Long-Distance Pipeline Safety Early Warning: A Distributed Optical Fiber Sensor Deep Learning Approach

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清華大學
Tsinghua University

Tsinghua University

Research interests:

time-series, industrial signal processing, optical fiber, multi-sensor fusion, data mining, machine learning and deep learning theory

Education and Intern

He is seeking a Ph.D position!

Undergraduate：（2015-2019）

- Huazhong University of science and technology (HUST),

Artificial intelligence and Automation department,

(Experimental Class on Innovation at the Crossroads of Automation and Science).

- **GPA : 90.45 / 100 (3.91 / 4.0)**， Rank 10/300.
- Smart Car Team & control Innovation Team （2016-2019）
- National Encouragement Scholarship、First(Grand) Prize of Goodix Scholarship、Outstanding Undergraduate.

Postgraduate：（2019-2022）

- Tsinghua University,

Automation department.

- **GPA : 3.98 / 4.0，Rank 1/65**， 90% courses with full GPA.
- Second Prize Scholarship, Tsinghua University.
- time-series, industrial signal processing, optical fiber, multi-sensor fusion, data mining, machine learning and deep learning.

Exchange student：（2019.1-2019.2）

- University of Cambridge

Artificial intelligence field.

UNIVERSITY OF CAMBRIDGE

Teaching assistant：（2020.7-2020.8; 2020.10-2020.12）

- Teaching assistant of Rakesh Kumar, professor of electrical and computer engineering at UIUC, USA. The class name is "Artificial Intelligence for Undergraduate".
- Teaching assistant of Nicholas Lane, professor of computer science at Cambridge, UK. The class name is "Introduction to Deep Learning".

Intern：（2021.2-2021.8）

- Huawei,

AI Research Intern in Decision Making & Reasoning Lab.

- Conducted research on workload I/O time-series prediction for storage systems.

HUAWEI

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Journals:

- **Y. Yang**, H. Zhang, Y. Li, "Pipeline Safety Early Warning by Multi-feature-fusion CNN and LightGBM Analysis of Signals from Distributed Optical Fiber Sensors," *IEEE Transactions on Instrumentation and Measurement (**TIM**)*, 2021. (Accepted) (**Q1, IF=4.016**)
- **Y. Yang**, H. Zhang, Y. Li, "Long-Distance Pipeline Safety Early Warning: A Distributed Optical Fiber Sensing Semi-Supervised Learning Method," *IEEE Sensors Journal (**IEEE Sensors J**)*, 2021. (Accepted and Early Access) (**Q1, IF=3.301**)
- Z. Xu, F. Wu, **Y. Yang**, Y. Li, "ECT Attention Reverse Mapping algorithm: visualization of flow pattern heatmap based on convolutional neural network and its impact on ECT image reconstruction," *Measurement Science and Technology (**MST**)*, vol. 32, no. 3, pp. 035403, 2020. (**Q1, IF=2.046**)

Conferences:

- X. Li, Q. Shi, G. Hu, L. Chen, H. Mao, **Y.Y ang**, M. Yuan, J. Zeng and Z. Cheng, "Block Access Pattern Discovery via Compressed Full Tensor Transformer," 30th ACM International Conference on Information and Knowledge Management (**CIKM 2021**), 2021. (**CCF-B**)
- **Y. Yang**, Y. Li, H. Zhang, "Pipeline Safety Early Warning Method for Distributed Signal using Bilinear CNN and LightGBM," Proceeding of the IEEE International Conference on Acoustics, Speech, and Signal Processing (**ICASSP 2021**), 2021. (**CCF-B**)
- **Y. Yang**, Y. Li, T. Zhang, Y. Zhou, and H. Zhang, "Early Safety Warnings for Long-Distance Pipelines: A Distributed Optical Fiber Sensor Machine Learning Approach," *Proceeding of the Thirty-Fifth AAAI Conference on Artificial Intelligence (**AAAI 2021**)*, 35(17), 14991-14999, 2020. (**CCF-A**)

Workshops:

- "Long-distance Oil and Gas Transportation Pipeline Safety Early Warning System Based on Deep Learning Approach," The XVII International Forum-Contest of Students and Young Researchers Topical Issues of Rational Use of Natural Resources, in Saint Petersburg, Russia, 2021. (**Oral & First prize**)
- "Pipeline safety warning system based on distributed optical fiber sensing," The 13th Doctoral Candidate Nanshan Academic Forum of Guangdong-Hong Kong-Macau Grand Bay District & No. 635 Doctoral Forum, Tsinghua University, in Shenzhen, China, 2021. (**Oral & First prize**)

Patents:

- **Y. Yang**, H. Zhang, Y. Li, "A method for feature extraction of optical fiber warning signals for oil and gas long-distance pipelines", Chinese invention patents, 2021.
- M. Zhang, G. Wu, Y. Li, **Y. Yang**, "A complex multi-frequency real-time capacitance tomography imaging method based on multiple measurement vectors", Chinese invention patents, 2020.

Oil and gas pipelines are called the backbone of global energy. According to the statistics from CIA, the total length of the global oil and gas pipelines is already **3.55×10^6 km**. However, the average accident rate of oil-gas pipelines is **3 times/1000 km•year** in China, **0.5 times/1000 km•year** in the United States and **0.25 times/1000 km•year** in Europe. At present, the safety monitoring and early warning of oil and gas pipelines has become an urgent technical problem in industry, but has not been adequately addressed by the industry community.

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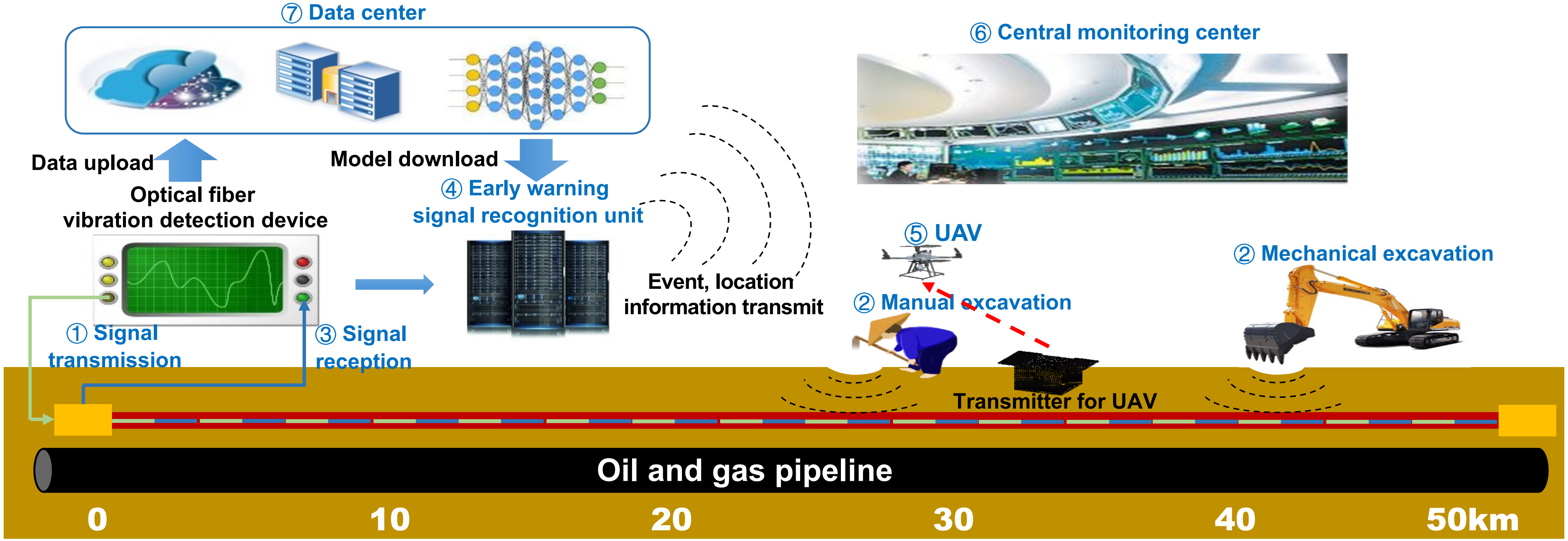

The system uses **AI,** intelligently identify threats (excavation, drilling, destruction) along the pipeline, and quickly and accurately locate incidents. Using **cloud computing technology** to realize automatic model update and continuously improve model stability. Combined with the **UAV** intelligent linkage mechanism, it can automatically check, obtain evidence, and shout at the incident site, replacing the traditional way of regular pipeline inspections by personnel, and realizing intelligent monitoring and early warning of dangerous event.

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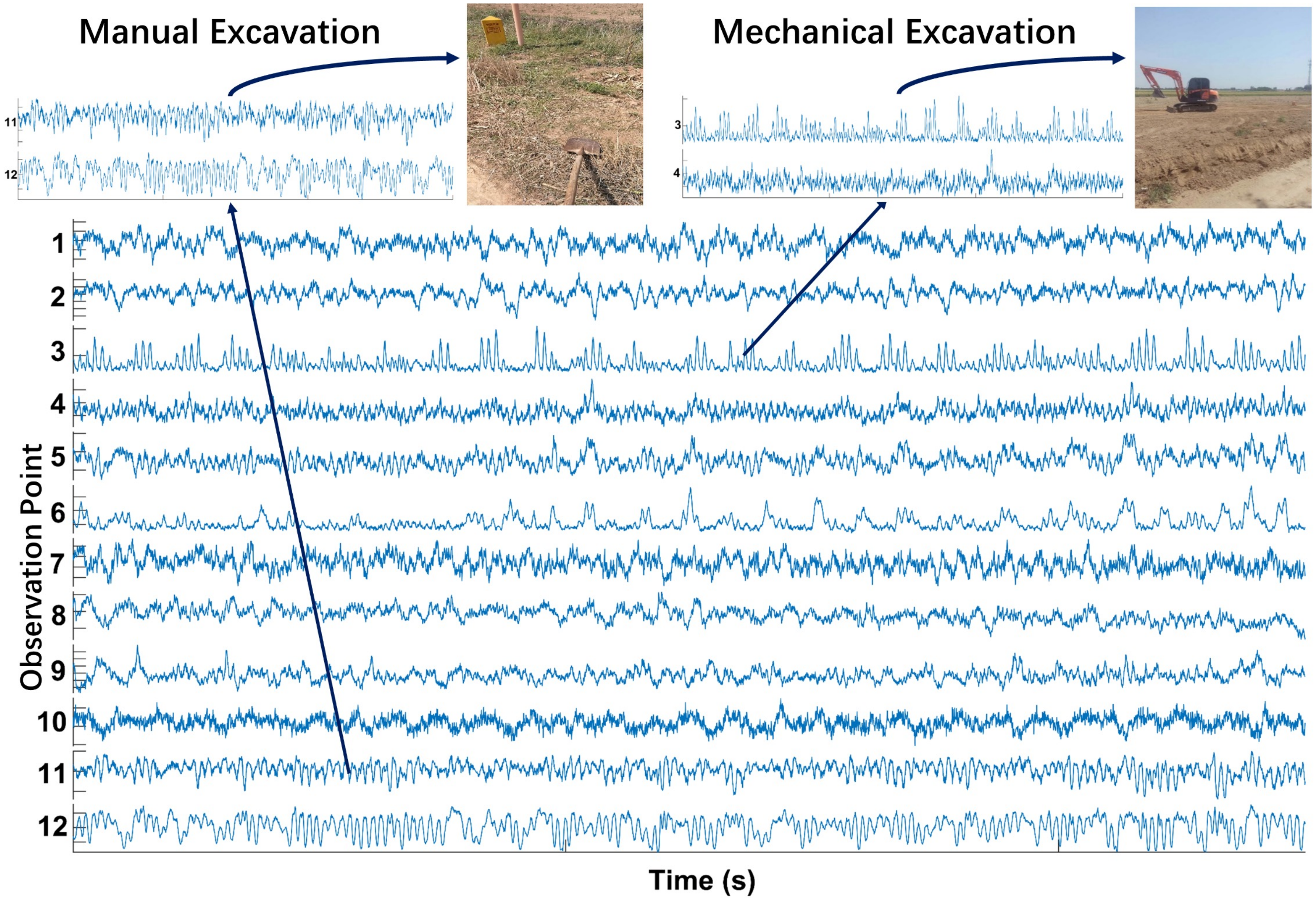
Related researches and products

Brands	FFT Co., Australia	QinetiQ Group, UK	Fotech Solutions, UK	Omnisens, Switzerland
Technology	Mach-Zehnder interferometer	Φ-OTDR	Φ-OTDR	BOTDR
Measurement parameters	vibration	vibration	vibration	vibration & temperature
Number of fiber	3	1	1	1
Monitor distance	<40 km	<50 km	<50 km	<70 km
Positioning precision	50 m	5-15 m	5 m	------
Accuracy	>67 %	------	------	------

PS: Short monitoring distance; Low recognition accuracy; time and space signal drift problem.

Spatiotemporal Information of Distributed Signals



Two Complementary Characteristics Based on the Spatiotemporal Information

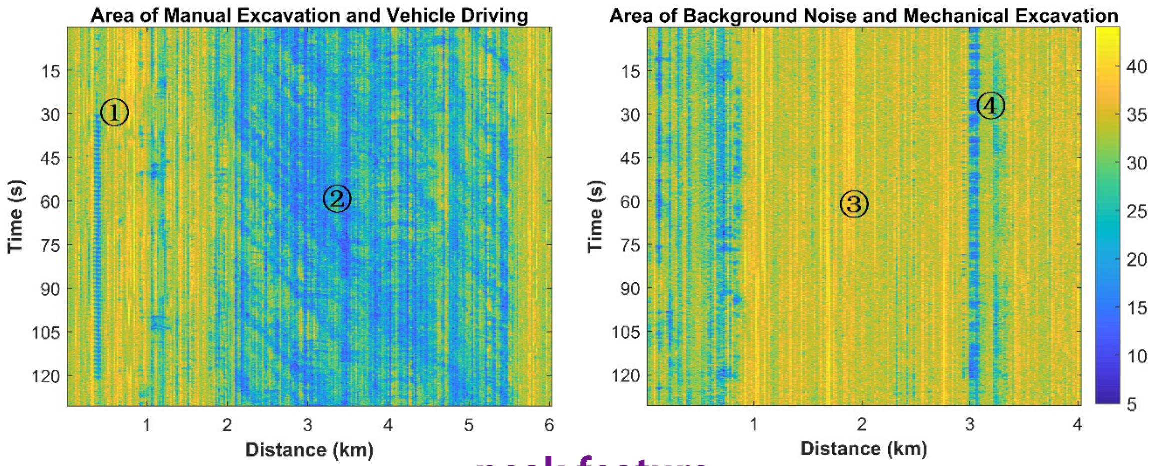
Algorithm I Matrix of Peak and Energy Features M_{peak}, M_{energy}

Input: Origin data X, Background noise data X_{base}.

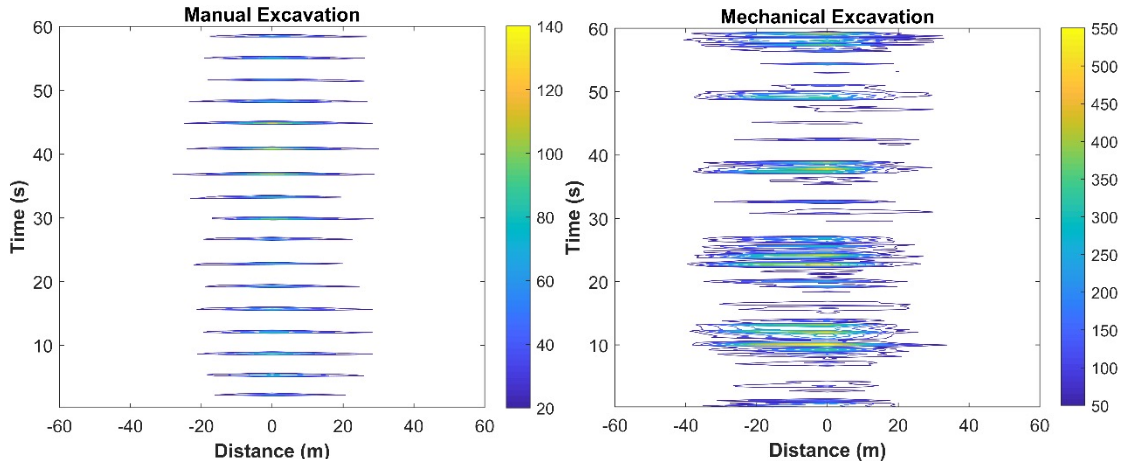
Output: Matrix of Peak and Energy Features M_{peak}, M_{energy}

variable: Length of window and step N_{win}, N_{step}, Number of observation points L, Number of data in time dimension T, Number of observation points and windows to be considered $N_{d-point}$, N_{d-win}, Threshold α and β.

```
Attenuation compensation and standardization of X and X_base.
for each i = 1, …, L do
    for each j = 1, …, T/N_win do
        F_peak[i, j] ← Count peak(X[i, j * N_step : j * N_step + N_win])
        for each k = 1, …, N_win − 2 do
            F_energy[i, j] ← Σ(data[k+α] − data[k])^2 / (T * X_base)
        end for
        Set F_energy[i, j] ← 1 if F_peak[i, j] > β
    end for
end for
for each m = N_d-point/2, …, L − N_d-point/2 do
    for each n = 1, …, T/(N_win * N_d-win) do
        M_peak, M_energy ← F_peak, F_energy[m − N_d-point/2 : N_d-point/2 + (m+1)/2,
                  n * N_d-win/2 : n * N_d-win/2 + N_d-win]
    end for
end for
```



peak feature



energy feature

A Novel DL Method for Action Recognition and Spatiotemporal Localization

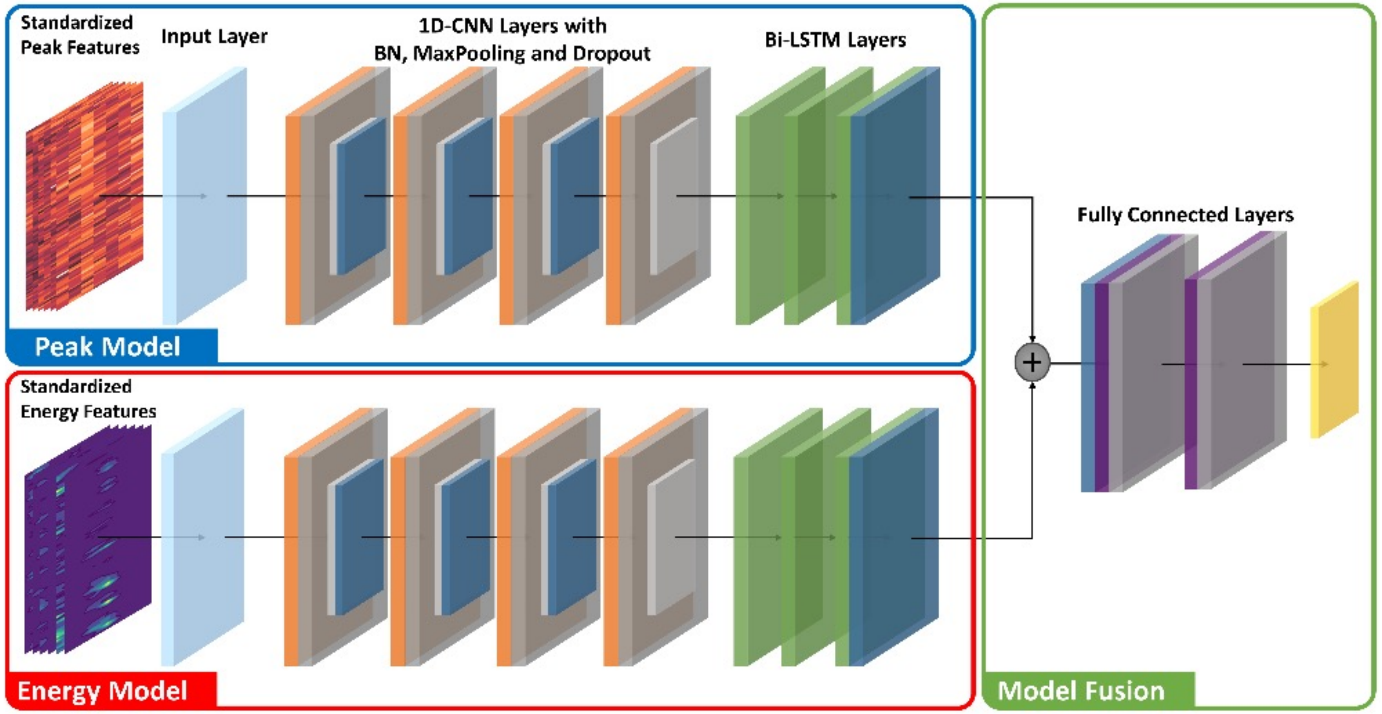
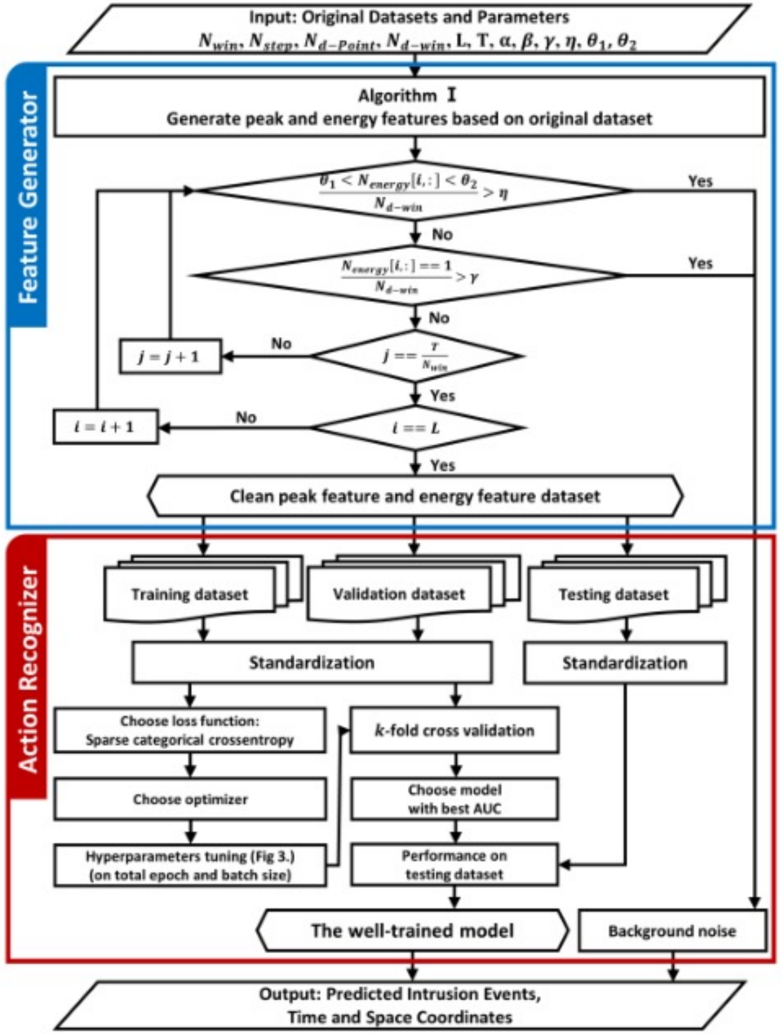
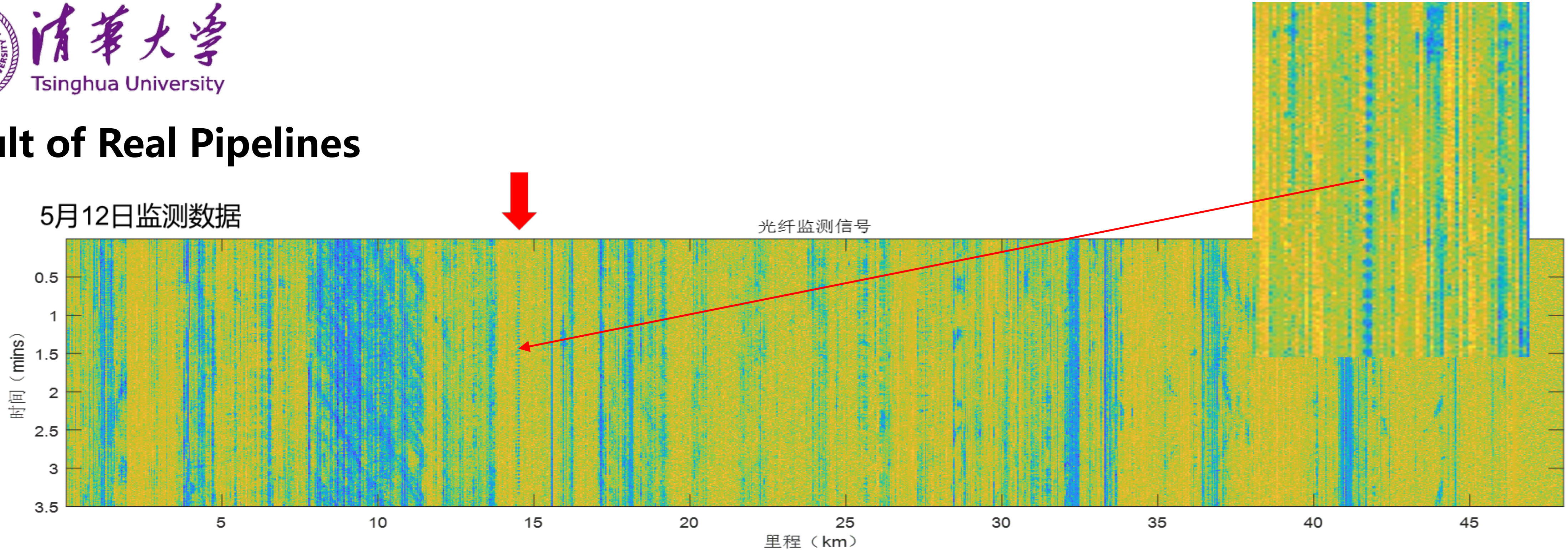


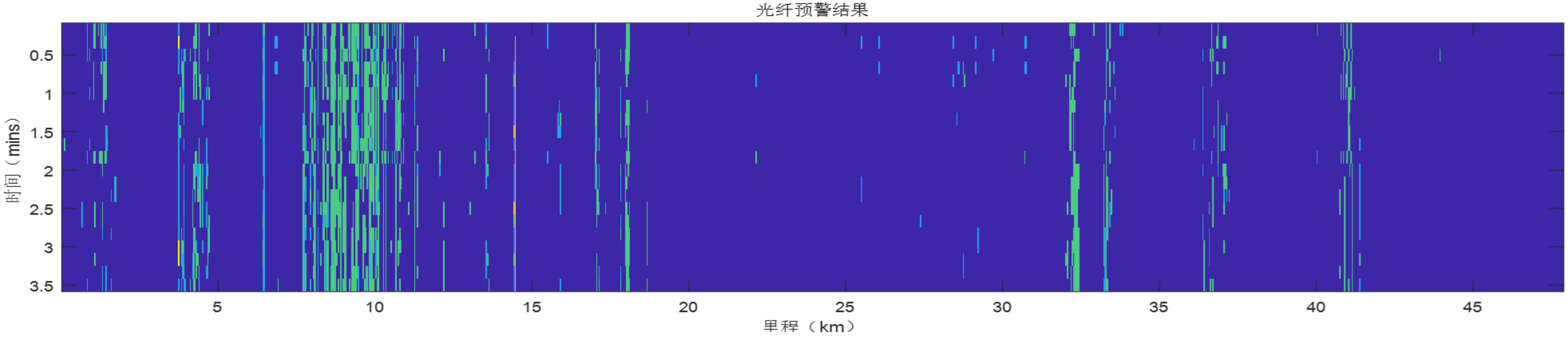
Figure 3: Action recognizer model. Orange is the Conv1D layer, dark grey is batch normalization, light grey is max-pooling, blue is dropout, green is the Bi-LSTM layer, and purple is the fully connected layer. The peak and energy features were expressed by heat maps and contour maps respectively.



Result of Real Pipelines

5月12日监测数据





蓝色：背景噪声，绿色：车辆行驶，粉色：人工挖掘

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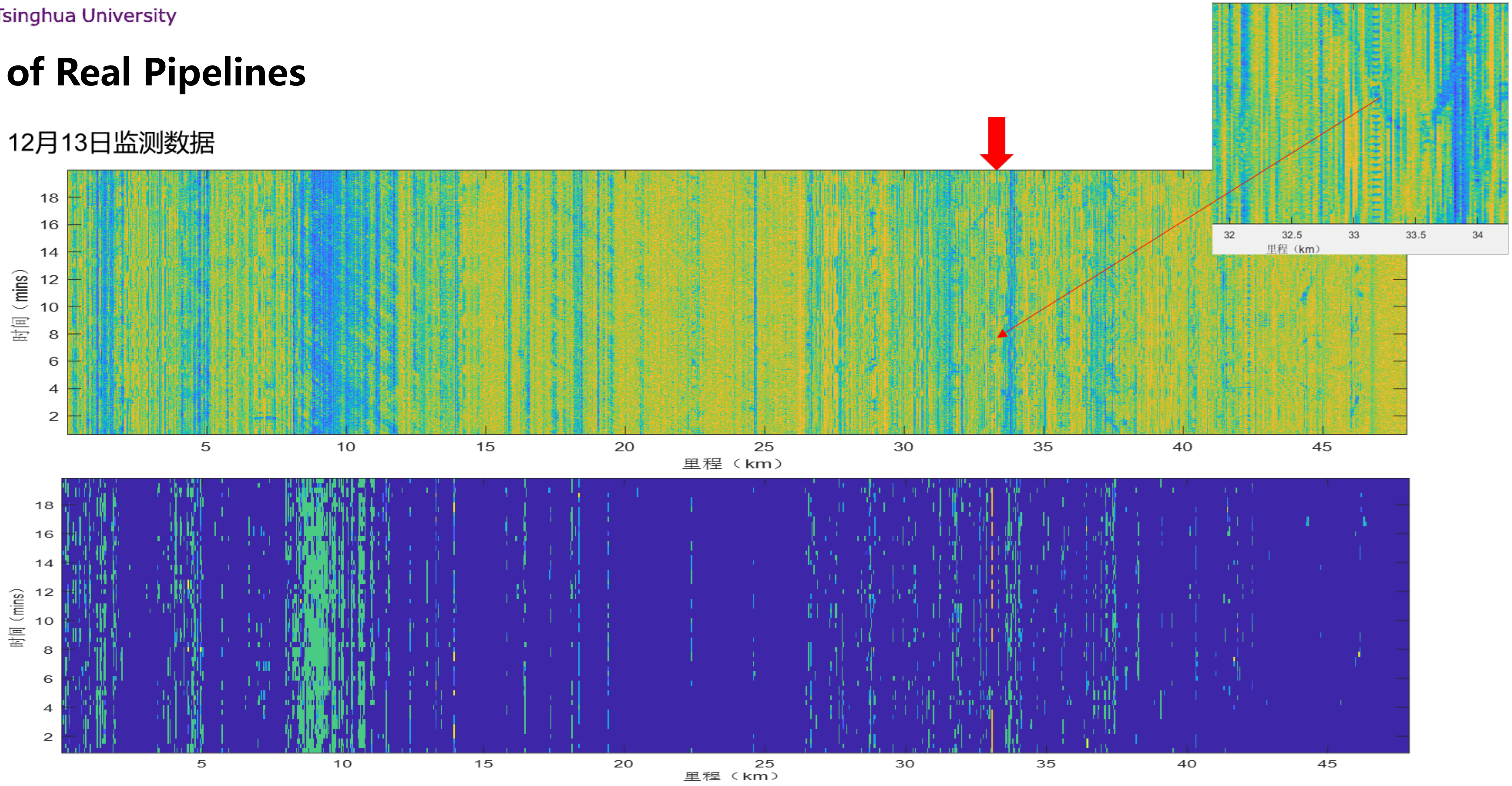
Result of Real Pipelines

12月13日监测数据



蓝色：背景噪声，绿色：车辆行驶，粉色：人工挖掘

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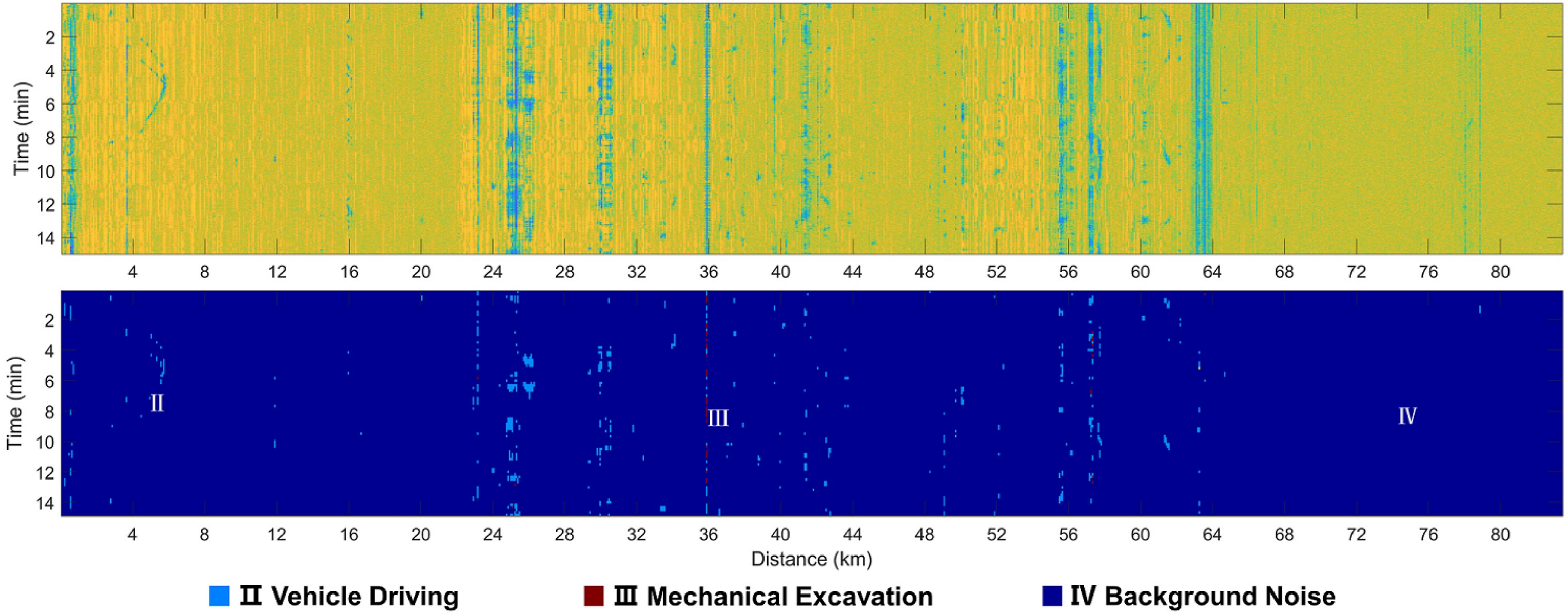
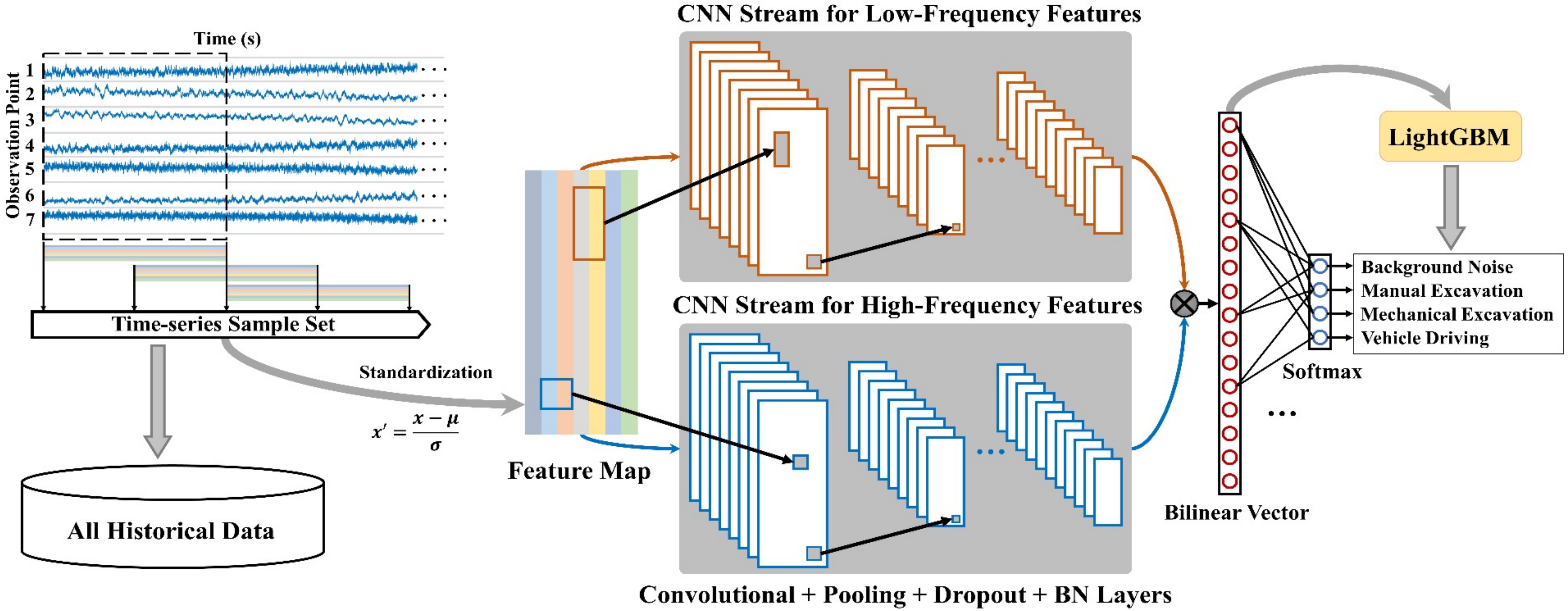
Result of Real Pipelines



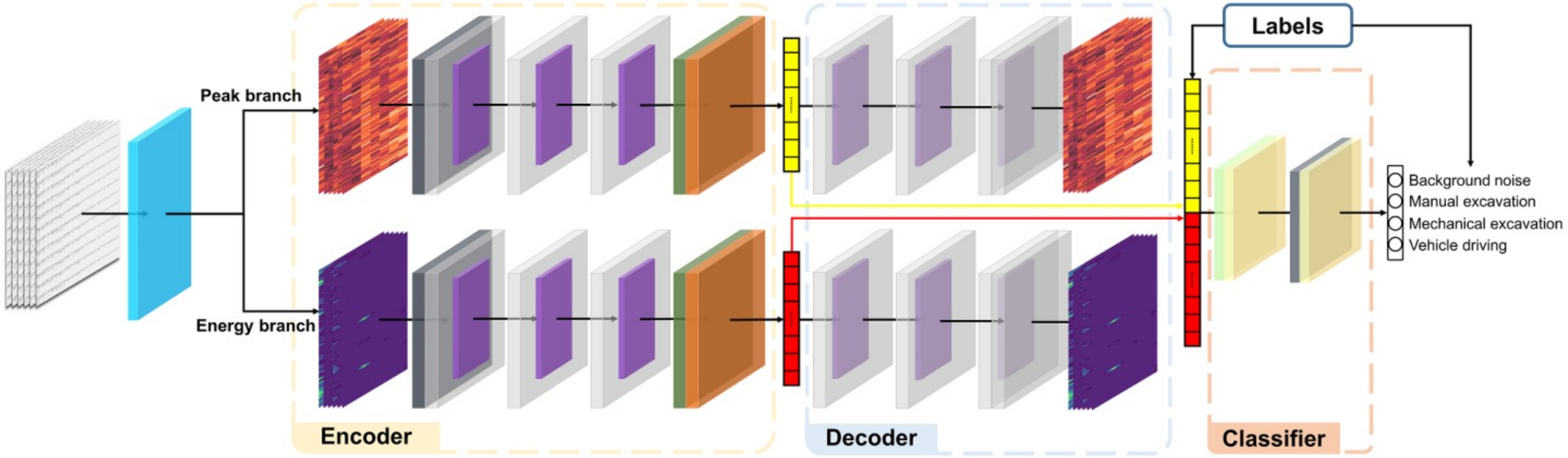
Group	Classifier	Monitoring distance	Positioning resolution	Accuracy	Reference
FOCUS S.L., Spain	GMM	45km	5m	68.11%	[42]
National Engineering Laboratory for Transportation Safety of Oil&gas Pipelines, China	HMM+SVM	131km	10–20m	83.0%	[43]
Future Fibre Technologies Co., Australia	–	<55km	<5m	–	[44]
Fotech Solutions, UK	–	<100km	10m	–	[45]
Omnisens, Switzerland	–	<140km	–	–	[46]
Tsinghua University, China (Our method)	MFCNN_LGB	<100km	20m	>95%	–

ICASSP 2021



Bad visualization effects!

IEEE Sensors J. 2021 （semi-unsupervised methods）



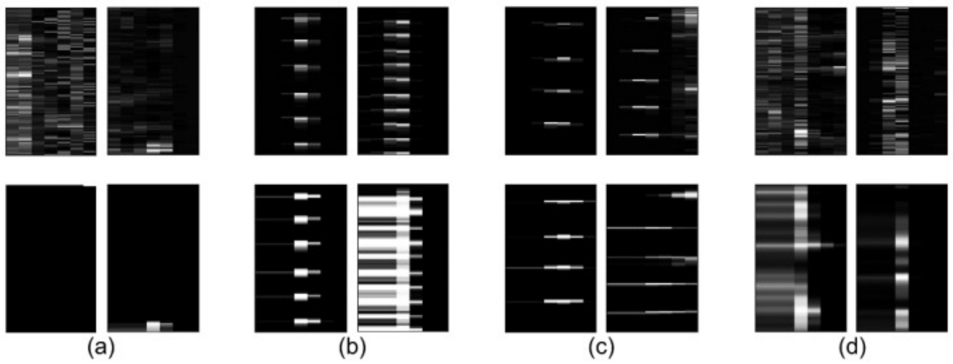


Fig. 7. Decoded features (lower) vs. input features (upper).

TABLE V
DEPLOYMENT PERFORMANCE TESTING

Data (Hz)	latency (ms)	AE size (KB)	Classifier size (KB)
100	0.68	678	345
500	1.73		

Better visualization effects and robustness!

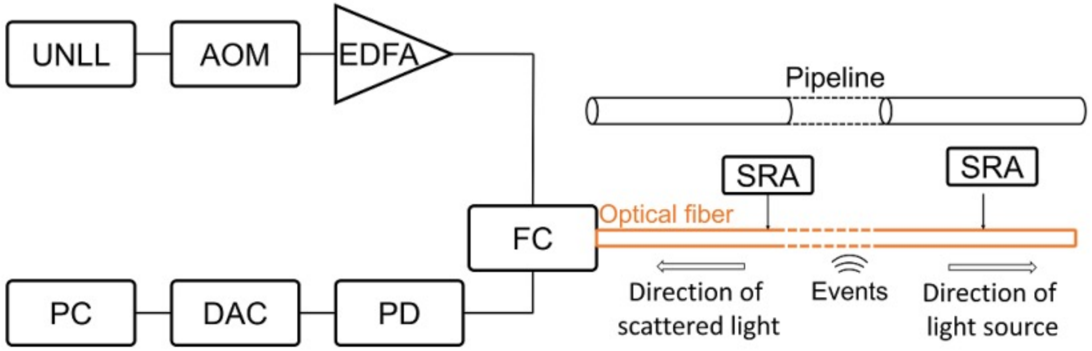
Application case: Jinhua line（津华线） fiber optic early warning

The Tianjin Port-Huabei oil pipeline has a total length of **189 kilometers**. There are 11 large and medium-sized river crossing projects along the pipeline, 7 ordinary railways and 13 various highways. The surrounding environment along the pipeline is **complex**, passing through a large number of farmland, factories, accompanying roads and areas with high groundwater levels. Human activities are frequent, and ground-breaking construction often occurs, which puts forward **higher requirements for pipeline safety protection**.

Application case: Jinhua line fiber optic early warning

(a) (b)

Fig. 6. Real-site deployment and experimental facility of the PSEW system. (a) Relative positions of the underground energy pipeline and optical fiber cable. (b) Deployed facilities.



(c)

Fig. 3. Real scenarios used for data acquisition and experiments.

Testing and Experiments

position of pipe and optical cable
black is pipe, yellow is optical cable

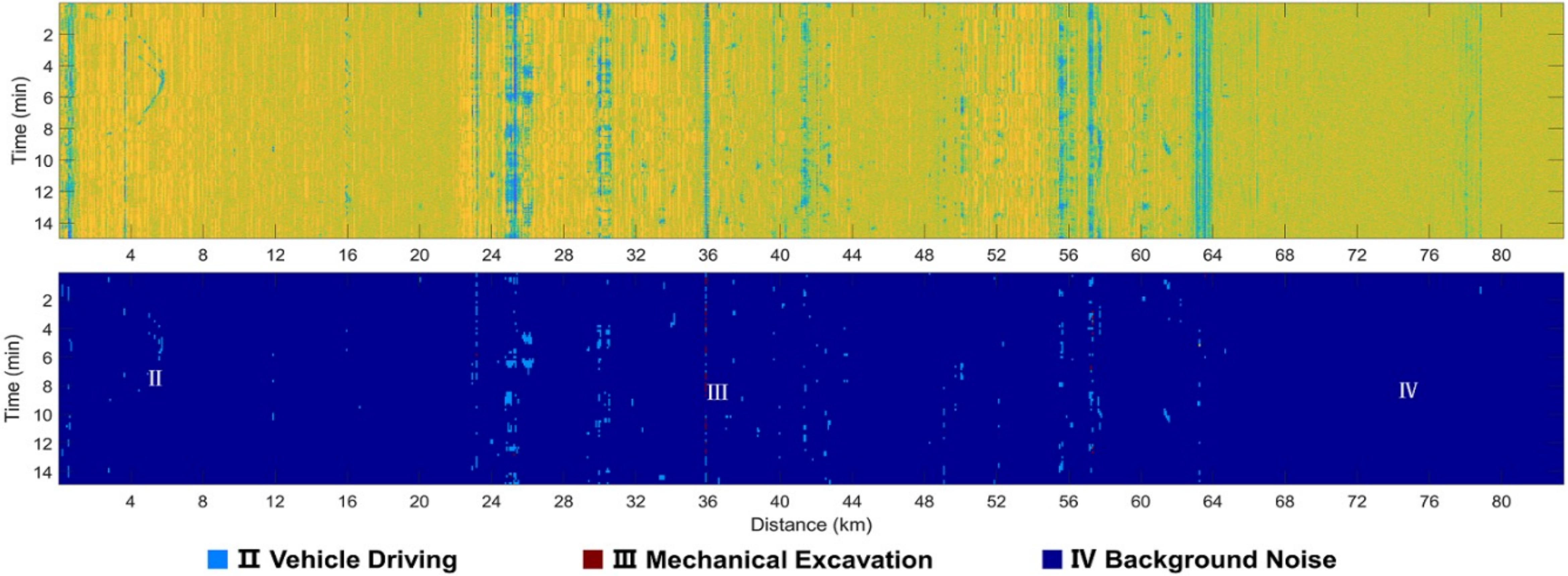
manual excavation

mechanical excavation

Result

TABLE V
DEPLOYMENT PERFORMANCE TESTING WITH THE CASE 1 PIPELINE

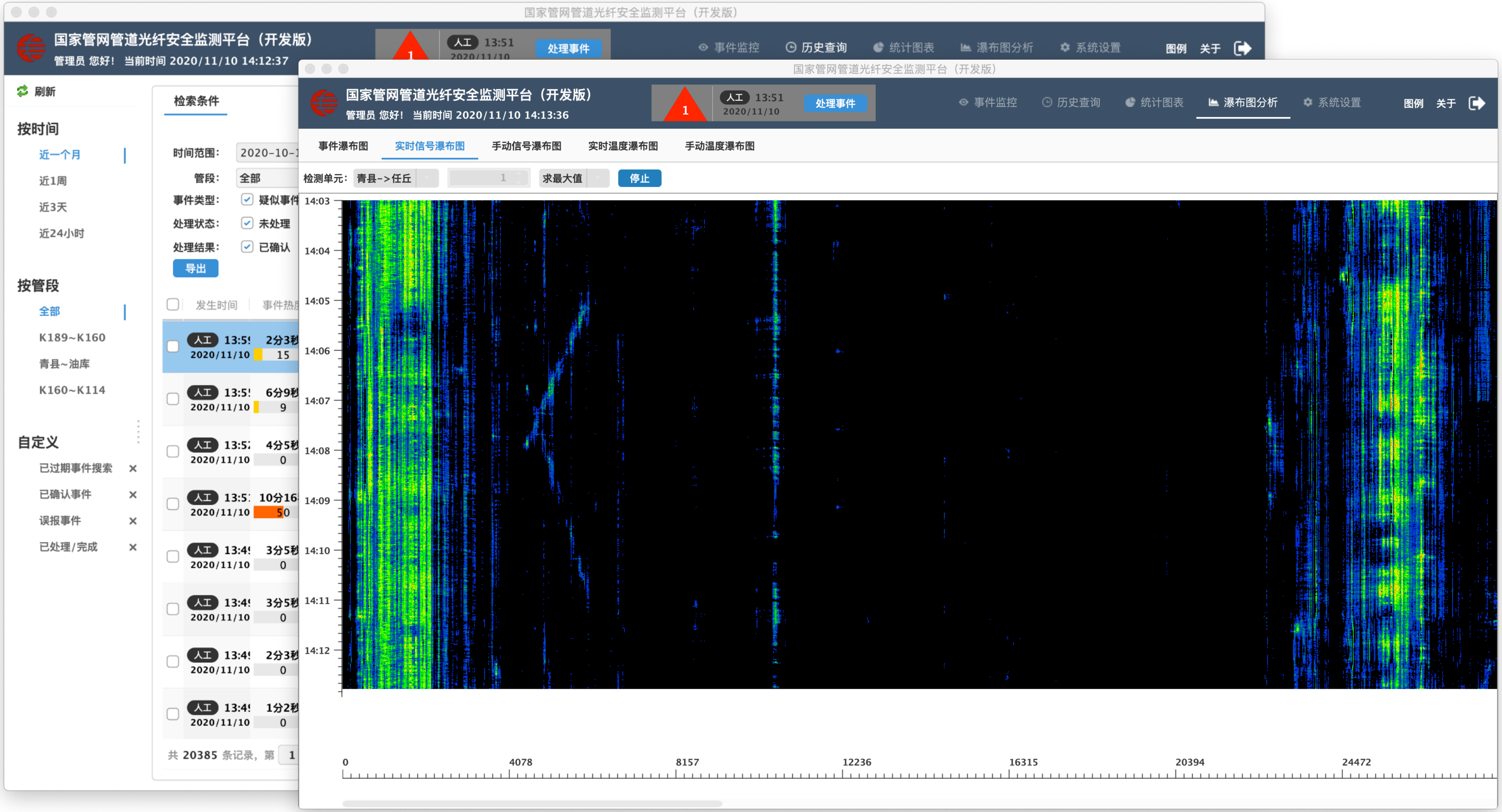
Data	Processor	Feature time	Model time	Model size
100 Hz	CPU	4.268 s	5.268 s	13.79 MB
	GPU	2.956 s	3.186 s	
500 Hz	CPU	16.20 s	5.437 s	
	GPU	11.96 s	3.685 s	



Software

国家管网管道光纤安全监测平台（开发版）
管理员 您好！ 当前时间 2020/11/10 14:12:37
人工 13:51
2020/11/10
处理事件
事件监控
历史查询
统计图表
瀑布图分析
系统设置
图例
关于
刷新
按时间
近一个月
近1周
近3天
近24小时
按管段
全部
K189~K160
青县~油库
K160~K114
自定义
已过期事件搜索
已确认事件
误报事件
已处理/完成
检索条件
时间范围：2020-10-11 14:02 至 2020-11-10 14:02
管段：全部
事件类型：疑似事件 威胁事件 包括屏蔽事件
处理状态：未处理 已处理 处理中 已过期(未处理)
处理结果：已确认 误报
导出
重置
保存条件
搜索
发生时间 事件热度 事件位置 事件类型 处理结果 是否屏蔽 操作
共 20385 条记录，第 1 /204 页
每页 100 条
GIS图
2020-11-10 13:59:49
已持续 2分3秒 人工挖掘
管道桩里程： K166+354 - 1165m
光纤里程： --
至瀑布图
原始数据
瀑布图 | 列表
演变记录
发生时间 威胁程度 位置
共 3 条记录，第 /1 页
每页

Software


国家管网管道光纤安全监测平台（开发版）
管理员 您好！ 当前时间 2020/11/10 14:12:37
处理事件
事件监控
历史查询
统计图表
瀑布图分析
系统设置
图例
关于
刷新
检索条件
按时间
近一个月
近1周
近3天
近24小时
按管段
全部
K189~K160
青县~油库
K160~K114
自定义
已过期事件搜索
已确认事件
误报事件
已处理/完成
时间范围：
管段：
事件类型：
处理状态：
处理结果：
导出
发生时间
共 20385 条记录，第
管理员 您好！ 当前时间 2020/11/10 14:13:36
人工 13:51 2020/11/10
事件瀑布图
实时信号瀑布图
手动信号瀑布图
实时温度瀑布图
手动温度瀑布图
检测单元：
青县->任丘
求最大值
停止
14:03
14:04
14:05
14:06
14:07
14:08
14:09
14:10
14:11
14:12
0
4078
8157
12236
16315
20394
24472

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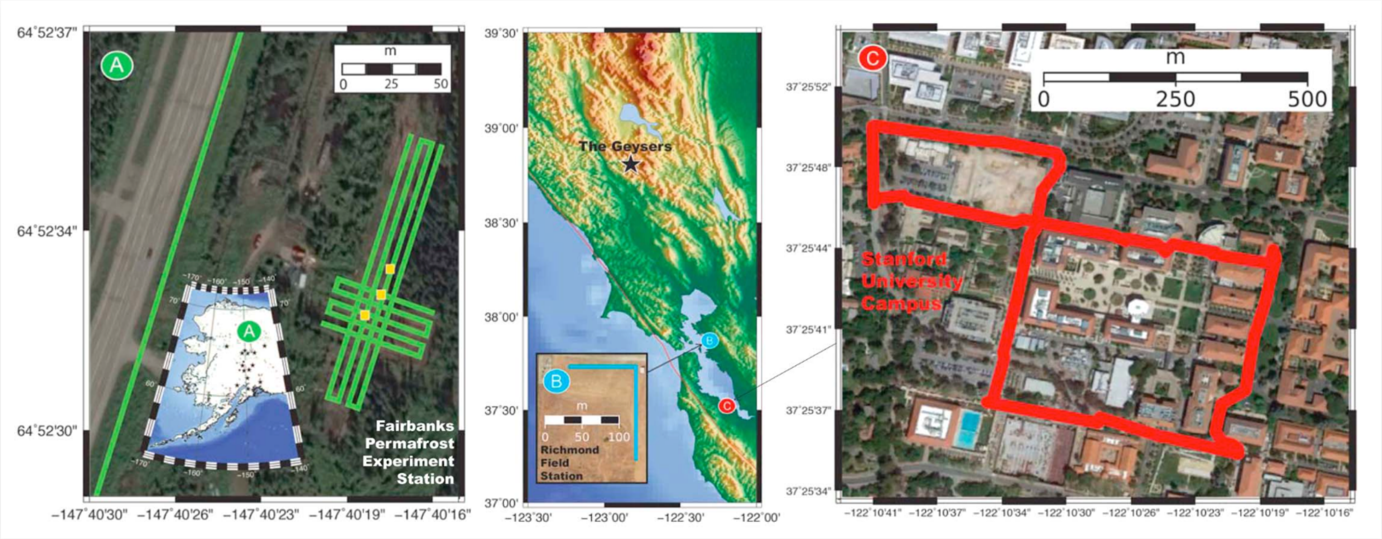
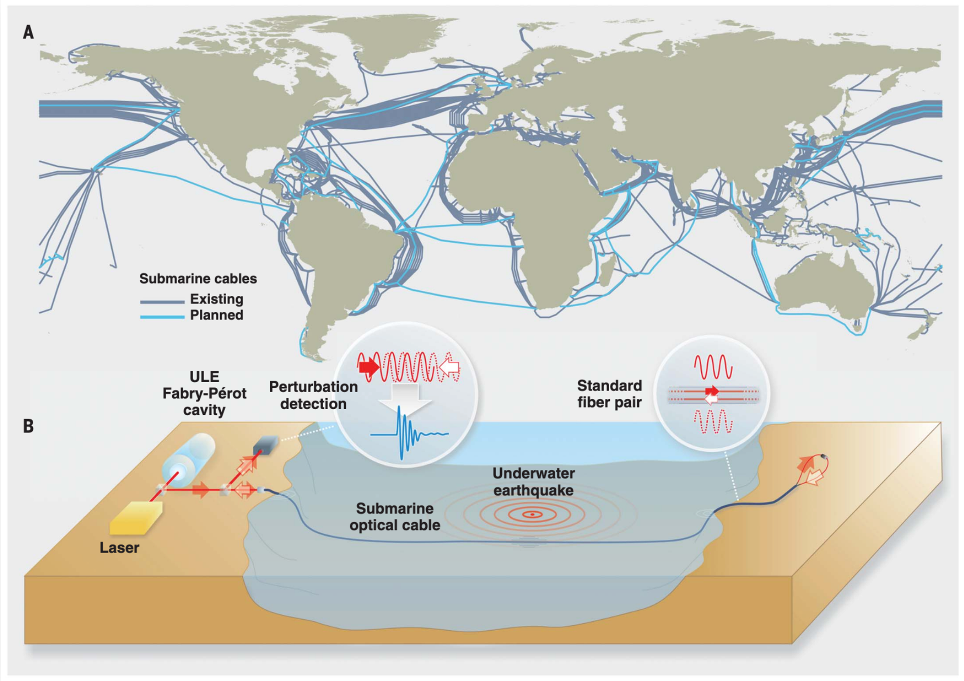
Further Work

Method： Using online learning to update samples, and one-shot method to save the cost.

Application： Early warnings of undersea and land earthquakes, traffic flow statistics for urban road networks, and illegal cross-border behavior monitoring.



Lindsey N J, Martin E R, Dreger D S, et al. Fiber-optic network observations of earthquake wavefields[J]. Geophysical Research Letters, 2017, 44(23): 11,792-11,799.



Marra G, Clivati C, Luckett R, et al. Ultrastable laser interferometry for earthquake detection with terrestrial and submarine cables[J]. Science, 2018, 361(6401): 486-490.