香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Time-Reversal of Waves for Intelligent Monitoring of Pressurized Mains

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Acknowledgement: Hong Kong RGC; TRS project team; DSD; WSD and HKUST

Intelligent Health Monitoring?

- Non-intrusive
- Rapid to perform
- Economical
- Good for all problems (faults)
- Able to anticipate problems
- Reliable and low cost

→ **WAVES!**
e.g., Medicine, SONAR, RADAR

How?

Wave Transmitter

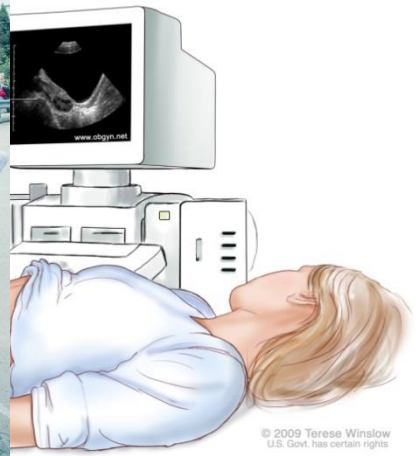
Inaccessible, poorly known, complex **medium/system**

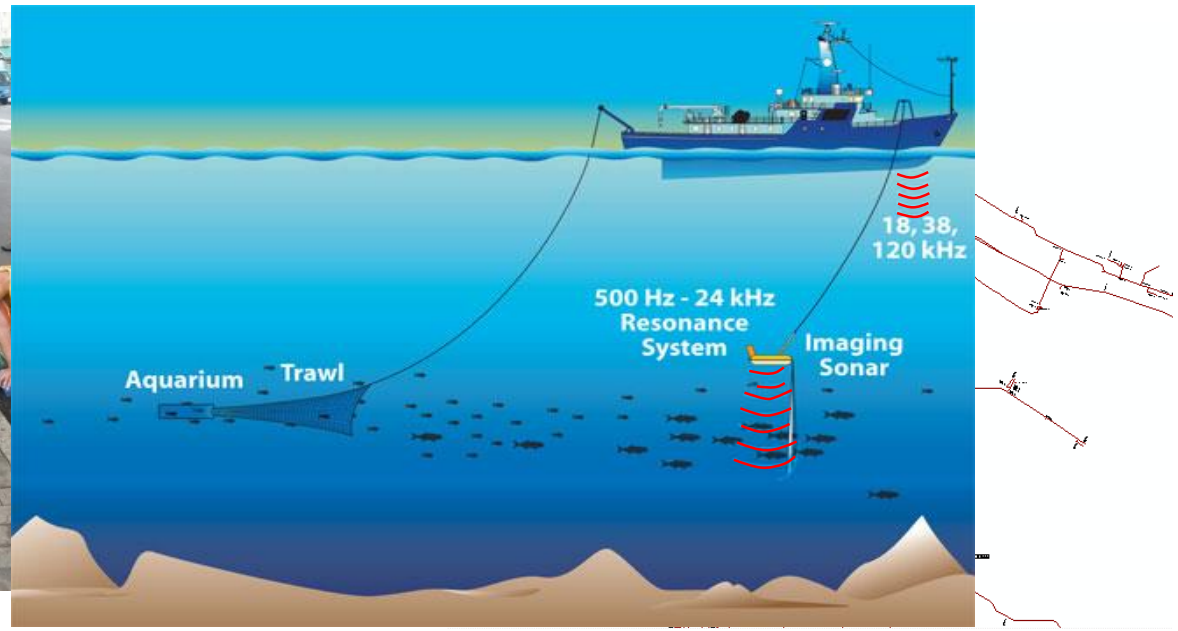
e.g. Pipelines?

Wave Receiver

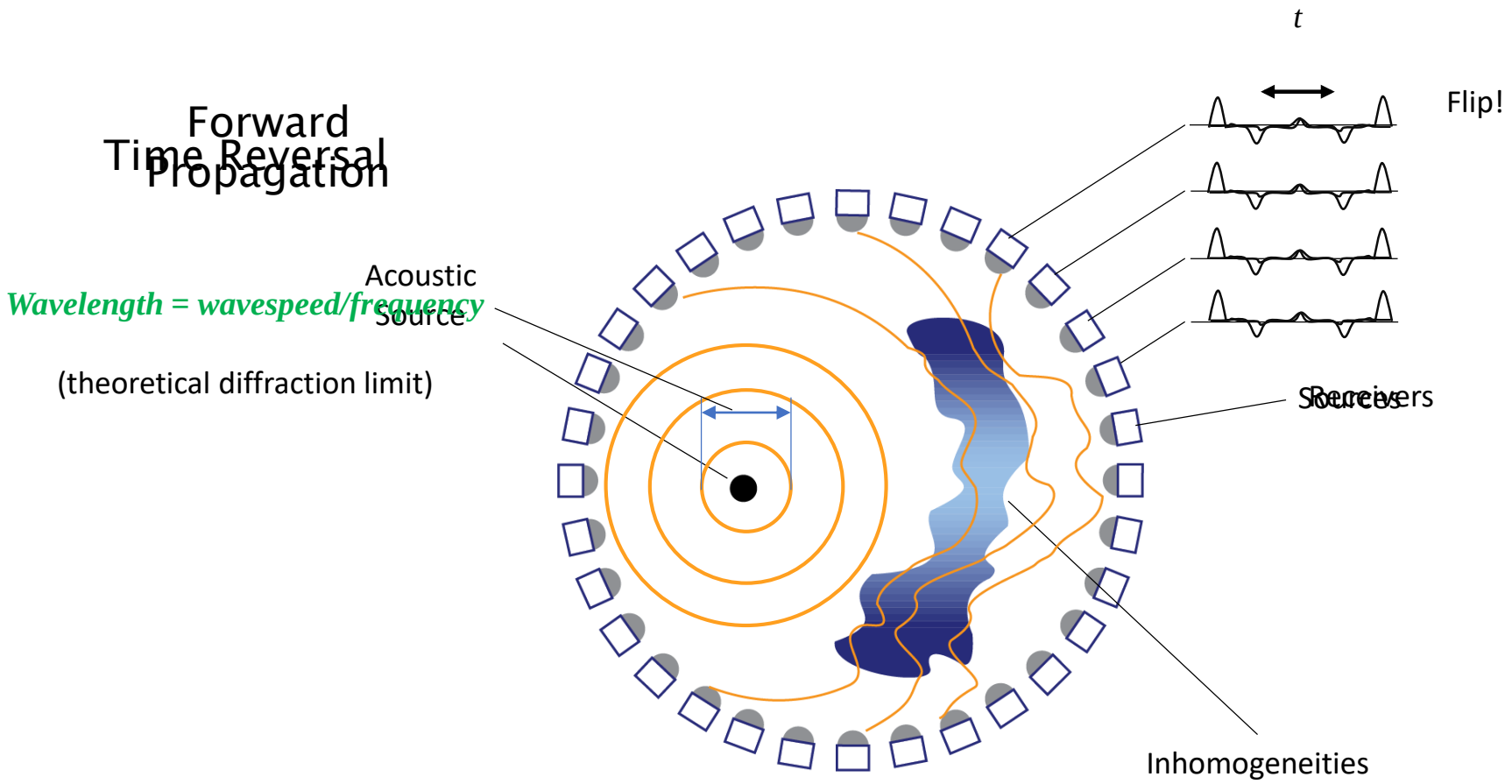
Wave Theory

"Health Assessment"





How to Turn Waves to Health Assessment? Time Reversal (TR)!

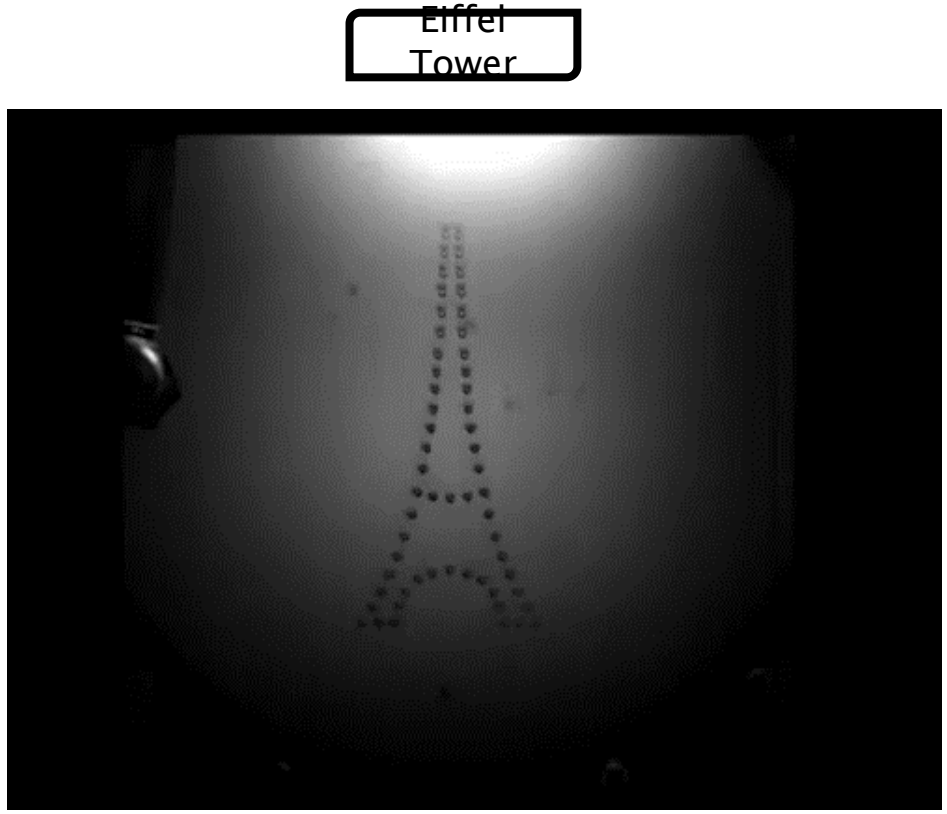


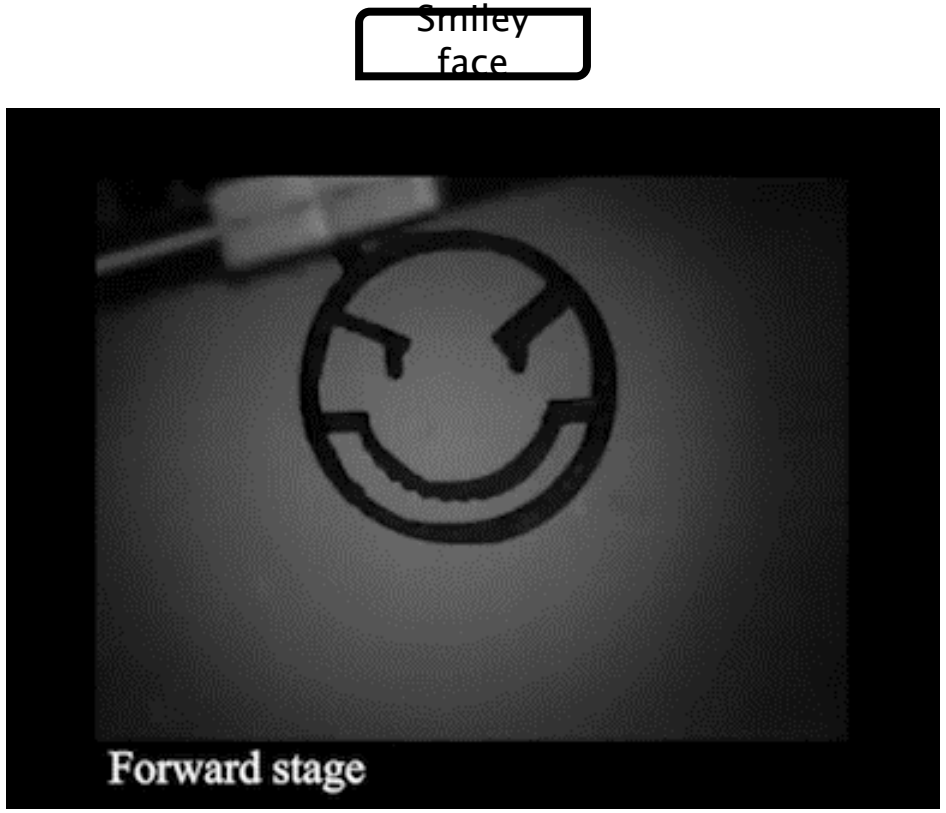
Fink, M. (1999). Time-Reversed Acoustics. *Scientific American*, *281*, 91-97.

TR of Gravity Waves

de Mello, P., Pérez, N., Adamowski, J., & Nishimoto, K. (2016). Wave focalization in a wave tank by using time reversal technique. *Ocean Engineering*, *123*, 314-326.

TR of Gravity Waves

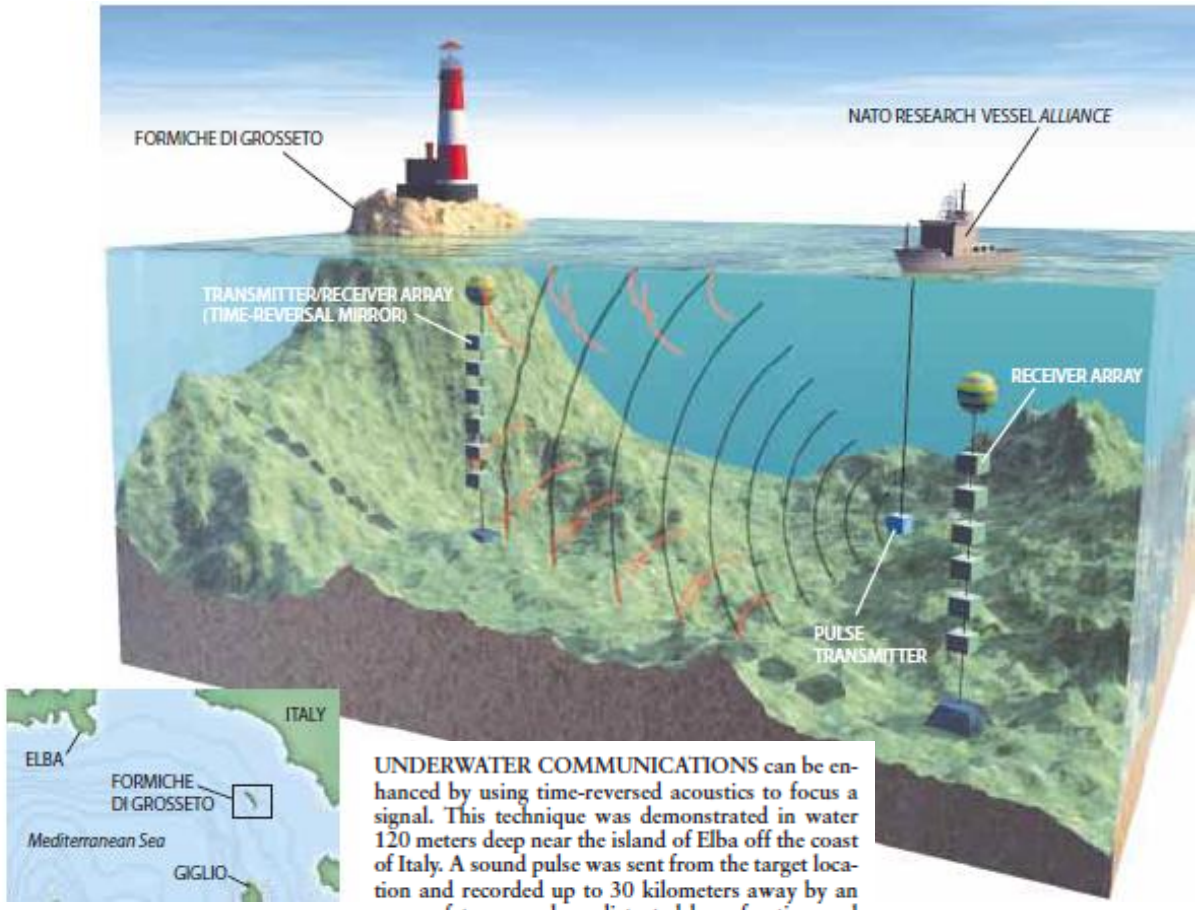




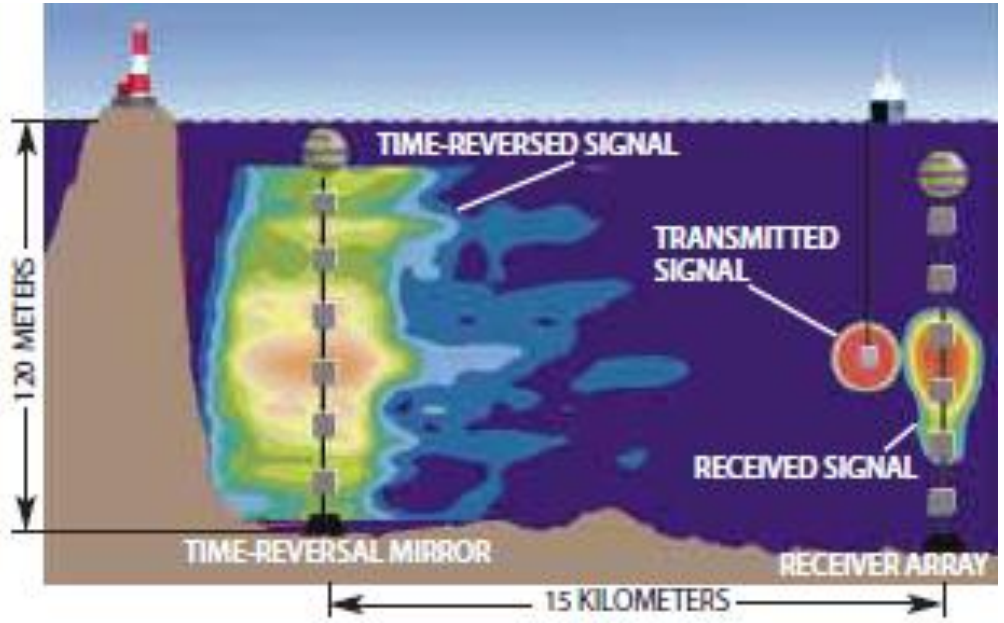
Bacot, V., Labousse, M., Eddi, A., Fink, M., & Fort, E. (2016). Time reversal and holography with spacetime transformations. *Nature Physics*, *12*, 972-977.

TR of Acoustic Waves

TR of Acoustic Waves in the Ocean



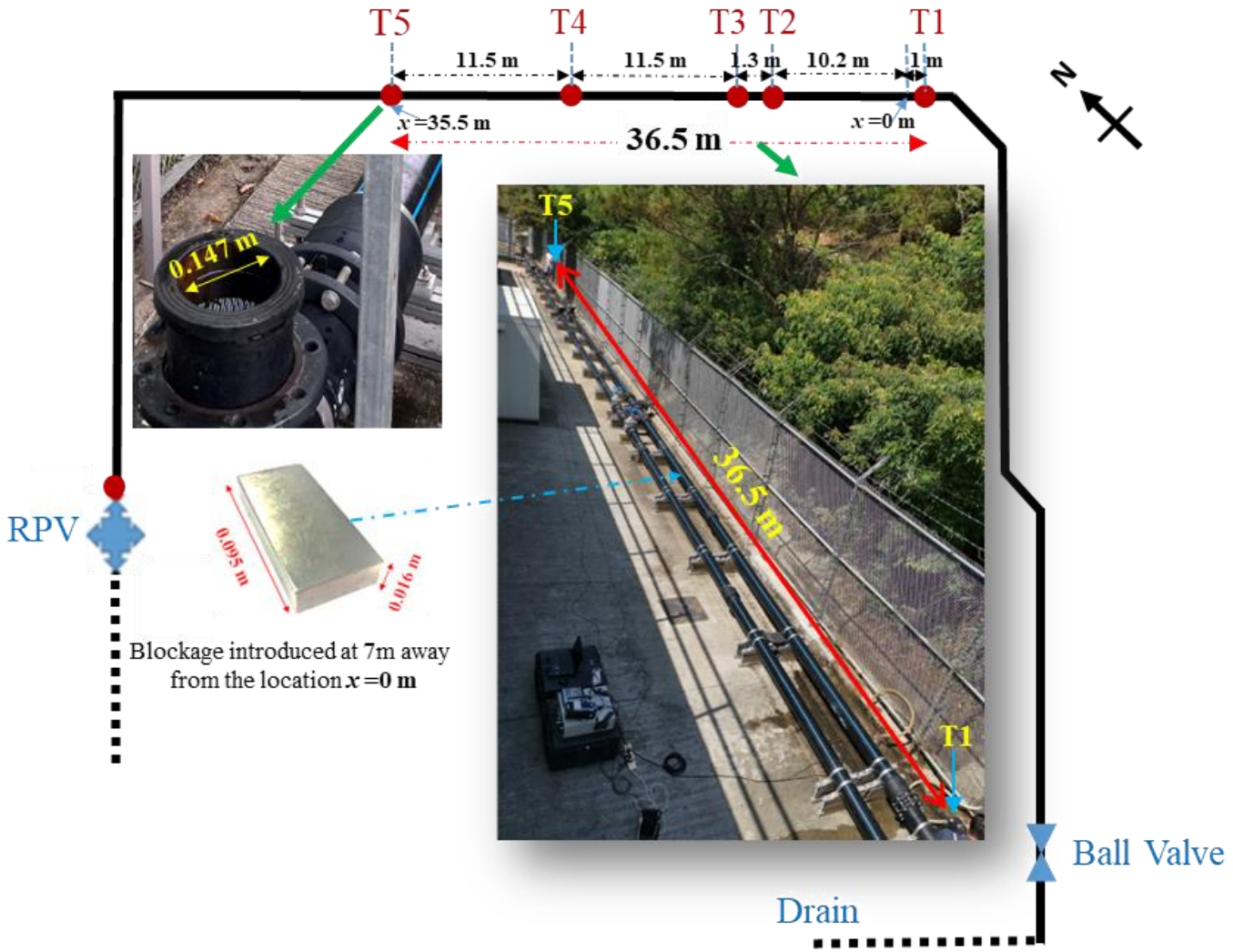
UNDERWATER COMMUNICATIONS can be enhanced by using time-reversed acoustics to focus a signal. This technique was demonstrated in water 120 meters deep near the island of Elba off the coast of Italy. A sound pulse was sent from the target location and recorded up to 30 kilometers away by an array of transponders, distorted by refraction and multiple reflections (*red*) from the surface and the seabed. The time-reversed signal sent by the array was well focused at the target location.



Fink, Mathias (1999). "Time-Reversed Acoustics." *Scientific American*, 281, 91-97.

Experimental proof of TR in pressurized pipes in Beacon Hill

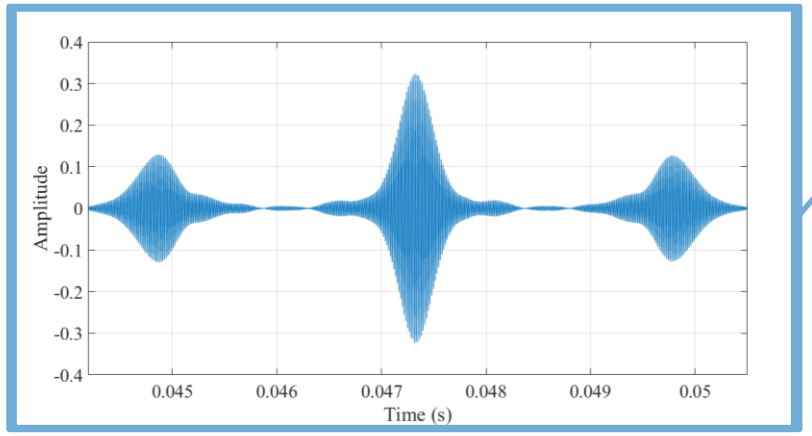
Experimental proof of TR in pressurized pipes in Beacon Hill

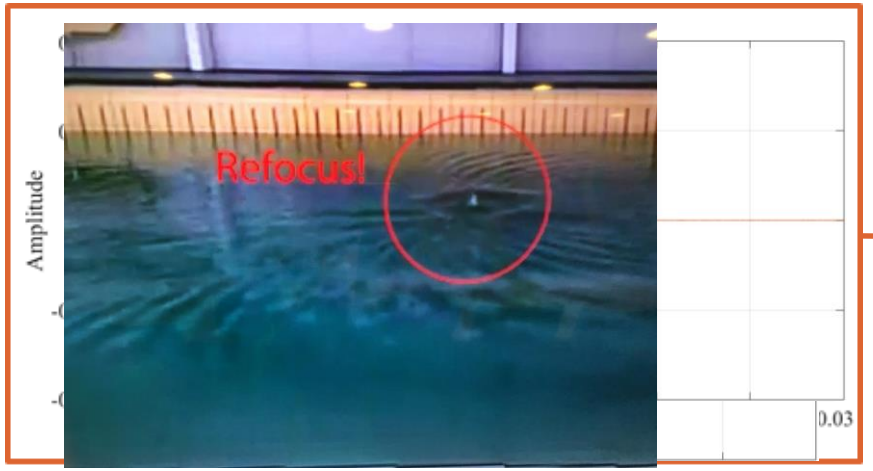


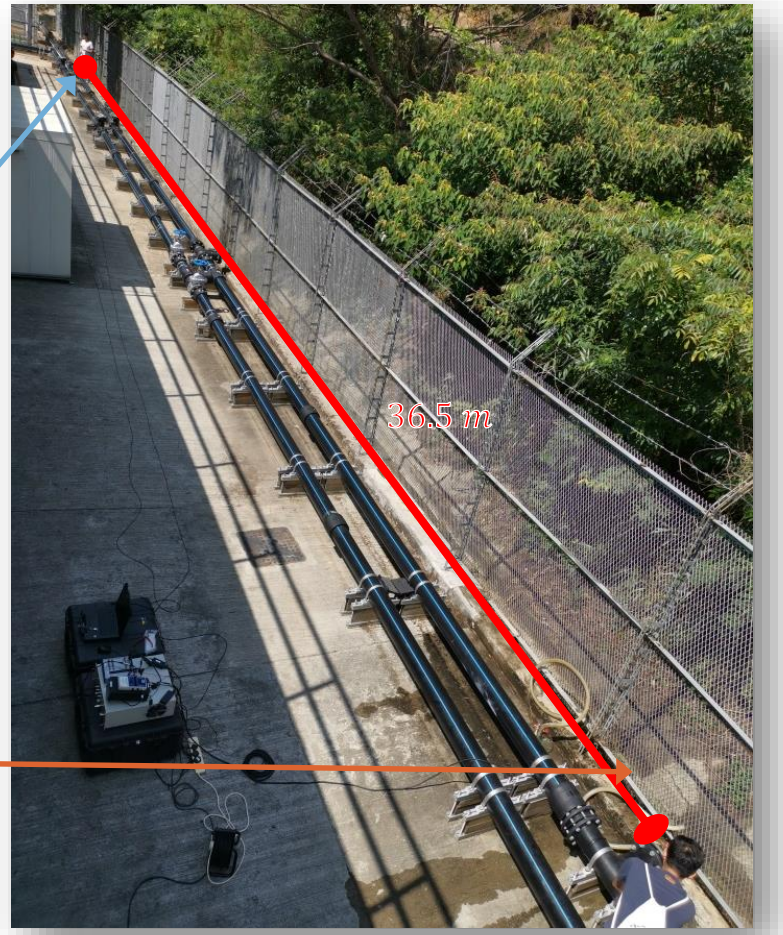
Experimental proof of TR in pressurized pipes in Beacon Hill

Time-reversal

- Recreated Original Source
- Original Source
- System Response @ 36.5 m
- TR Source







TR applications at low frequencies (LF): Defect detection in pipes

1. Pioneered Time Reversal (TR) in UWSS
2. 5 US patent were awarded;
3. Established 11 unique testbeds; 8 under development
4. Advanced the state-of-the-art of high- and low-frequency waves in UWSS
5. Developed real-time systems for defect detection (2 completed & 3 under development)
6. Silver medal award at Geneva Expo 2023


DIPLÔME

Inventions Geneva

SALON INTERNATIONAL DES INVENTIONS GENÈVE

Après examen, le Jury International a décidé

de remettre à: Drainage Services Department, Government of HKSAR
Prof. Mohamed S. Ghidaoui, Prof. Moez Louati,
Dr. Muhammad Waqar, Mr. Mohamed H. E. Ben Arab, HKUST

pour l'invention: Technologie intelligente d'inversion du temps pour surveillance des canalisations d'égouts

MÉDAILLE D'ARGENT
SILVER MEDAL
SILBERMEDAILLE

Genève, le 28 avril 2023

Le Président du Jury: David Tay

Le Président du Salon: Jean-Luc Vincent

RGC Panel

"The overall progress appears to be exemplary... technology deployment in the field that appears to have real world impact …"

"The team has built up impressive installations for the field experiments ... The review team should give the PC an excellent rating on this project."

"The team introduced 'time reversibility', a new technique… their work is highly interdisciplinary..."

TR methodology being applied in the field

Pilot tests in Canada in collaboration with HydraTek

Pilot tests in UK in collaboration with FIDO

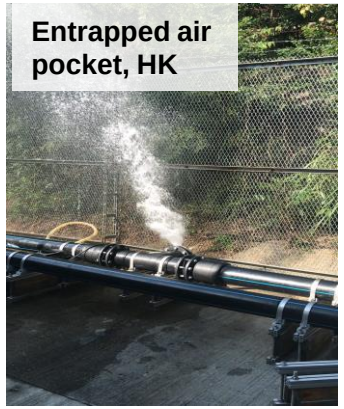
TR methodology gets the job done

Identified and located leaks, malfunctioning devices, unknown branches, blockages (e.g., entrapped air pockets), unknown water withdrawal, and proposed system improvements


Leak @ HK

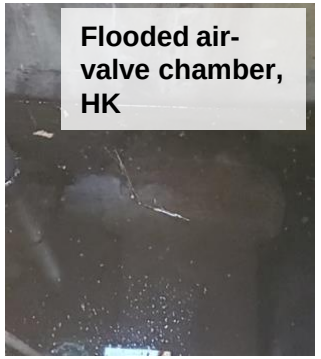

Unknown water withdrawal, HK

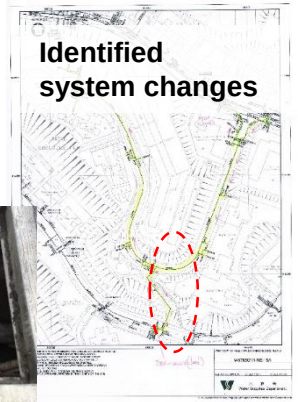

Leak @ Italy


Entrapped air pocket, HK


Proposed system improvement, HK

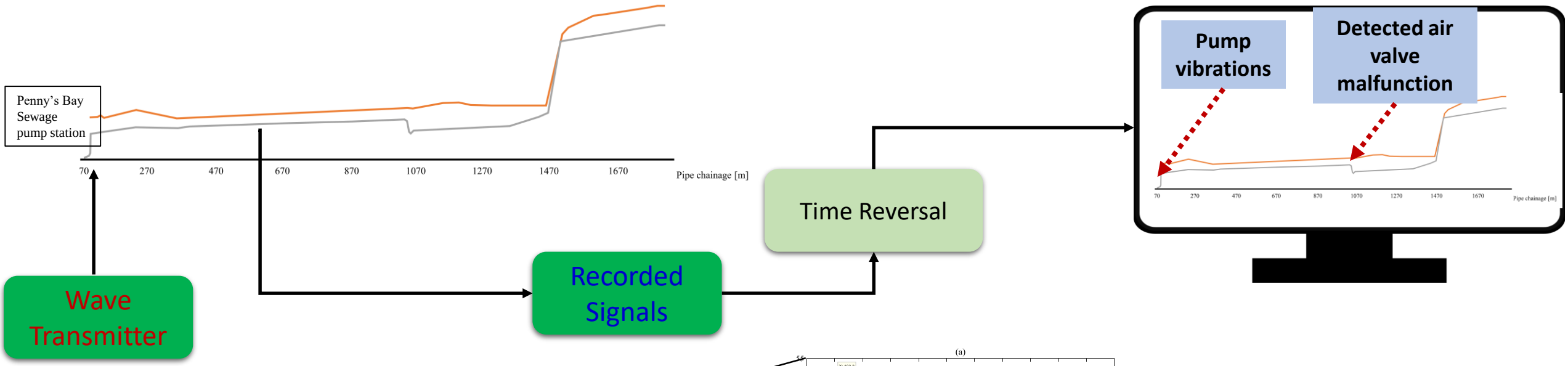

Leak @ HK


Flooded air-valve chamber, HK


Identified system changes

Penny’s Bay Sewage Pumping System

Typical data that we analyzed by TR in Penny Bay



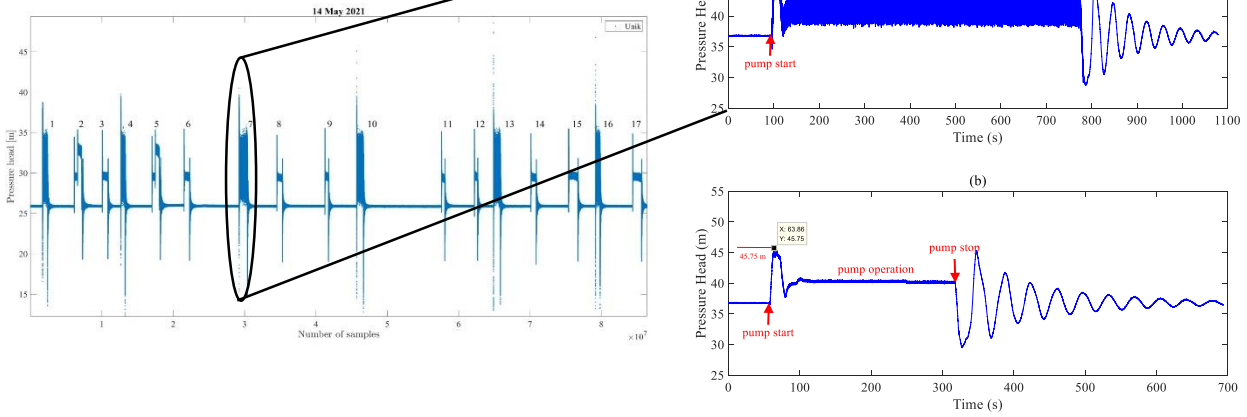
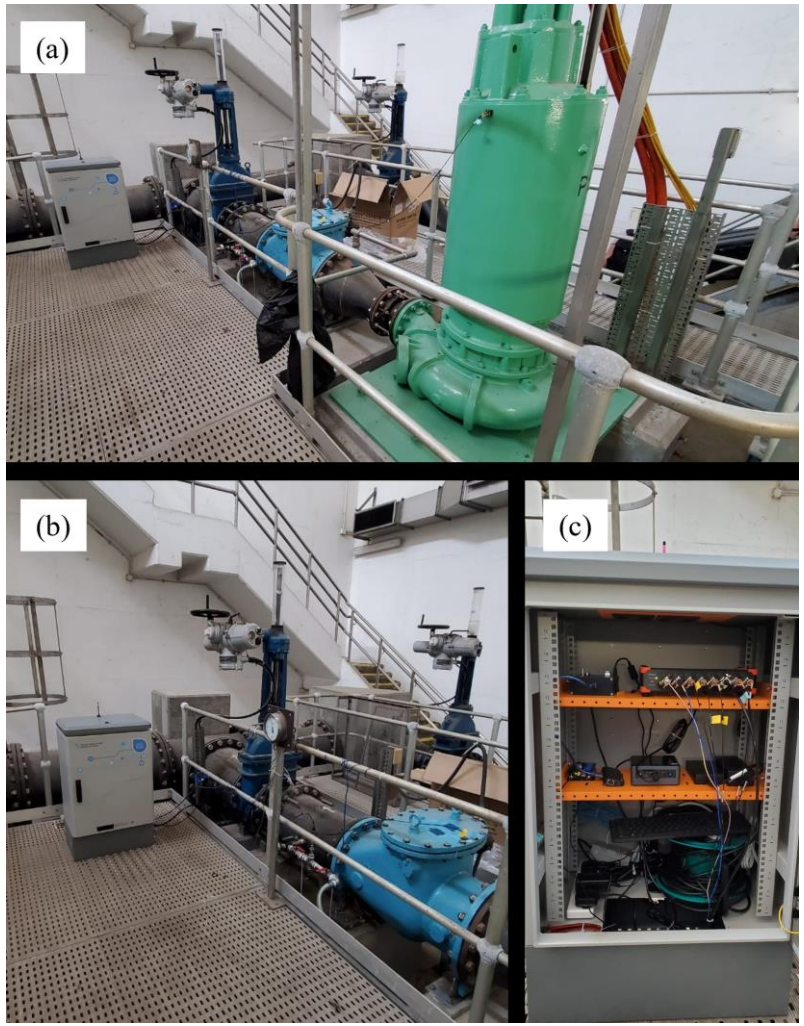


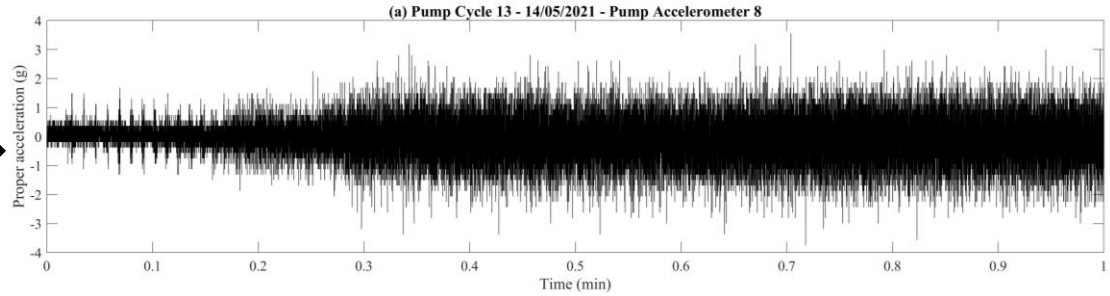
Figure 1 Transient signals measured at Pump 1 in Penny's Bay: (a) pump operation with large noise (06 April 2020); and (b) smooth pump operation (07 April 2020).

Air valve chamber malfunctioning

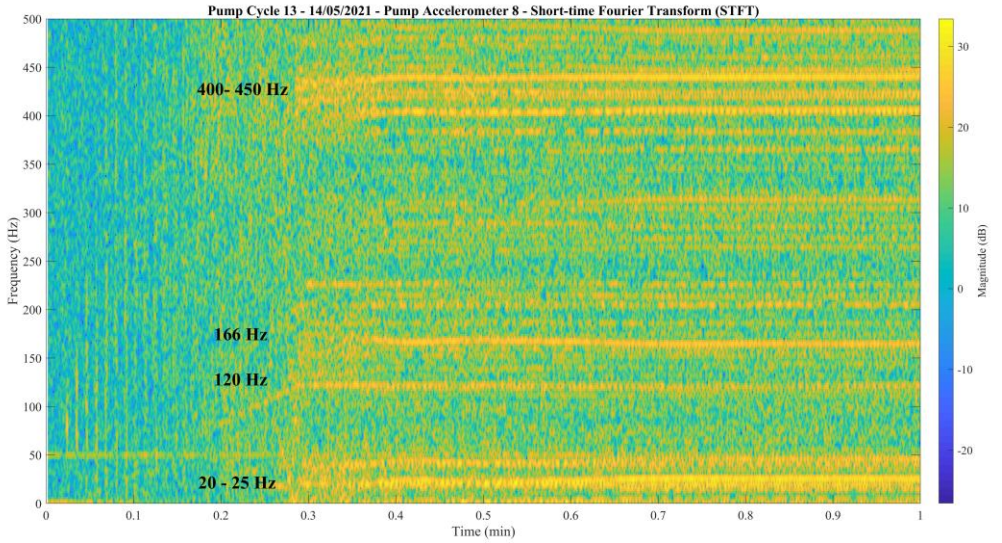
Air valve chamber malfunctioning

Excessive Pump Vibration



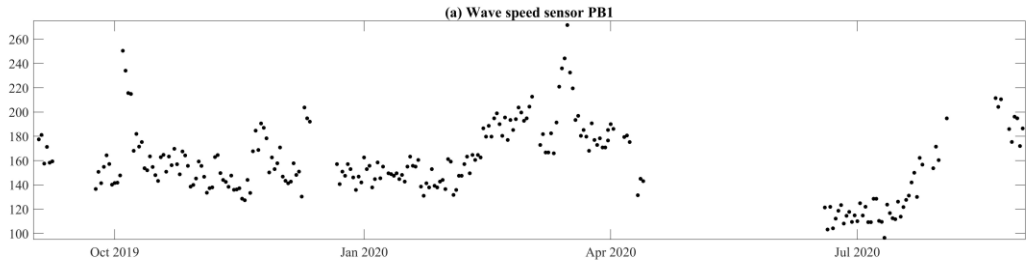


Spectrogram



Excessive undissolved gases

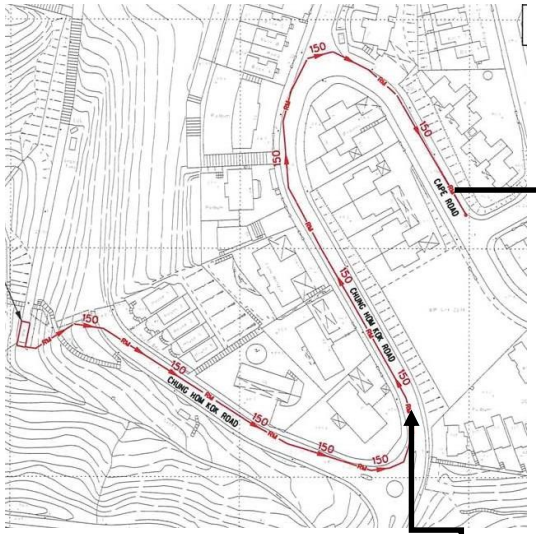
			Frequency Domain			Time Domain		
	Transient Event	Transient duration	$\frac{a}{4L}$ $[s^{-1}]$	a $[m/s^2]$	α [%]	$\frac{4L}{a}$ $[s]$	a $[m/s^2]$	α [%]
Dataset1	PB120200101TE1	5 min	0.02364	171.67	0.34	44.812	162.09	0.38
	PB120200101TE2	5 min	0.02193	159.25	0.4	46.211	157.18	0.4
	PB120200102TE1	5 min	0.02247	163.17	0.38	44.328	163.86	0.37
	PB120200102TE2	5 min	0.02221	161.28	0.39	48.656	149.28	0.45
	PB120200103TE1	4.5 min	0.02268	164.7	0.37	37.438	194.01	0.26
	PB120200103TE2	4.5 min	0.02207	160.27	0.39	45.821	158.52	0.4
Dataset 2	PB120200406TE1	5.5 min	0.02639	191.64	0.27	35.601	204.03	0.24
	PB120200406TE2	6 min	0.02735	198.61	0.25	35.39	205.24	0.23
	PB120200407TE1	6 min	0.02746	199.41	0.25	38.29	189.7	0.27
	PB120200407TE2	6 min	0.02735	198.61	0.25	37.594	193.21	0.26
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	176.75	0.32
	[illegible]						166.89	0.36



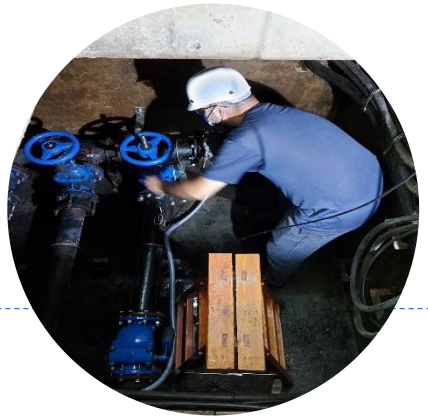
"High concentrations of hydrogen sulfide gas are known to cause corrosion, leaks and eventual breakdown of pipes!!!"

Chung Hom Kok Road Sewage Pumping System

Sewage leak at Chung Hom Kok Road (Stanley)

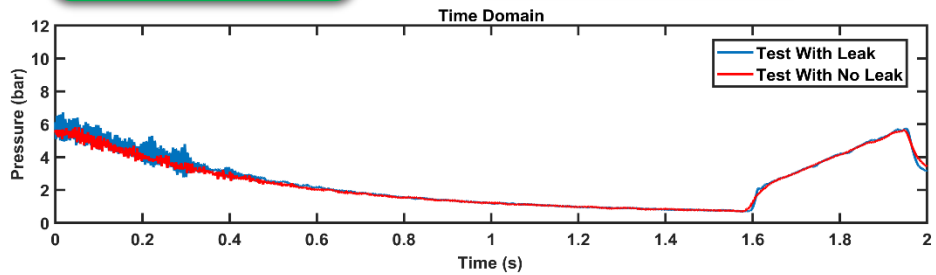


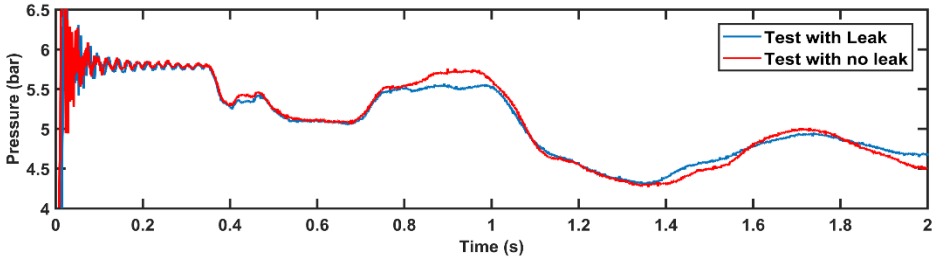
Wave Transmitter

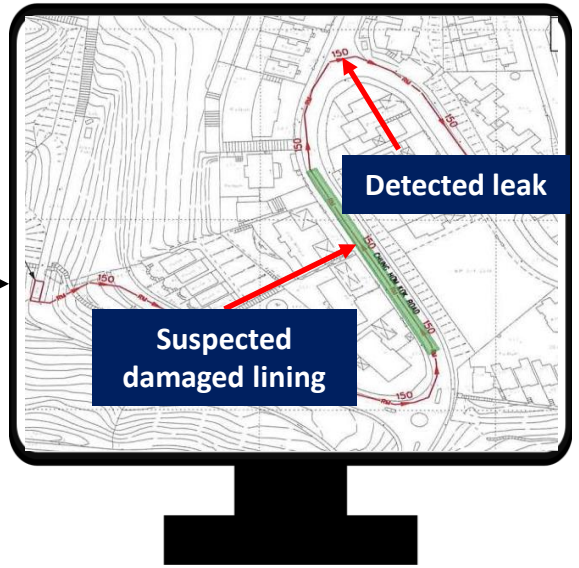


Recorded Signals

Time Reversal



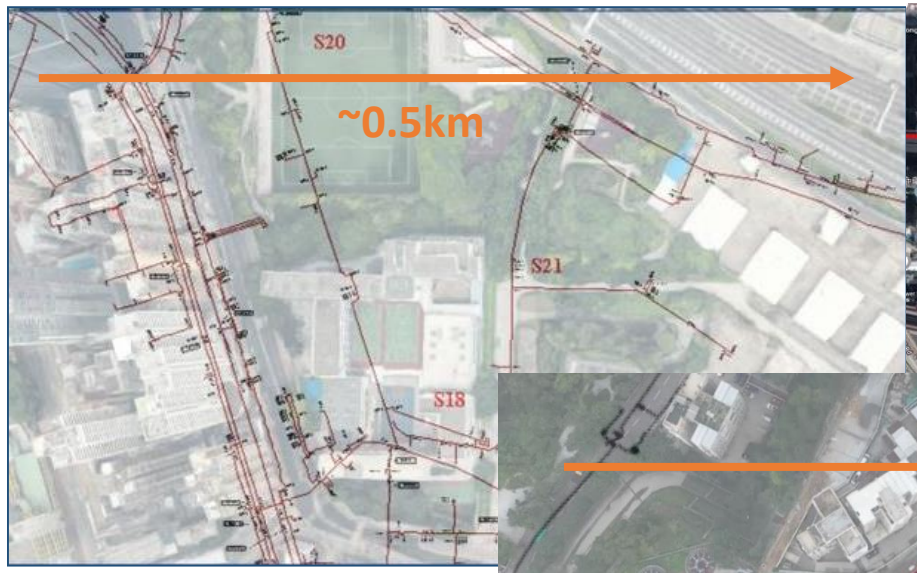




Leak at the road junction

Applications in Fresh Water Supply Systems

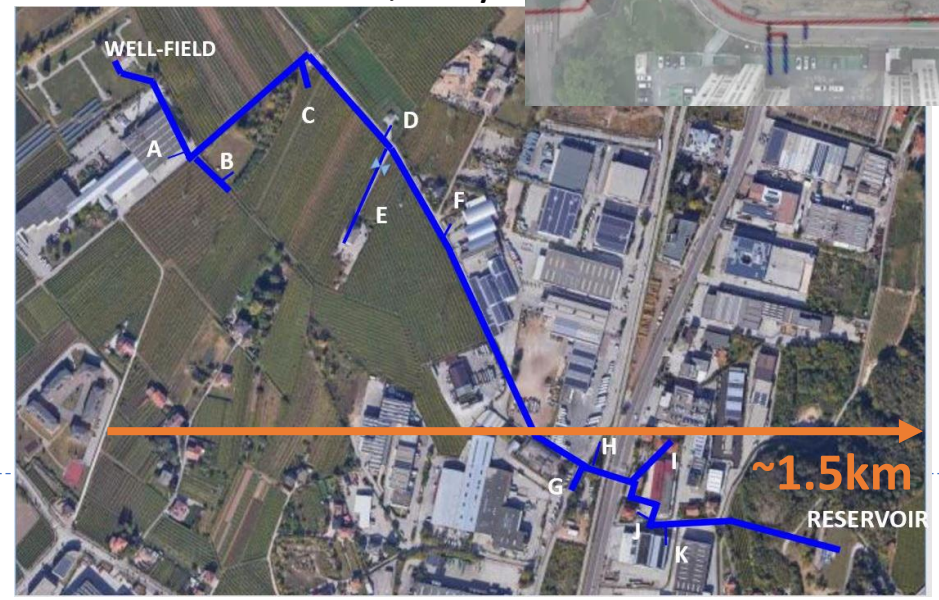
North Point, Hong Kong



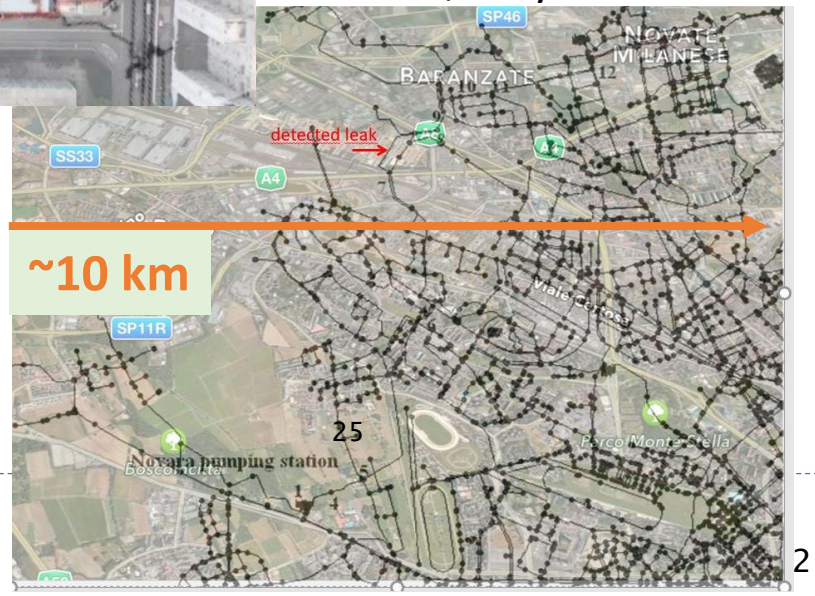
Yuen Long, Hong Kong

Ngau Tau Kok, Hong Kong

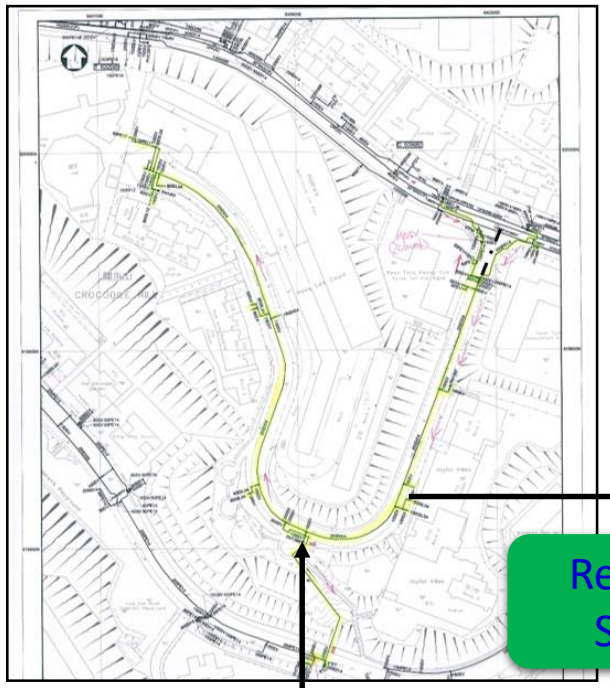
Trento, Italy



Milan, Italy



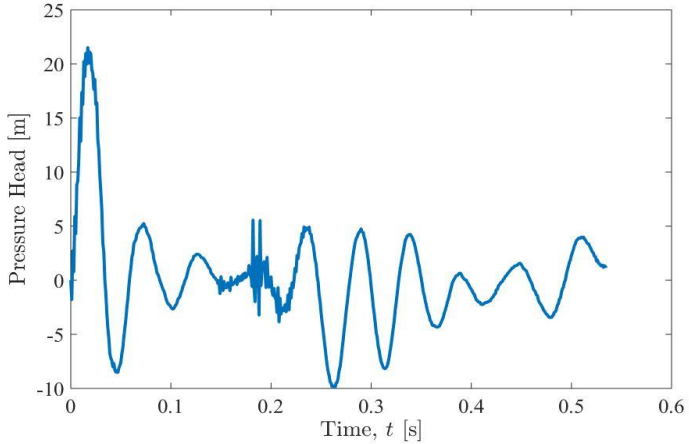
Leak Identification (NTK, HK)

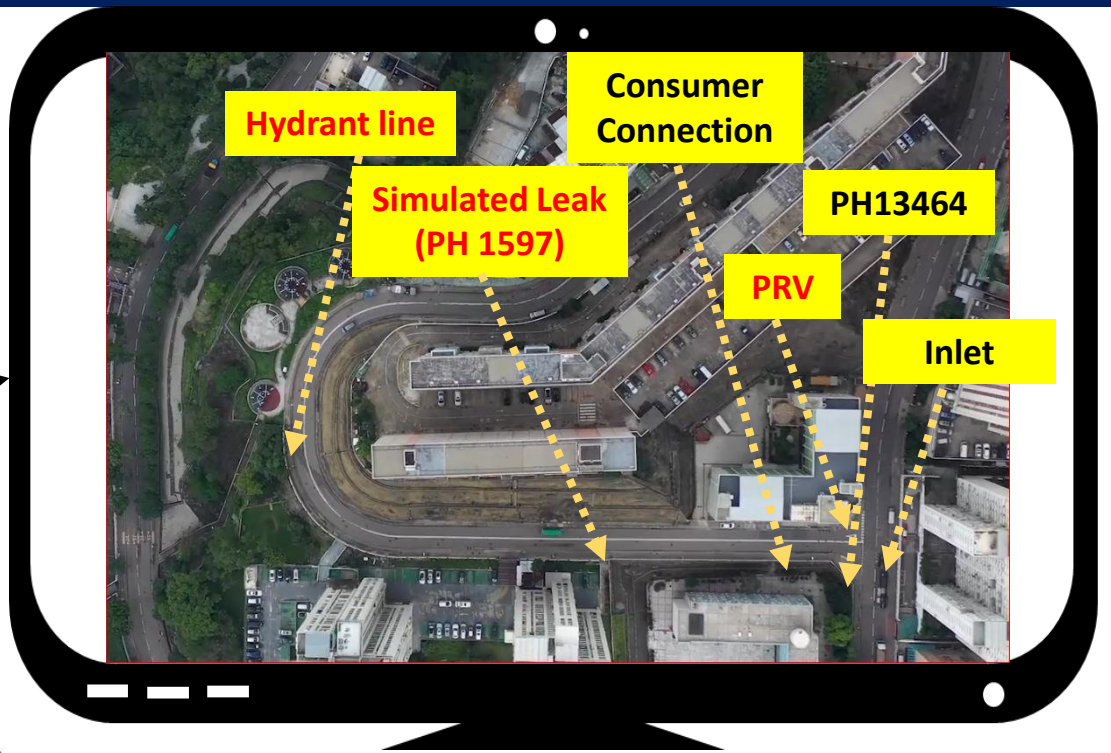


Time Reversal

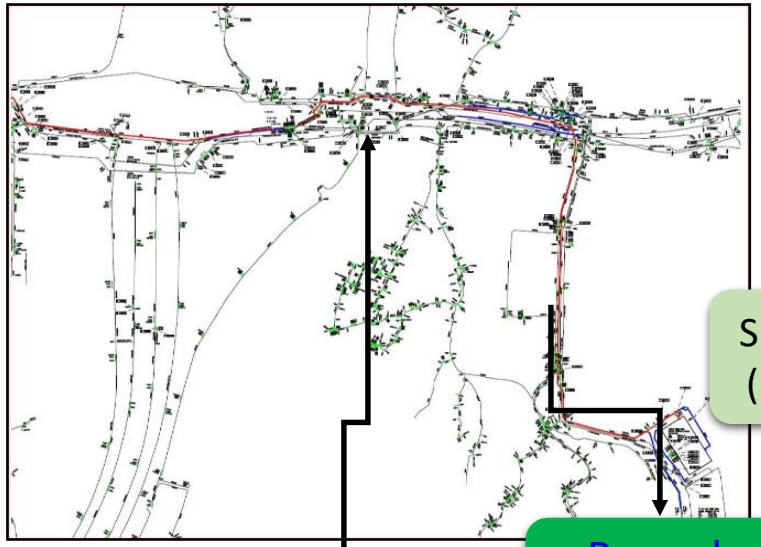
Recorded Signals

Wave Transmitter





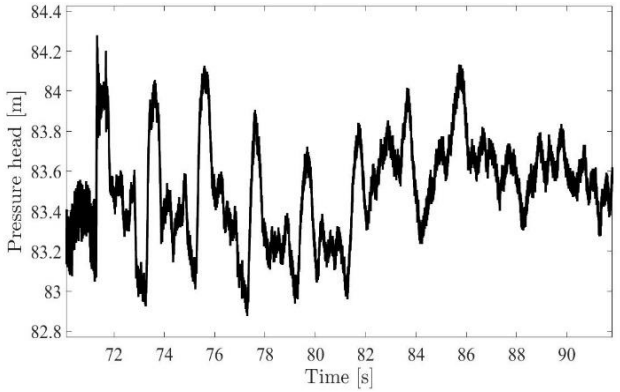
Test in September 2019 - Leak Identification (Yuen Long, HK)

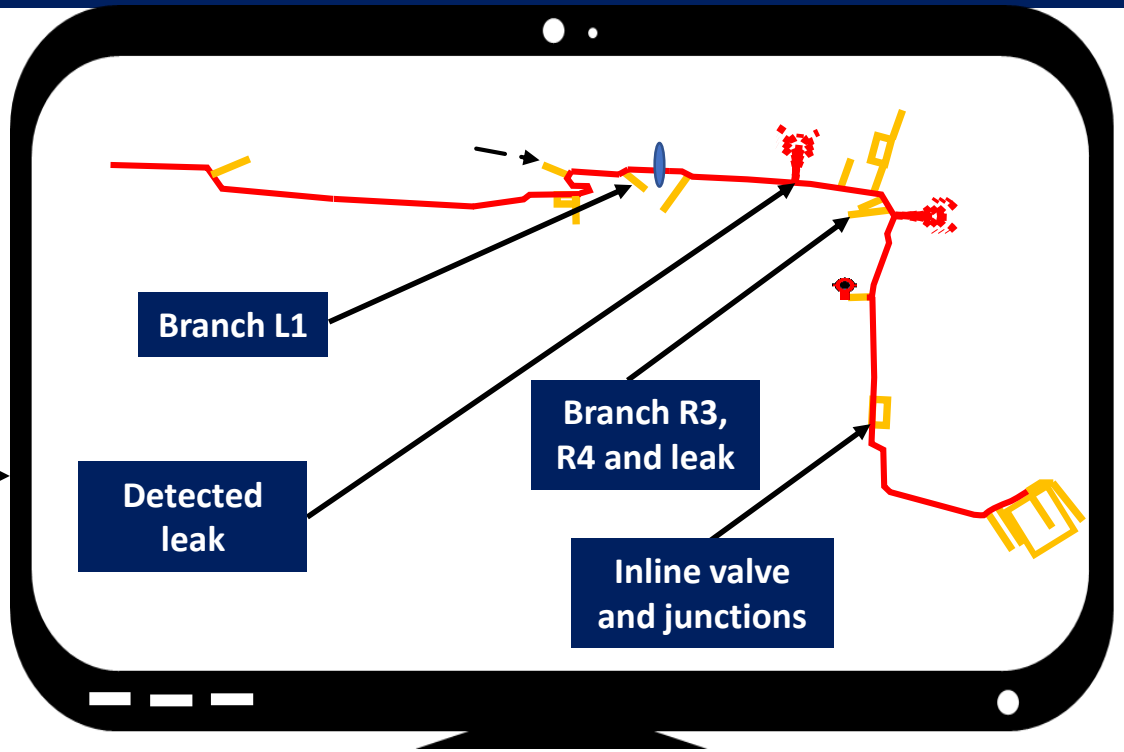


Signal Processing
(Model vs. data)

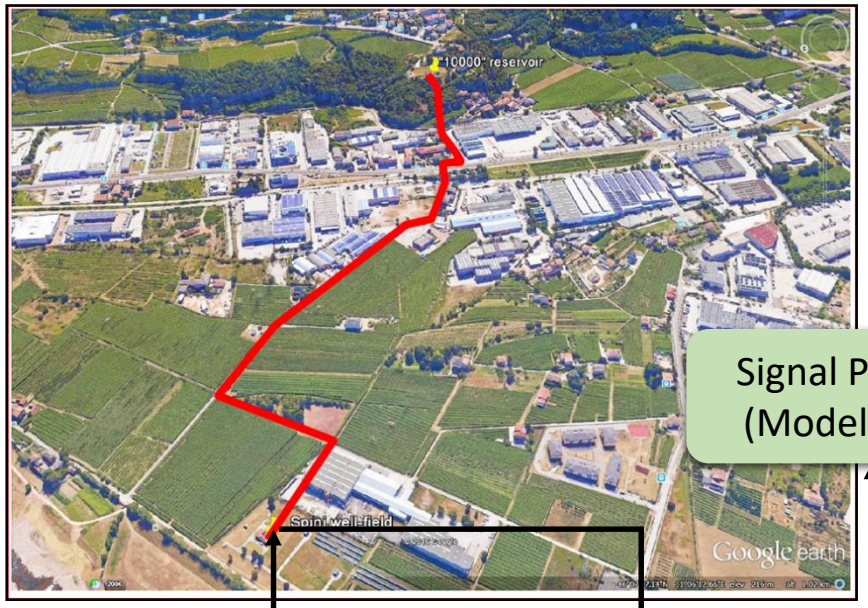
Recorded
Signals

Wave
Transmitter

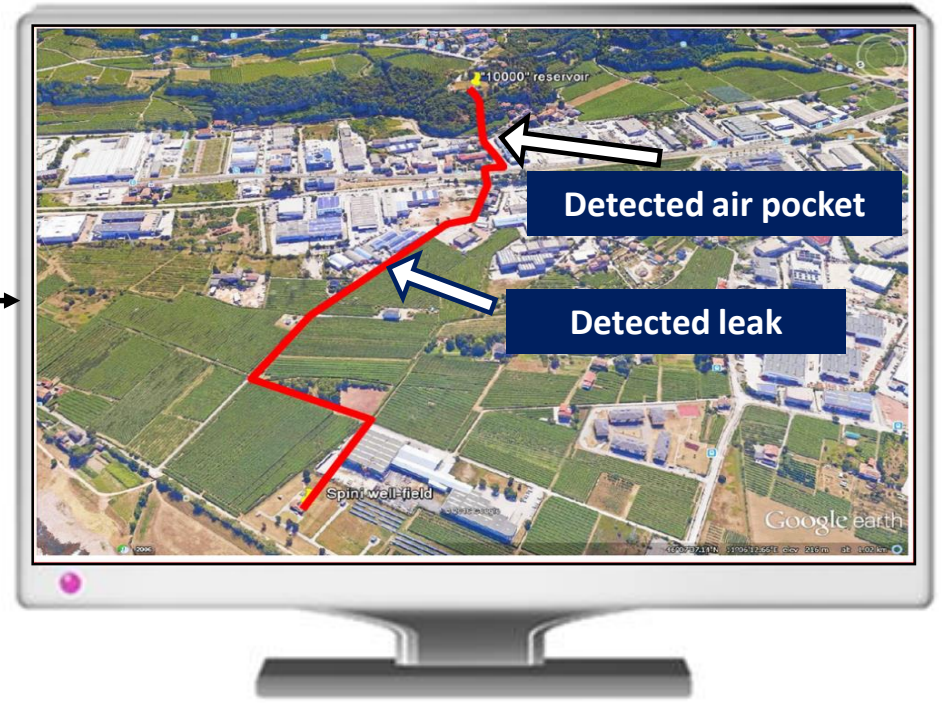




Field Site 3: TRENTO, ITALY

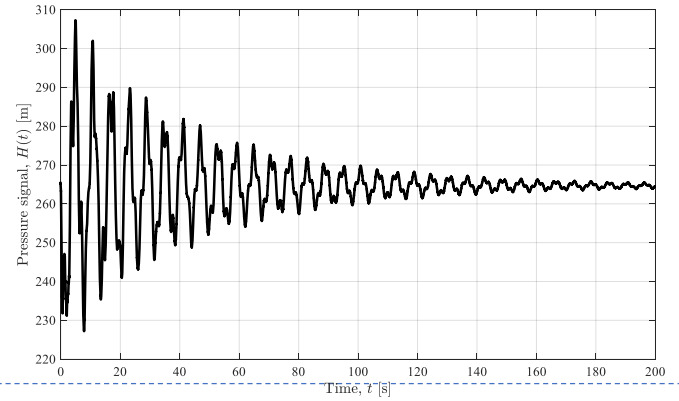


Signal Processing
(Model vs. data)

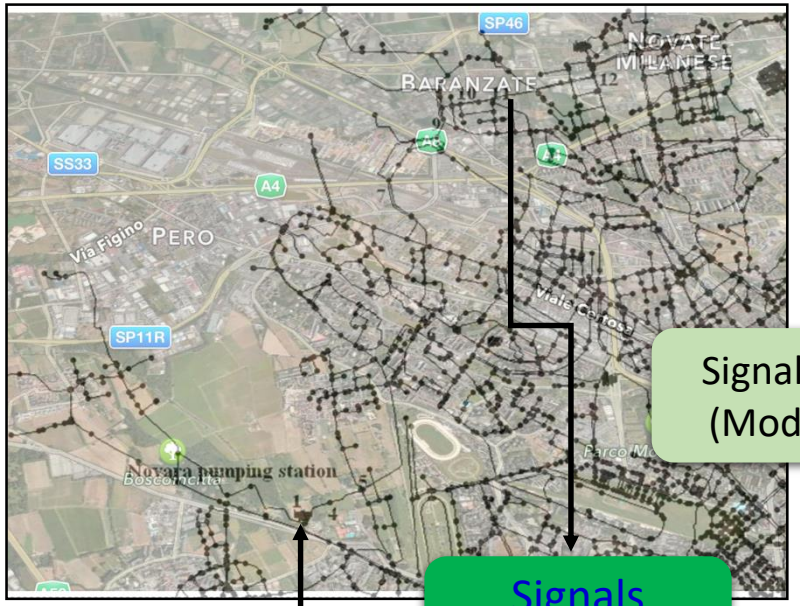


Signals
Received

Wave
Transmitter



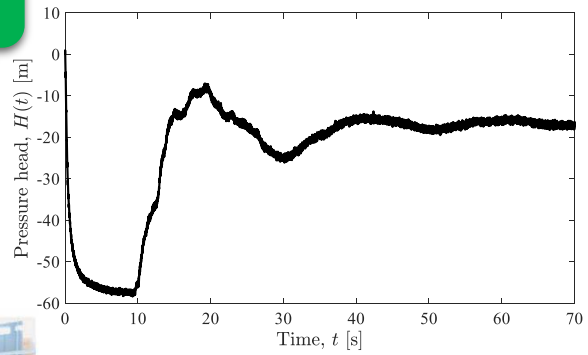
Field Site 3: MILAN, ITALY



Signal Processing (Model vs. data)

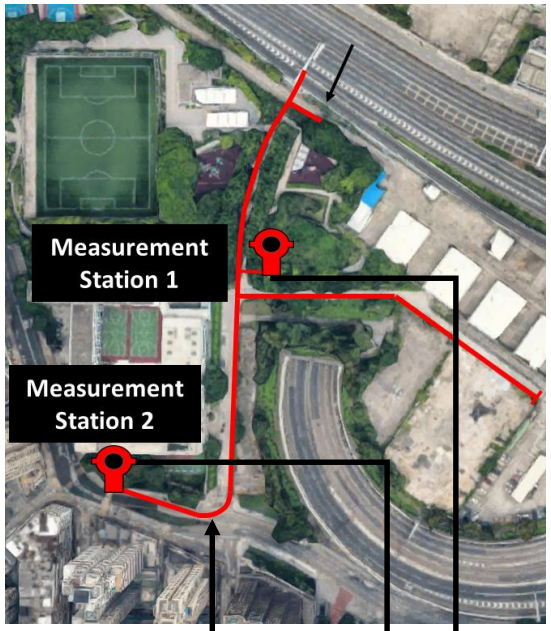
Signals Received

Wave Transmitter



(b)

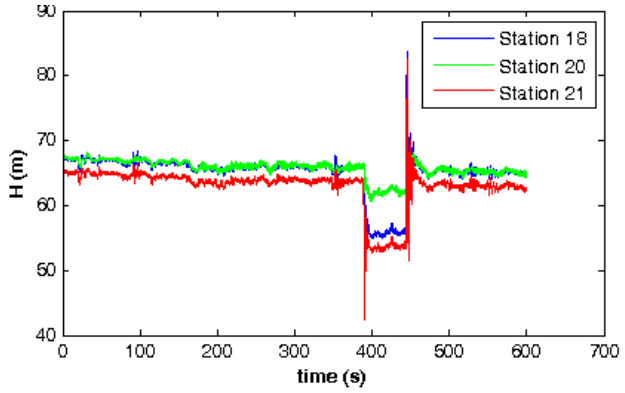
Type of Test: Source Localization



Signal Processing

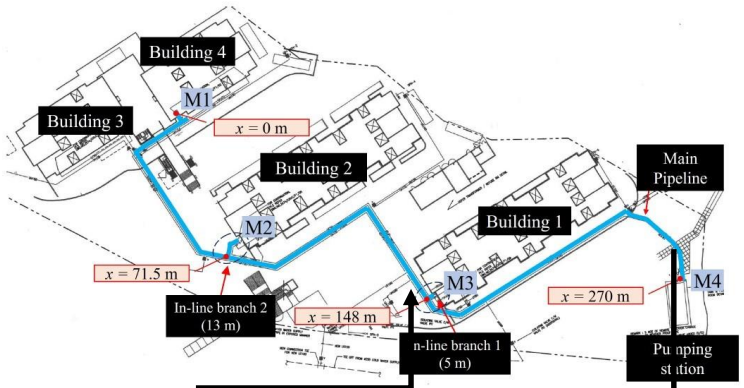
Signals Received

Source = ?



Dead end branch

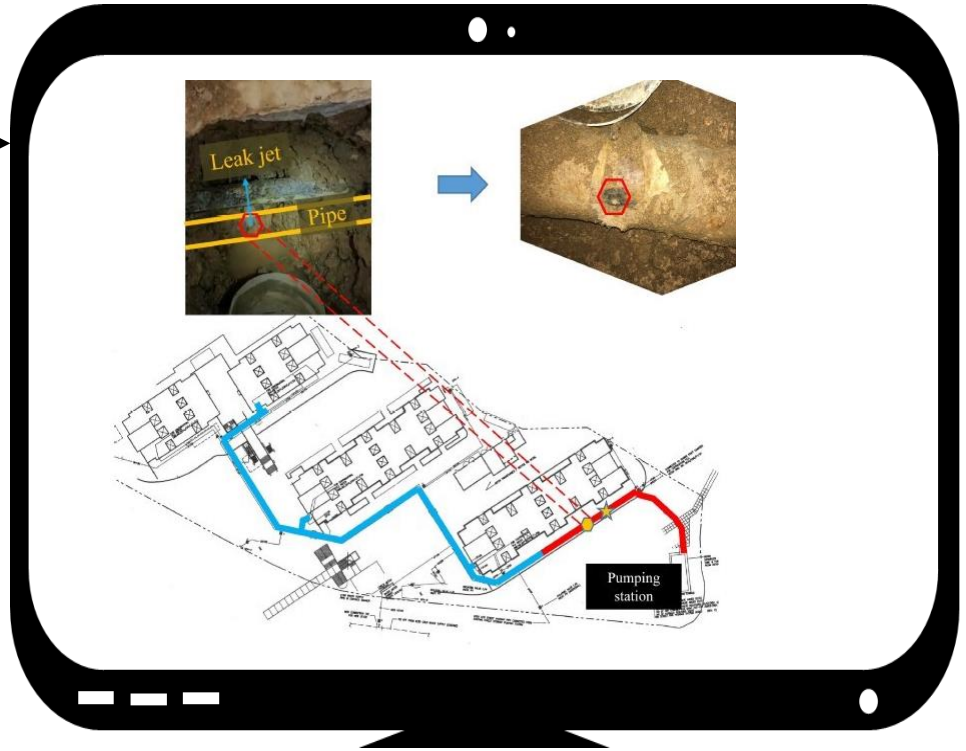
HKUST Sprinkler System

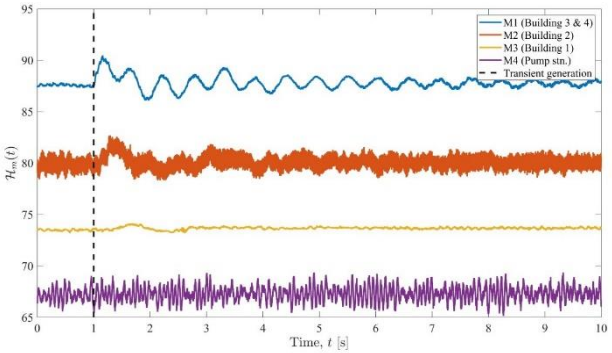


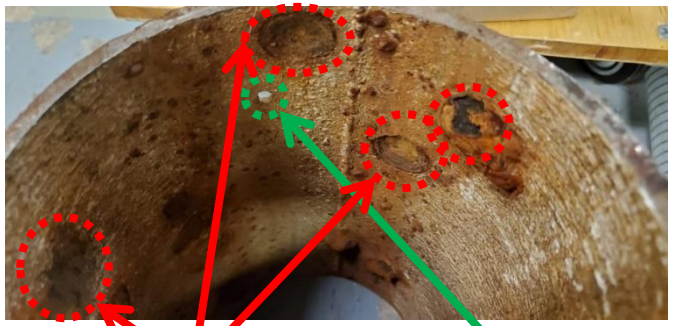
Transmitted wave

Signals Received

Signal Processing







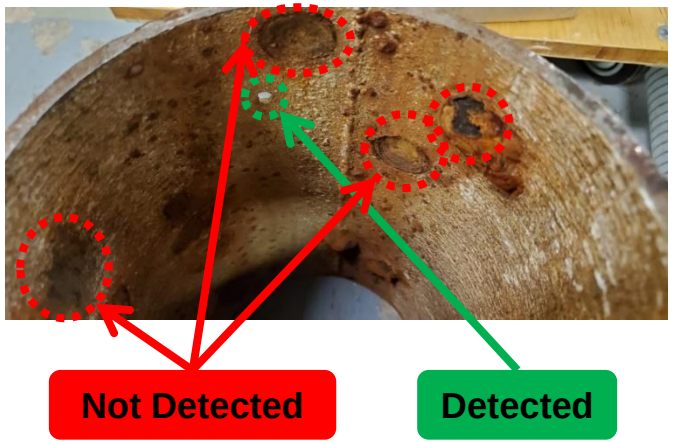
Not Detected

Detected

Need for IMAGING: TR at high frequencies (HF)

Not Detected

Detected



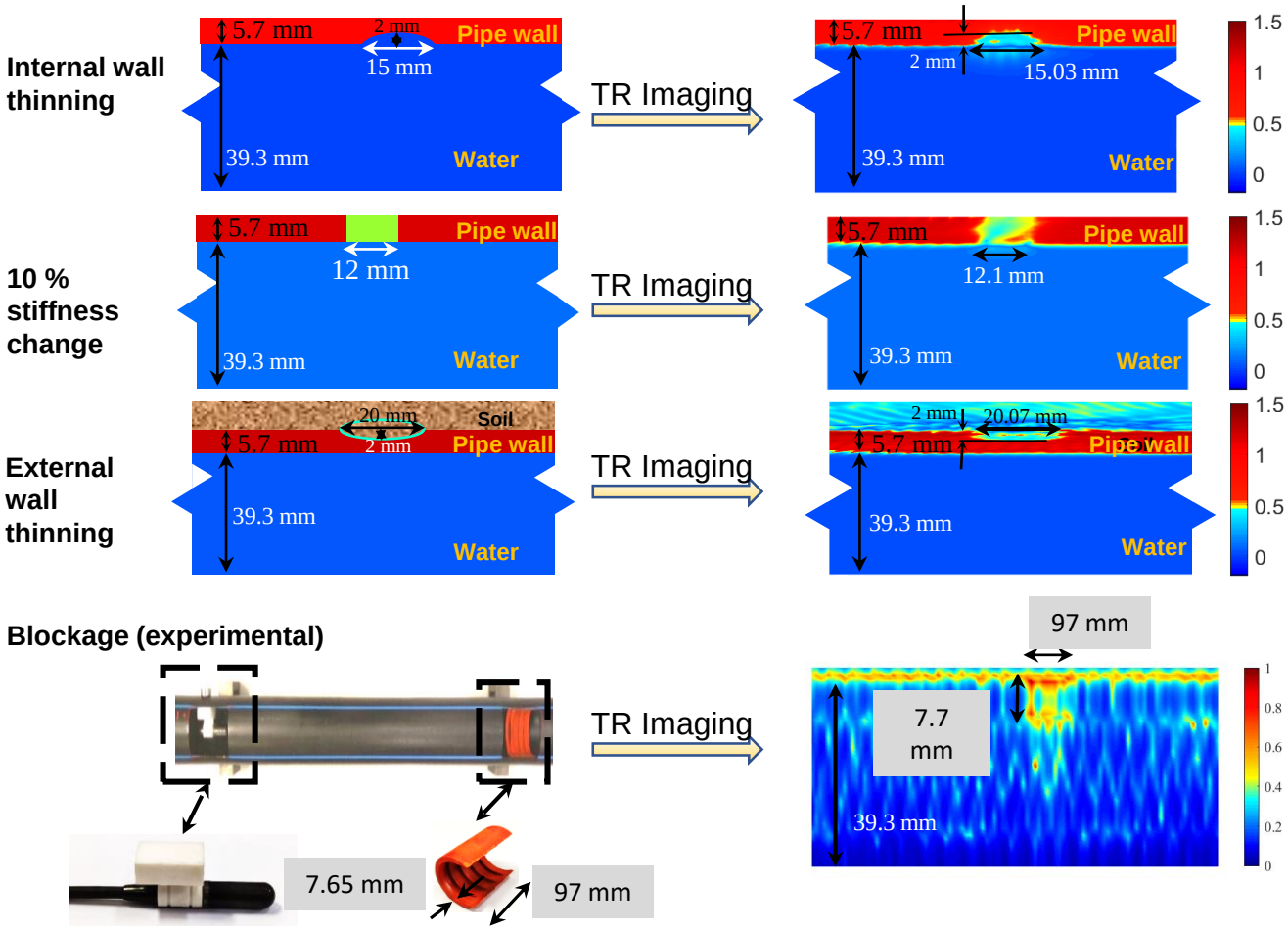
Not Detected

Detected

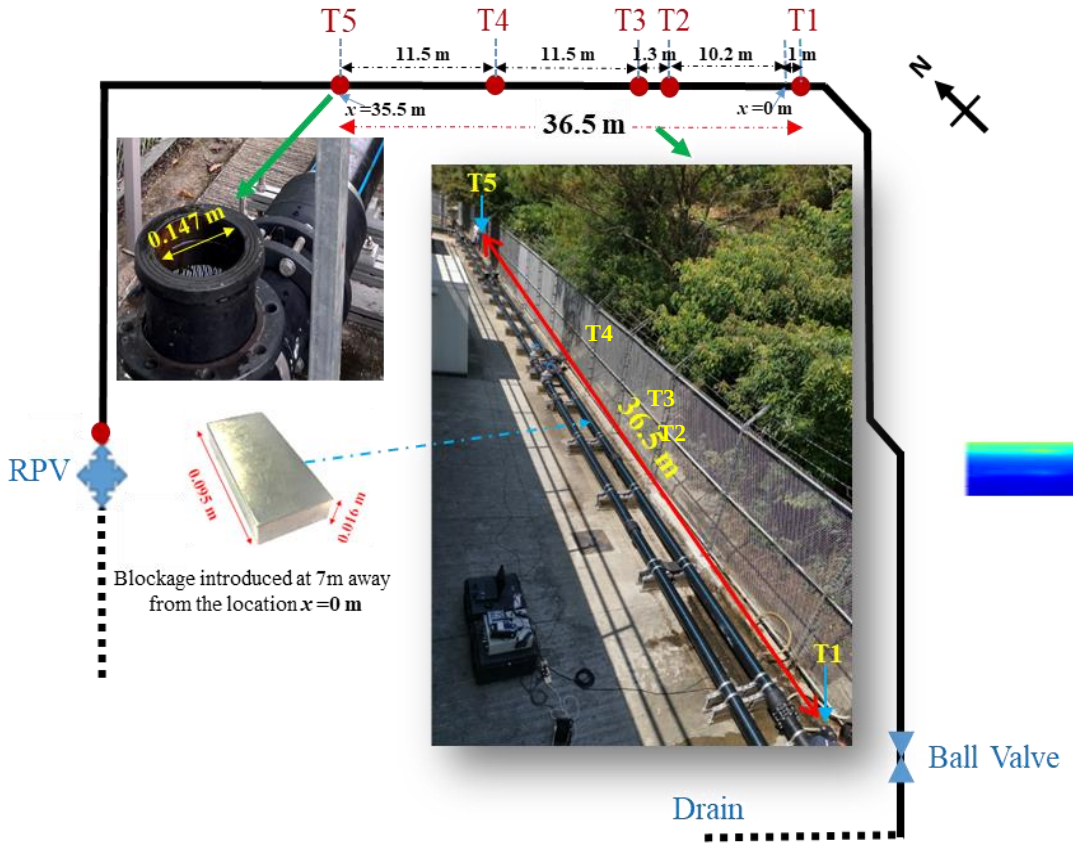
Imaging ➞

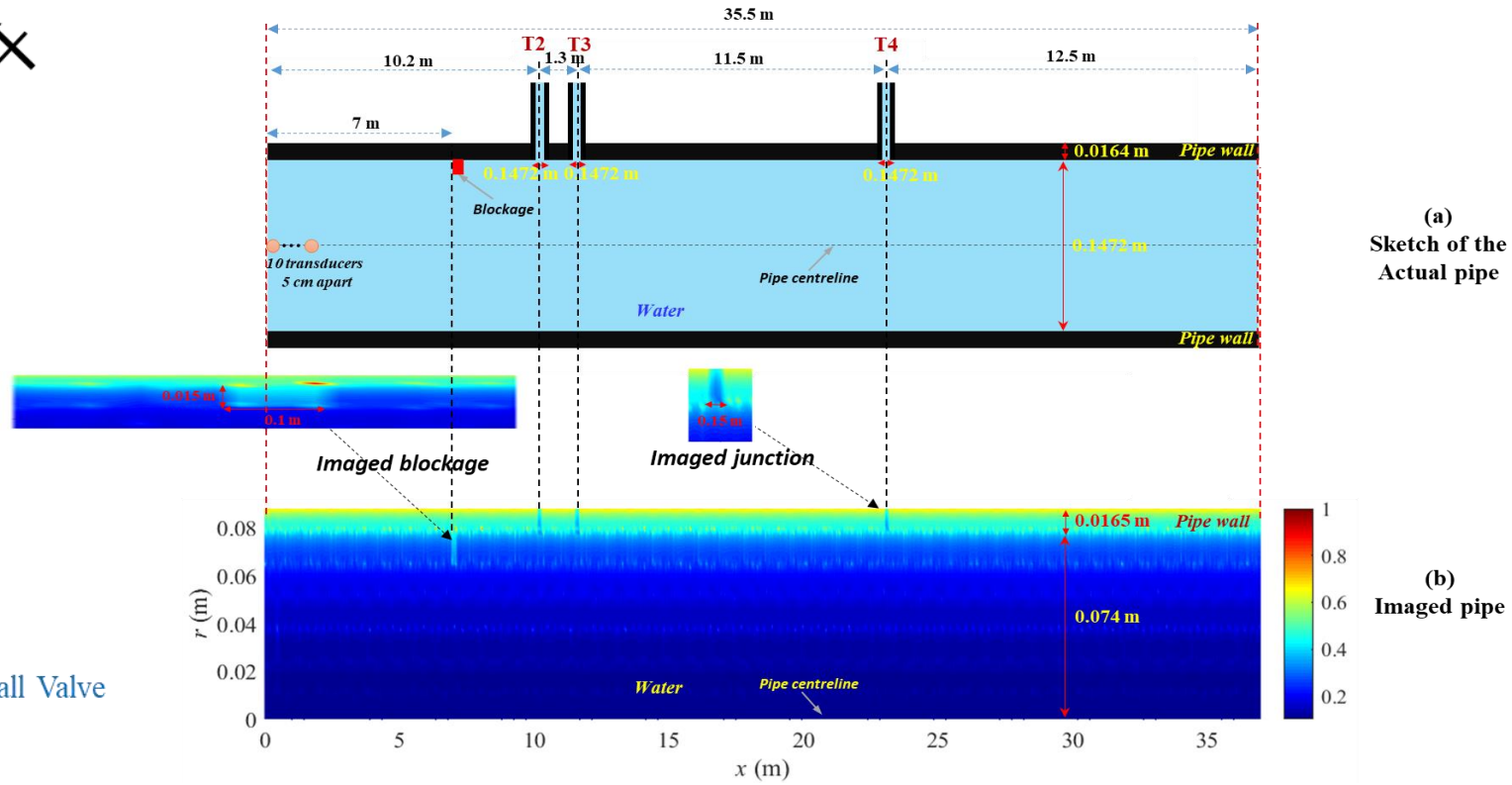
- ✓ **Using waves to “see” inside the pipe systems**
- ✓ **Enables timely preventive intervention**

Imaging — Proof of Concept



TR Images produced in Beacon Hill





(a) Sketch of the Actual pipe

(b) Imaged pipe

Conclusion

- Wave-based monitoring of water infrastructure is highly promising and has led to the detection of leaks, faulty air valves, air blockages, excessive pump vibration etc
- DSD is to be congratulated for its leadership and vision in collecting wave data and seeking ways to turn such data into information
- The main difficulties that need to be addressed to arrive to the same gains achieved by Ultrasound, SONAR and RADAR

  - lack of data about the topology and physical and geometrical parameters of our systems…BIM solves this problem!
  - lack of access points…Our team designed the HKUST-Guangzhou to make the world's 1st fully accessible system…We must replicate this design in HK!

- First step in developing smart systems: keep complete data and develop access points!
- Buying gadgets to systems we know nothing about is not the answer!

Thank You!