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FIDO Cloud Correlation - A novel cloud-based correlator for water leak localisation in underground pipelines

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Abstract

FIDO AI is an accurate leak detection and localisation system which is designed to significantly reduce the frequency of false alarms and reduce the repair cost. First, the suspected leak pipe is identified by FIDO AI. Then, leak engineers visit the site to determine the precise location of the leak by applying a correlation technique. In this study, we define a new, effective and easy method to correlate leak noise samples which is called as FIDO Cloud Correlation (FCC).

1. FCC Framework

The FCC framework consists of two sensor nodes, a mobile application, and the FIDO AI intelligent software in the cloud (Edwards N. , 2021; Edwards V. , 2021). The sensor nodes used are called FIDO Bugs (Bugs), as shown in Figure 1.1. Bugs consist of in-built acoustic sensors, a memory chip, and a Bluetooth (BLE) module, all encapsulated inside a waterproof casing with a magnet on the base. The magnet allows Bugs to be quickly, easily and securely deployed.



Figure 1.1 A FIDO bug

The two Bugs are deployed either side of the suspected pipe leak. Their highly sensitive internal acoustic sensors simultaneously record acoustic and kinetic samples and store them in the memory chip. These samples are extracted using the FIDO mobile application via BLE and transmitted to the cloud via WiFi or mobile data for processing as shown in Figures 1.2 and 1.3. The intelligent FIDO AI software in the cloud returns a near instant result to the leak engineer on the in-field mobile application. The computation for correlation is based on the acoustic samples which are recorded simultaneously by the Bugs.

In traditional correlators, synchronisation is achieved with RF samples that add cost and size to sensor nodes. For FCC, a simple and efficient synchronisation method is used by tapping the two Bugs together before deployment.

The leak noise samples are filtered and correlated in the cloud using a cross-correlation function (Gao, 2003). Cross-correlation is applied to find the similarity between the samples in terms of time difference called lag. Cross-correlation is computed using Equation 1.

$$u(t) \otimes v(t) \triangleq \int_{-\infty}^{\infty} \overline{u(\tau)} v(\tau + t) dt \quad 1$$

where, ' $u(t)$ ' and ' $v(t)$ ' are two samples recorded from Bugs, ' $\overline{u(\tau)}$ ' is complex conjugate and ' τ ' represents the lag of one signal to the other signal. In terms of leak detection, cross correlation computes the lag (τ) between the leak noise samples recorded across the suspected leak pipe. Equation 2 is subsequently applied to compute the location of leak.

$$L_a = \frac{L - v \tau}{2} \quad 2$$

where, ' v ' represents the velocity of sound in the pipe which depends on material of the pipe, ' L ' denotes the total length between the Bugs at points A and B, and ' L_a ' denotes the length of leak from Bug installed at point A.

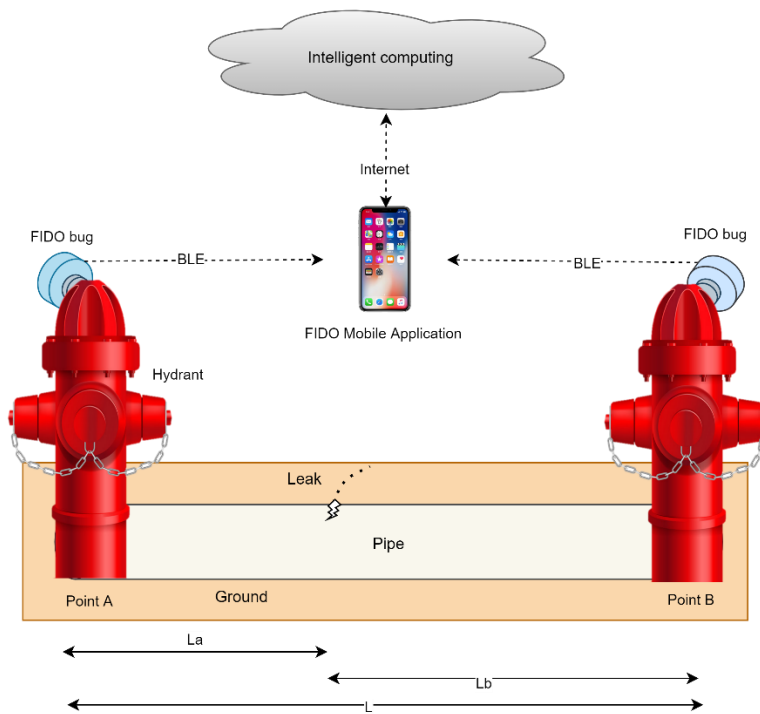


Figure 1.2 The FCC framework

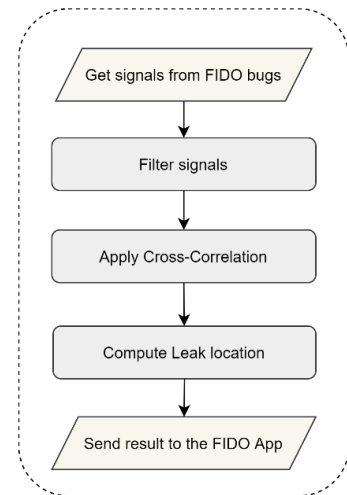


Figure 1.3 FCC processing

2. FCC Procedure

FCC offers a straightforward method for correlating leak noise. It requires direct access to the pipeline network either side of the suspected leak. The following steps are then applied to locate it in the pipe:

- 1) Set the Bugs to correlation mode using the FIDO mobile application via BLE
- 2) Tap the Bugs together to synchronise them as shown in Figure 2.1.
- 3) Deploy both Bugs across the suspected pipe leak as shown in Figure 2.2.
- 4) Wait to record the samples
- 5) Upload the samples to the cloud using the FIDO mobile application
- 6) Receive the leak location as a distance from Point A and inform the digging unit to start the repair process



Figure 2.1 Two Bugs are tapped together to synchronise



Figure 2.2 A FIDO Bug attached magnetically to a hydrant

3. Results and discussions

The accuracy of the correlation system depends on the accurate synchronisation of the recordings, the sound velocity of pipe material, and the filtering process for the leak noise samples. For this project, the synchronisation is achieved by tapping the Bugs and the results are discussed in next section. The sound velocity varies with pipe geometry and aging as well as the type of soil around the pipe. A reference table giving sound velocity values for various pipe materials and diameters is often used where pipe network information is available. The impact of aging and soil has been considered negligible. Noisy samples are filtered using band pass filters to extract leak noise.

3.1 Synchronisation

In traditional correlators, synchronisation is achieved by using radio frequency signals. With Bugs, synchronisation is achieved with the tapping mechanism. This can significantly reduce the size and cost of hardware. The real time clocks (RTC) attached with microprocessors, which are contained in each Bug, are not synchronised during the initial independent activation of the Bugs. Synchronisation occurs at the impact of the tap. This point of impact is also used as a reference point to start the timer. There then follows a 5-minute delay to allow adequate time for the manual deployment of the Bugs followed by two separate synchronised sample recordings separated by a minute. Each sample lasts 25 seconds. Two samples are taken to minimise the risk of a temporary noises affecting the results.

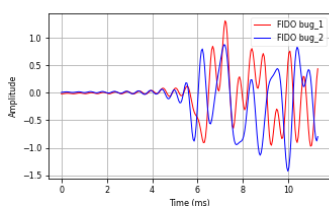


Figure 3.1 Drift trial

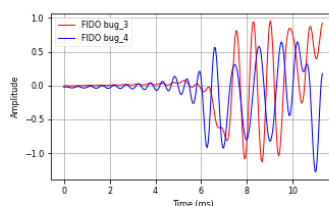


Figure 3.2 Drift trial

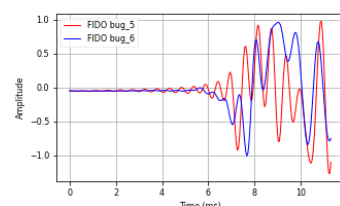


Figure 3.3 Drift trial

Several trials were performed to analyse the clock drift. Clock drift trials involved activating the two Bugs by tapping them to start the in-built RTCs and then tapping them together again during the recording of the second of the two samples. The peaks of both readings were analysed to find the time drift between the two Bugs. Three trials performed with three different pairs of FIDO Bugs are shown in Figures 3.1, 3.2 and 3.3. The time drift between FIDO bug_1 and FIDO bug_2 is 0.36ms, FIDO bug_3 and FIDO bug_4 is 0.51ms and FIDO bug_5 and FIDO bug_6 is 0.18ms. It can be concluded that the unsynchronised lag error fluctuates but remains less than 1ms which is considered an acceptable level.

3.2 Leak Localisation

Several correlation trials were performed to analyse the outcomes of using FCC. Leak noise travels slower in plastic pipe compared to metal pipes (Gao, 2003). Therefore, two existing segments of underground pipework, which were already connected to a live water utility network at hydrants, were selected. One was made of plastic medium density polyethylene (MDPE). The other was a metal ductile iron pipe. A water leak was created between the two hydrants and leak noises were correlated using the procedure discussed in section 2.

The MDPE pipe setup was located at the testing facility of United Utilities, Worthington Lakes, United Kingdom. The diameter of this MDPE pipe segment was 100mm and total length between the hydrants was 15m. The known leak was at 7.5m away from Point A. The ductile iron pipe setup was in a residential area of Standish, United Kingdom, which is also part of United Utilities' network. The diameter of this ductile iron pipe was 80mm and the total length between the hydrants was 31.6m. The known leak was at 20m away from Point A. In each case, FCC was applied in a quiet environment with very minimum background noise. The FCC has shown promising results that are shown in Table 1. 'FCC loc' represents the leak location predicted by FCC application.

Table 1 FCC results

Trial No.	Location	Material	Diameter 'mm'	Length 'm'	Leak loc 'm'	FCC loc 'm'
1	Worthington lakes	MDPE	100	15	7.5	7
2			100	15	7.5	7.1
3			100	15	7.5	7.1
4			100	15	7.5	7.2
5	Derngate drive	Ductile Iron	80	31.6	20	21
6			80	31.6	20	20.5
7			80	31.6	20	20.5
8			80	31.6	20	20.5

4. Conclusion and future work

The results presented in this study are promising, showing a drift in final leak location within 1m, even for plastic pipes. This is considered an acceptable range of disparity given the typical size of a leak repair excavation is at least 1m. FCC is a novel method of applying correlation for water leak localisation which offers several key advantages over traditional commercially available correlators (Latif J. , 2021; Latif J. S., 2022). It offers the superior processing power and memory of cloud computing as compared to edge devices and the ability to generate customised reports. It is easy to deploy without special skills or specialised tools. FCC can therefore be adopted across the large number of leak engineers within the company in a short period of time. Results are saved in cloud-based storage thus keeping a complete record of historical leakage data for the company in perpetuity and building a data library. This offers several opportunities for further service enhancements.

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