron, 22]. Besides, the price of an ultrasonic sensor is JD2. Therefore, TC is calculated as described in Eq.12.

$$TC = [TS * SP] + [TN * NP] + [OP] + [PU] \tag{12}$$

Thus, TC =[1 *10 + 1*2]+ [1 * 6] + [36]+[4] = JD58. Given the above result, the cost of our proposed system is cheaper than the cost of the previous work [Elleuchi, 19]. Thus, our system outperforms the system proposed in [Elleuchi, 19] in terms of system cost. The authors in [Zhiyuan, 19] did not calculate the cost of their system. However, we calculate the cost of their system with respect to the hardware used taking into account the best sale prices. The average best price for the Ultrasonic Water Flow Meter (UWFM)= $255 [Best Selling, 22] which equals to 180.54JD. The ultrasonic flow converter (Time to Digital Converter: TDC-GP22) price is JD8.34. Besides the cost of the MSP430F5438A MCU is €11,71= JD8.66 [MOUSER, 22]. Thus, the total cost of the main hardware used in their experiment: TC = 2 * 180.54 + 8.34 +8.66 = JD378.08 Given the above cost (TC=JD378.08), our system performs better than [Zhiyuan, 19]. The authors in [Zhiyuan, 19] did not mention anything about the pipeline length used in their experiment. However, the above calculation is carried out for a 100- meters pipeline in order to facilitate the comparison. The authors in [Thilagaraj, 20] did not calculate the cost of their system. However, we calculate the cost of their system based on the hardware used in their experiment. In their experiment, the authors used the following hardware: ultrasonic sensor, the Global System for Mobile (GSM) communication module, and the water flow sensor. The price of the GSM module is JD55 [Mikroelectron, 22]. The equation Eq.13 describes the TC for their system.

$$TC = TS * SP + GP \tag{13}$$

Where the GP is the price of the GSM module. Thus, TC = [1* 2 + 2*180.54] + 55 = JD418.08, Therefore, our system outperforms [Thilagaraj, 20] in terms of system cost. In [Martini, 17], the authors concluded that the axial accelerometer sensor is suitable for their prototype system for detecting water leakage. The average cost of this sensor is JD178.61[Ubuy Water, 22]. They also used the water flow meter and a piezoelectric hydrophone. The cost of a piezoelectric HydroPhone (HP) is JD178.61 [Electro Mechanical, 22]. This hardware is attached to a 28m long pipe. The total cost of their system is TC =TS*SP +HP, thus, TC = 1*178.61 + 1* 178.61 = JD357.22, where the HP is the hydrophone price. As a result, in terms of system cost, our system performs better than [Martini, 17]. Fig. 11 compares the proposed system with the previous work with respect to system cost. The prior work's lowest cost is [Martini, 17] (as described in Fig. 11). When compared to [Martini, 17], our proposed system reduces the cost in [Martini, 17] by 83%.

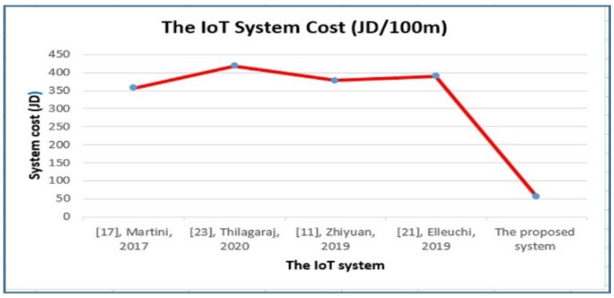

Figure 11: A comparison between the proposed system and the state-of-the-art with respect to system cost

To the best of our knowledge, no previous work compared between various techniques of water pipeline leakage based on system cost and water-leakage detection time. One reason could be that the previous works ignored calculating the cost of their systems as well as the time required for detecting water pipeline leakage.

We also calculate the total cost of our proposed system for 100 meters as described in Eq. 9 as follows:

C_E :

- Outer pipeline cost: for 100 meters, we may use the 2-inch irrigation water High-Density PolyEthylene (HDPE) pipe. The cost of this pipe is $0.5 per meter. Thus, for 100 meters, OP = 100 *0.5 = $50.
- Inner pipeline cost: for 100 meters, we may use 1.5-inch black poly agricultural irrigation pipe. The cost of this pipe is $80 for 100 meters [Alibaba, 23].

Thus, the total cost of CE is $50 + $80 = $130.

C_H:

- Horizontal mini submersible water pump (flow rate: 80–120 L/H). The price of this pump is $5.64.
- Ultrasonic sensor. The price is $2.82.
- The capacitive soil moisture sensor V1.2. The price is $4 [Elecbee, 23].
- NodeMCU (ESP-12E). The price is $14 [Elecbee, 23].
- Relay (5-volt low-level trigger one). The price is $2.3 [Elecbee, 23].
- HW-131 power supply module. The price is $0.93 [AliExpress, 23].
- 9-volt batteries. The price is $8.47. [AliExpress, 23].
- Power bank, 3 AA (1.5 V). The price is $0.14. [AliExpress, 23].

Thus, the total cost of CH is $38.3.

C_S:

- The Android application and the Arduino Uno code were built from scratch by the authors of this paper. However, in Jordan, the cost of building an Android application is about $36 per hour, as is the Arduino Uno code. Our Android application needs about 5 hours as well as the Arduino code, so the total cost is 2 x 5 x 36 = $360.

C_C:

- Wireless router ZTE, Airbox 4G-Wi-Fi SSID. The price is $24 [AliExpress, 23].
- Internet Access: In this paper, the authors used Orange's 4G 100GB line, which costs $26 per month.
- Firebase cost: The authors of this paper built their database in the Firebase database for free (A/B testing, [Firebase, 23]).

Thus, the total cost is $24 + $26 =$50

C_M :

- This process includes the maintenance of the inner and outer pipelines when a crack occurs. However, this cost can be calculated after the system has been installed and used for a while. However, the maximum value of this cost is when, for example, we replace the 100 meters of inner and outer pipeline, which is equal to $130 as described previously when calculating the C_E value above.

Thus, the total cost = $130.

C_R:

- The cost of security includes authentication services provided by Firebase that cost $0.01–$0.06 per month [Firebase, 23].

Thus, the total cost of our proposed system (as described in Eq. 9) is:
$130 + $38.3 + $360 + $50 + $130 + $0.06 = $708.36. Note that some of the costs are calculated on a monthly basis.

7 Security Issues

In this section, we describe our proposed IoT system for securing the buried water-pipelines against intruders (human damages). Our proposed system is composed of a set of vibration sensors and light sensors that are distributed at the top of the inner pipeline, but inside the outer pipeline of the shielded pipeline as described in Fig. 12. In Fig. 12, the shielded pipeline is enhanced with the SW-420 vibration sensor module which works well to detect even feeble impacts [Electro Schematics] and a Light Dependent Resistor (LDR) sensor. When an adversary attempts to damage a buried pipeline, he starts digging and thus, the vibration sensor monitors and records the vibrations result from digging the ground. At this point, our IoT system sends a low level warning message. However, when an adversary continues digging the ground and makes a crack in the outer pipeline, he allows the light to touch the LDR sensor which is affixed to the top of the inner pipeline, and thus, our system sends a high level warning message to the IoT system's manger.

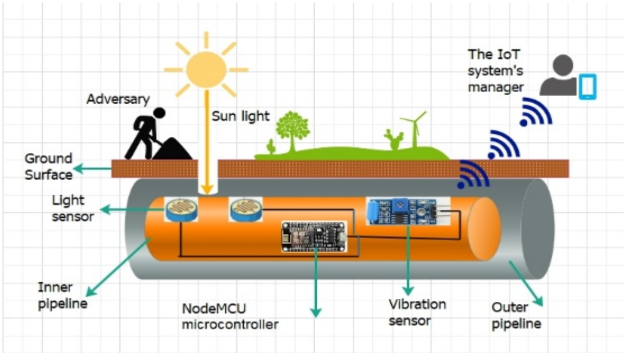

Figure 12: The proposed IoT for securing water pipelines against adversaries

The warnning message contains the NodeMCU's identifier to which the vibration sensor is attached and this makes it easy for the system's manager to determine the location of an adversary. The vibration sensor works as follows: when there is vibration then it returns one otherwise it returns zero. We measure the average value of the LDR sensor when it is buried under the ground, the average value of twenty trails is 74.7. Besides, We measure the average value of the LDR sensor when it is exposed to light, the average of twenty trails is 966.45. The proposed IoT system works as follows: If an adversary statrts digging near the pipeline without making a crack in the pipe, then the value of the vibration sensor is change to one, but the value of the LDR sensor remains 74.7. In this case, our system sends a low level warning message which says: "Vibration arround the pipeline". However, if an adversary makes a crack in the pipe, he allows, for example, the sun's light to touch the LDR sensor. In this case, the value of the LDR sensor is changed to a value (V) where $74.7 \leq V \leq 966.45$, at this point our system sends a high level warning message says "Vibration and crack in the pipeline" to the IoT system's manager. Fig. 13, describes the vibration signals when there is vibration and when there is not.

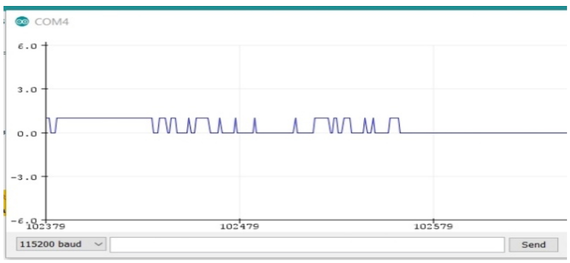

Figure 13: Testing the vibration sensor

Fig. 14, describes the proposed IoT system for securing the buried pipelines before affixing it to the shielded pipelines. The vibration sensor is connected to the NodeMCU as follows: the (vcc), (D0) and (GND) pins of the vibration sensor are connected to the (3V), (D0) and (GND) pins of the NodeMCU respectively. The LDR sensor is connected to 10K ohm resister and to the NodeMCU as described in Fig. 14. Fig. 15 describes the above two messages sent to the IoT system's manager.

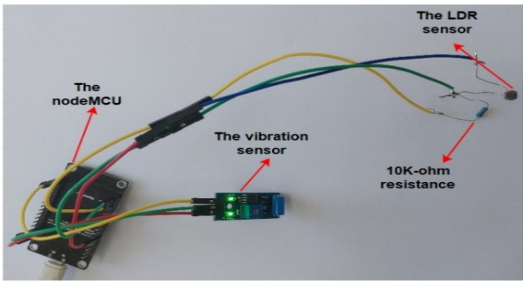

Figure 14: the proposed IoT system for securing the buried pipelines

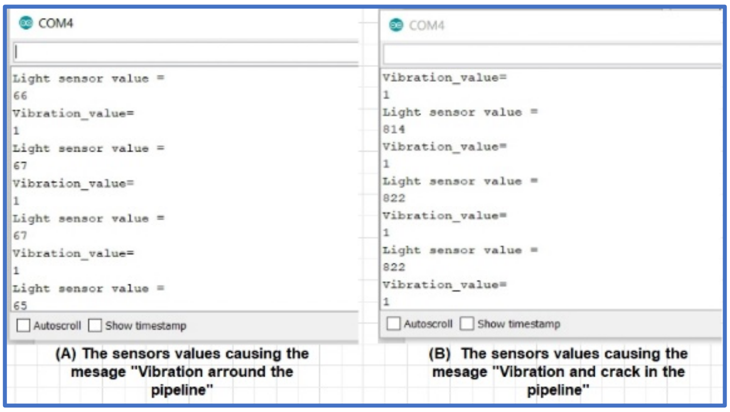

Figure 15: The sensors values for both warning messages: low and high-level warning

Fig. 16 describes the proposed IoT system for securing a buried pipeline against adversaries when it is buried in the ground and an adversary makes a crack in the pipe. The message sent (in this case) is "Vibration and crack in the pipeline".

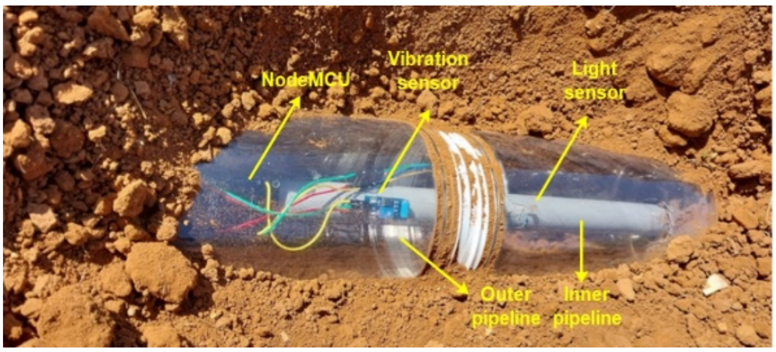

Figure 16: The proposed IoT system when it is buried under the ground

Besides, in our proposed system we use the library “AESLib” to protect the data sent by the NodeMCU board to the Firebase database. The AES is a shortcut for Advanced Encryption Standard algorithm. The AES is one of the most commonly used encryption algorithm and it is used with various IoT systems and applications [Al-Mashhadani, 2022]. The library “AESLib” is uploaded to an Arduino code on the NodeMCU board using the library manager. The AESLib library can be downloaded from the website: https://www.arduinolibraries.info/libraries/aes-lib. This library adds the following files to an Arduino code: #include <AES.h> , #include <AESLib.h>, #include <AES_config.h>, #include <xbase64.h>. Before sending the plaintext message to the Firebase database, it must be converted into an array of bytes, then it is encrypted using the AES-128 encryption algorithm. For example, in our proposed system, the vibration sensor reads the data 111111111111111 (means there is vibration), then before writing these data to the Firebase database, we encrypt them using the AES-128, the result is the following ciphertext:

8uhGNfBR5LNgfWhalY2Zmp4DcCBwj9CAEB4xVqTZoOU=, and the AES decrypted output is MTExMTExMTExMTExMTExMQ==. After that the ciphertext is decrepted producing the original plaintext message 111111111111111.

8 Conclusion and Future Work

This paper proposed an IoT system that is able to detect water pipeline leakage efficiently when the pipeline is buried under the ground using a shielded pipeline, soil moisture sensor, a pump, and a NodeMCU Wi-Fi board, which is connected to a Firebase database in the cloud. Besides, this paper proposed a novel approach for securing the underground pipelines against adversaries. Compared with the state-of-the-art, the proposed system performed better than the other systems that use a single pipeline in terms of the time required for detecting water leakage and the system cost as well. The results showed that the proposed system reduced the time required for detecting water-pipeline leakage by 70% and the system hardware cost by 83% compared with the earlier work. However, it was difficult to compare the total cost of the proposed system (as described in Eq. 9) with the total cost of the systems proposed in the previous work since this cost (as described in Eq. 9) was not calculated in the previous work. To facilitate the comparison between the proposed system cost and the previous systems cost, we compared the cost of hardware (C_H) for the proposed system with an estimated cost for the previous systems taking into account the minimum prices available on the Internet.

Besides, unlike the other systems that are based on the pipeline vibration frequency or the vibroacoustic phenomena, the proposed system is not affected by vibrations or frequencies from the surrounding environment. In addition, unlike the previous work, the proposed system is tested when the pipeline is buried in various types of soil. The main advantage of the proposed IoT system is its efficiency and ability to quickly detect water leakage before losing a large quantity of water. The proposed IoT system can be used for detecting water leakage, oil leakage and other liquids moving in a pipe. In future, we intent to investigate more security issues related to our proposed IoT system. Besides, we propose to use machine learning and encryption techniques [Rifaee, 22] [AL-Allaf, 13] [Hawashin, 20] [Oufqir, 21] [Abusukhon, 21b] [Abusukhon, 21c] with our proposed system.

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