

# SHM-Enriched High-Speed Rail Systems

Yi-Qing Ni

The Hong Kong Polytechnic University  
Hong Kong, China

IWSHM 2015  
September 1-3, 2015



# Outline

- 1. Why SHM needed for HSR ?**
- 2. Vision for rail-SHM systems**
- 3. Sensory systems for rail application**
- 4. Predictive modelling tools**
- 5. Looking into the future**

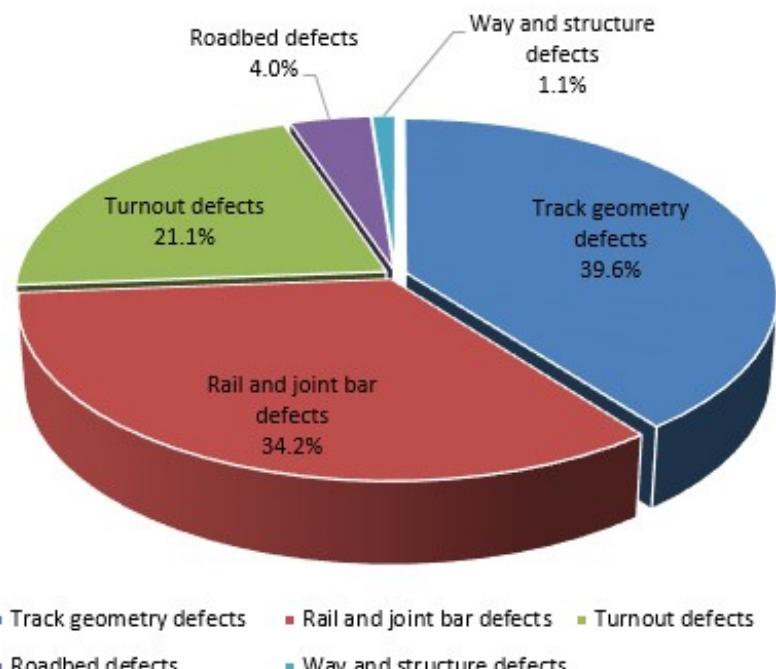
# 1. Why SHM needed for HSR (1)?

- **The development of HSR in some countries is being tied to several grand issues such as**
  - **Globalization;**
  - **Urbanization;**
  - **Carbon footprint;**
  - **Energy efficiency;**
  - **Regional economic/resource rebalancing.**

# 1. Why SHM needed for HSR (2)?

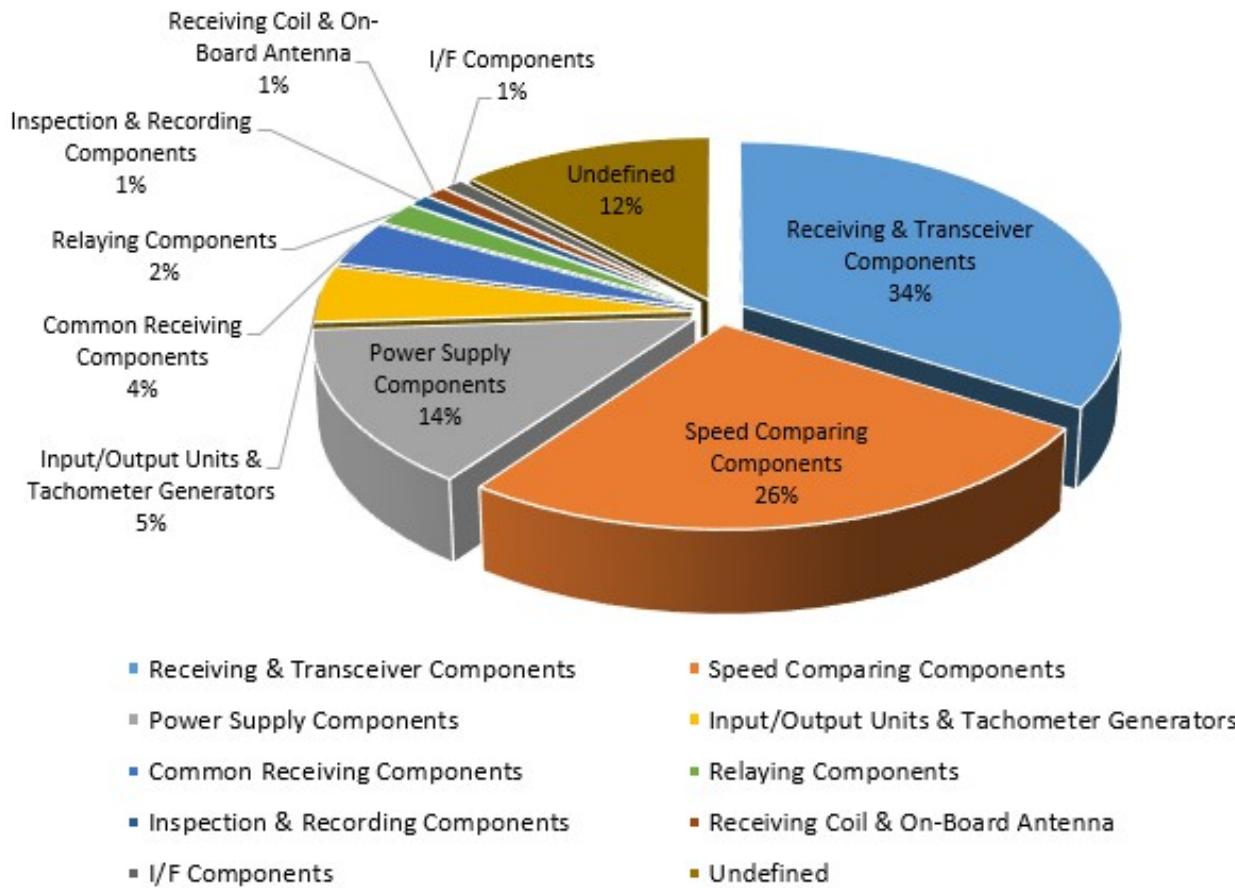
Year	Total		Reportable damage		Casualty	
	Count	%	Amount (\$)	%	Fatal	Nonfatal
2010	1,337	64.3	214,484,420	80.9	2	48
2009	1,358	65.7	189,880,057	81.8	1	37
2008	1,772	67.2	238,981,334	76.6	—	38
2007	1,918	65.6	256,345,360	79.9	—	79
2006	2,171	67.8	264,995,385	79.3	3	87
2005	2,280	65.8	248,827,584	71.5	2	229
2004	2,367	67.3	257,669,474	76.6	2	94
2003	2,113	66.7	237,370,531	77.5	1	117
2002	1,989	67.6	210,325,825	76.2	7	1,691
2001	2,234	69.0	236,572,759	73.3	1	113
2000	2,112	66.1	214,656,118	77.2	2	121
1999	1,961	67.1	189,888,914	70.8	1	41
1998	1,757	64.0	189,797,985	76.4	1	61
1997	1,741	68.0	168,322,227	74.6	2	111
Total	27,110	—	3,118,117,973	—	25	2,867
Average	1,936	66.7	222,722,712	76.5	2	205

Derailment Causes Analysis



(Derailment causes analysis chart based on FRA Railroad Safety Statistics: 1997 annual report to 2010 annual report).

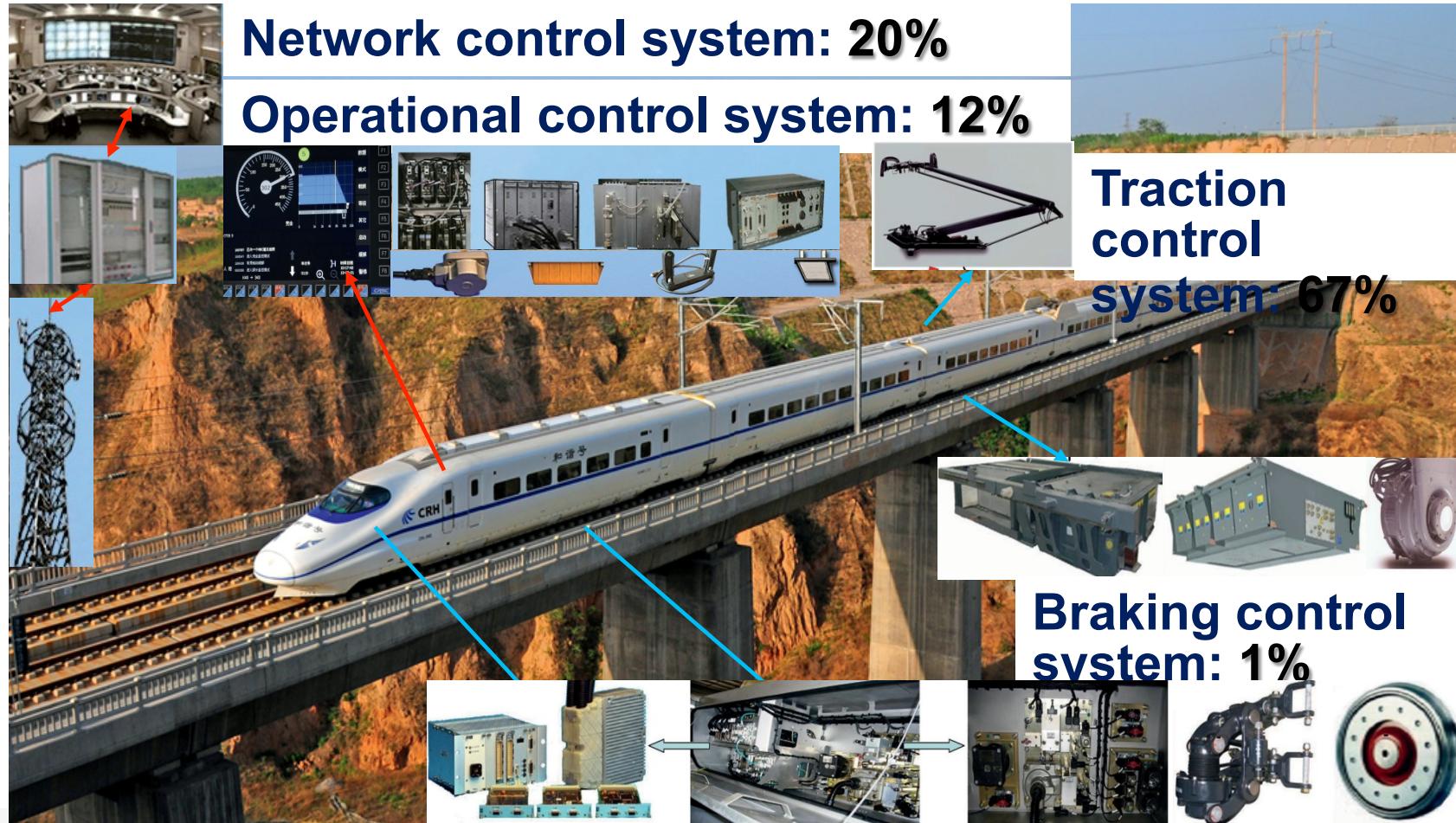
# 1. Why SHM needed for HSR (3)?



**(Failure analysis chart of on-board train protection devices based on a report by RTRI : M. Ogasa, 2015).**

# 1. Why SHM needed for HSR (4)?

## Evidence-based classification of faults in trains



# 1. Why SHM needed for HSR (5)?

## □ Justifications:

- SHM systems provide **online** and **on-board** monitoring to enhance HSR's safety and operational efficiency;
- Incorporating SHM systems into HSR makes the sensors '**mobile**' in collecting external effect and system response data when the instrumented train travels on railroads;
- SHM systems with the aid of appropriate predictive modelling tools enable **prognosis of breakdown before it occurs**;
- SHM systems enable the detection of **structural performance evolution** from micro-structural damage to macro-structural damage.

# 1. Why SHM needed for HSR (6)?

## □ Requirements:

- The requirements on **fidelity, accuracy, adaptability** and **environment-tolerance** for the sensors used in HSR are almost the same as those in airplane application;
- The operators of HSR hate any unstable sensors used in the existing ATO (Automatic Train Operation), ATP (Automatic Train Protection) and ATS (Automatic Train Supervision), which sometimes offer **false-positive alarming** and cease the running of trains;
- SHM systems deployed on HSR should be greatly helpful in eliminating the **false-positive alarming** and **unnecessary train stop** caused by abnormal performance or malfunction of the inspection sensors in the existing ATO, ATP and ATS.

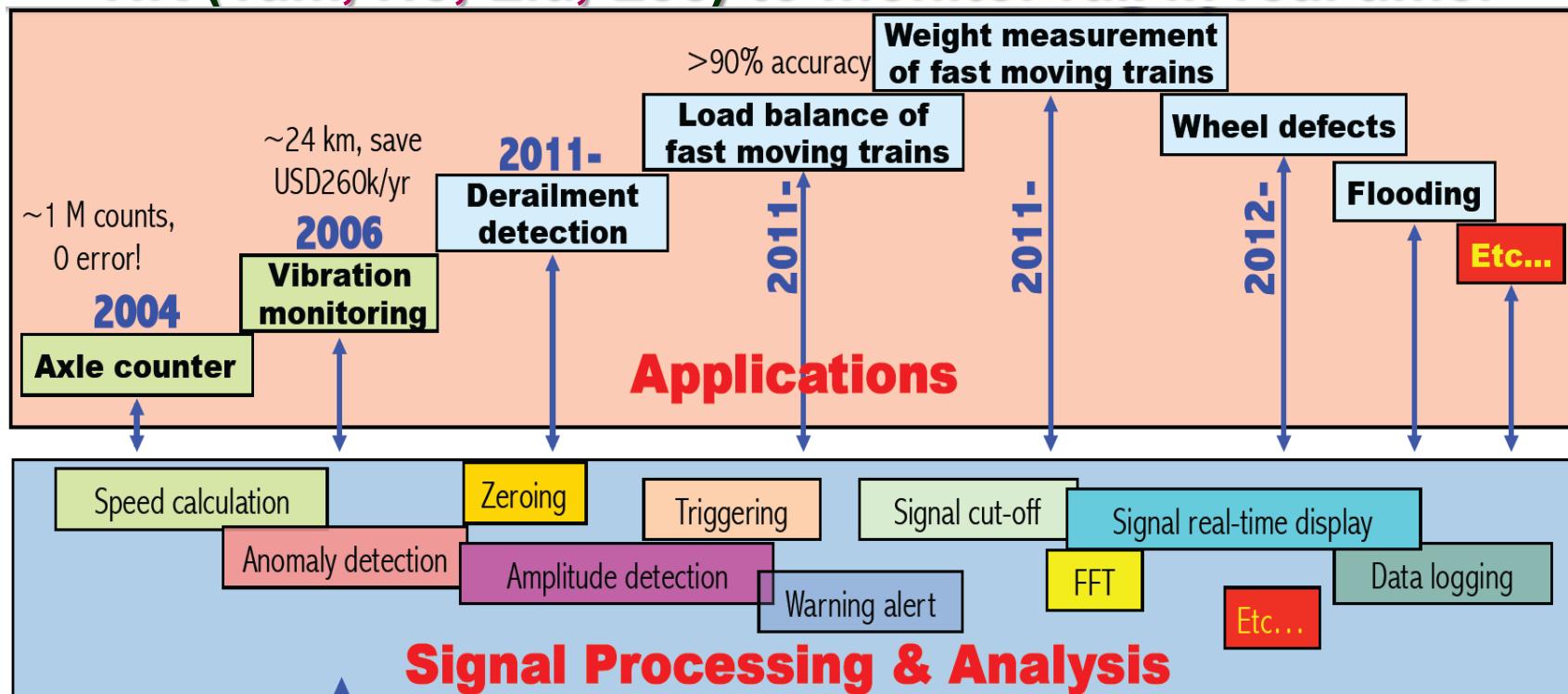
## 2. Vision for rail-SHM systems (1)

### □ Features:

- Provide **online, in-operation monitoring for all critical train components, track system and trackside objects (obstacles);**
- Enable **cross-check of information from the signaling and control systems** so as to enhance the accuracy of fault detection and reduce false defect indications;
- Enable **real-time diagnosis of faults and timely prognosis of breakdown before it occurs;**
- Enable **prediction of degrading and deterioration in component level and estimation of remaining service life;**
- Help **make decisions** and implement remedy measures to prevent the occurrence of catastrophic failure.

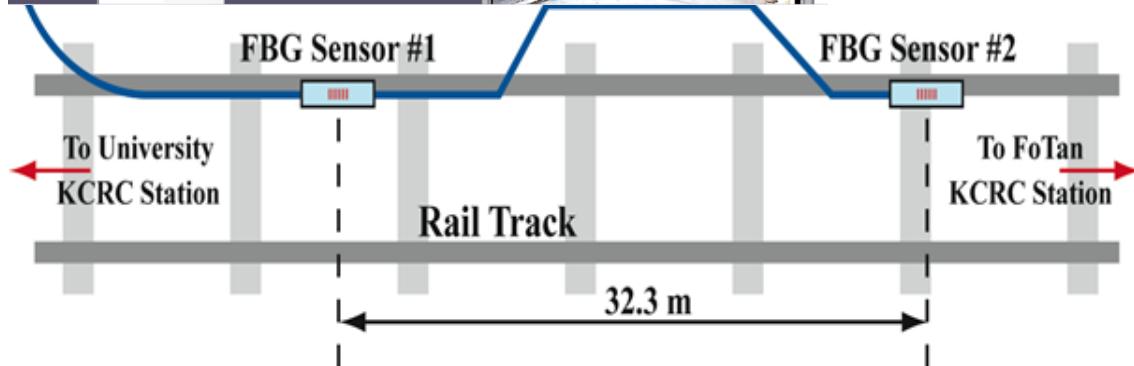
### 3. Sensory systems for rail application (1)

- A Smart Railway System (SRS) based on fiber optic sensors has been developed by a joint team from HK Polytechnic University and MTR Corporation in HK (Tam, Ho, Liu, Lee) to monitor rail in real time.



# 3. Sensory systems for rail application (2)

## Prototype of SRS and implementation on East Rail Line



**Prototype of SRS**

**Hong Kong: East Rail Line**

### 3. Sensory systems for rail application (3)

#### SRS – application in different countries

India: rail clamp breakage, exploring for derailment prevention; Singapore: metro – wheel rail interaction & third rail.

2006-

2013-

2015-

Australia: Metro Transit, UK: Cross Rail, and Spain: Spanish Railways; UK: Network Rail – overhead line of the mainline railway network in England.

Hong Kong: the entire railway network.

2012-

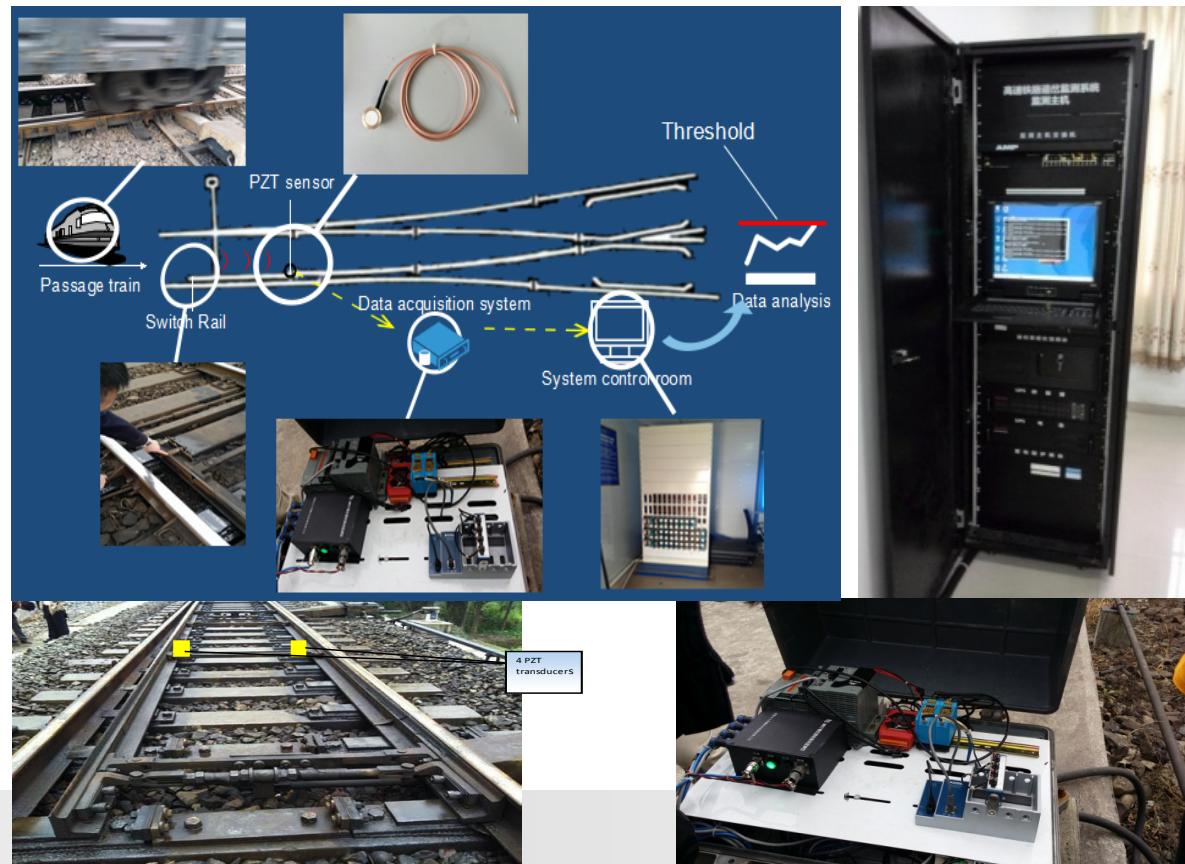
Australia: NWRL – critical components; Netherlands: Lloyds Railway – critical components, Axle Counting.

2014-

Turkey: State Railway – wheel rail interaction.

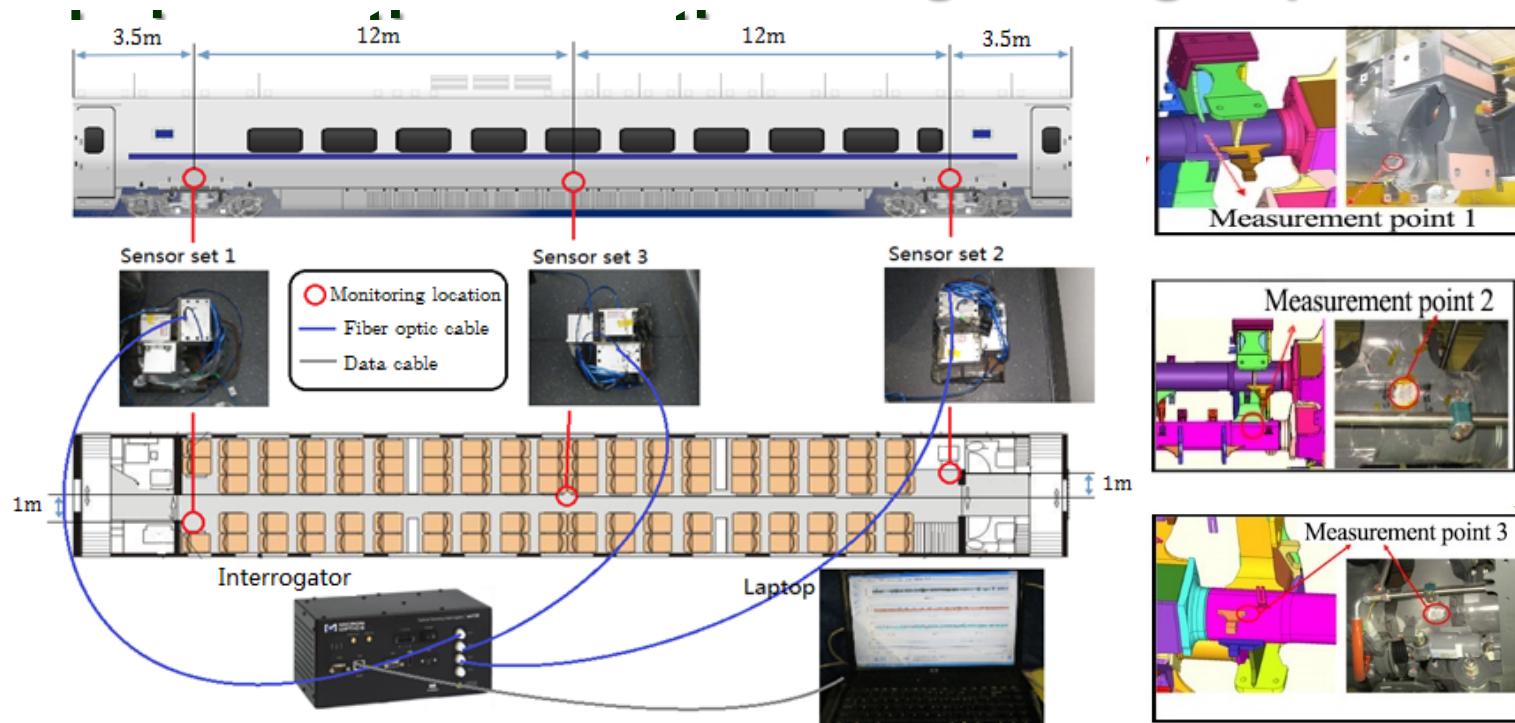
### 3. Sensory systems for rail application (4)

- A PZT-based rail switch/turnout online monitoring system has been developed by Southwest Jiaotong University in collaboration with HK Polytechnic University.



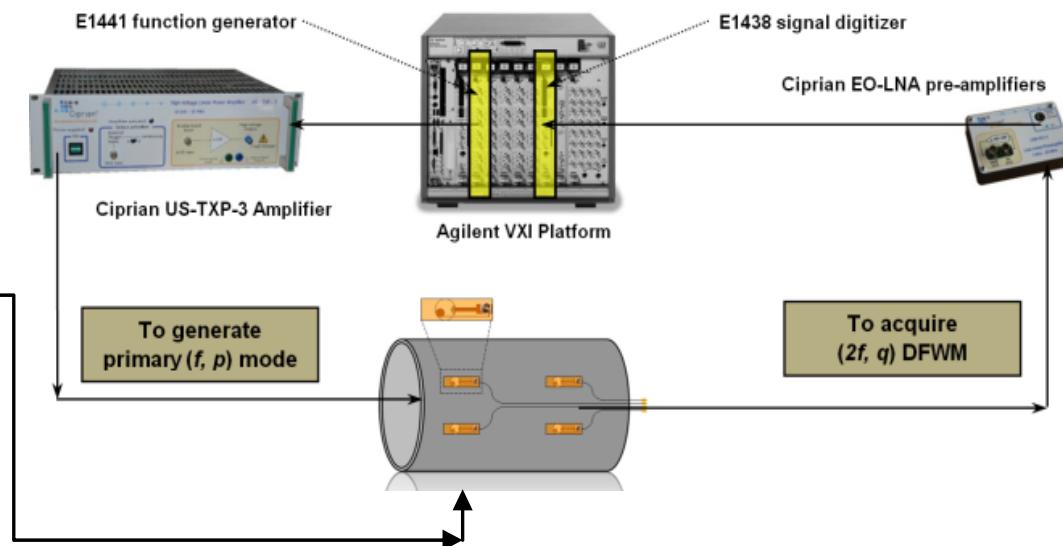
### 3. Sensory systems for rail application (5)

- An on-board instrumentation system has been developed by a joint team from HK Polytechnic University and Dalian Jiaotong University for rail vehicle condition monitoring of high-speed trains



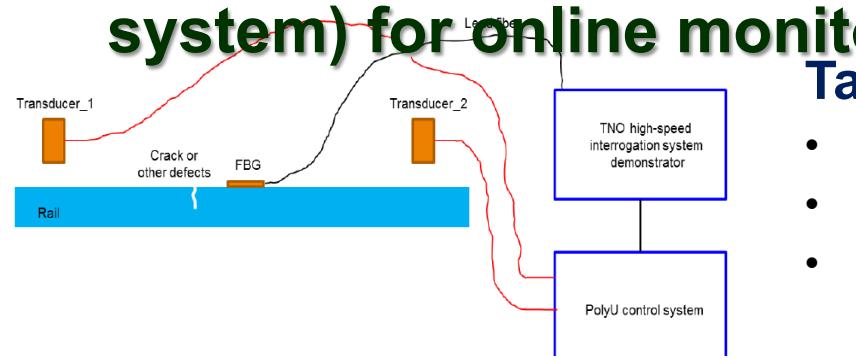
### 3. Sensory systems for rail application (6)

- A joint team from HK Polytechnic University, Polish Academy of Sciences, AGH University of Science & Technology (**Cheng, Su, Ostachowicz, Staszewski**) is developing a nonlinear ultrasonic sensing system for online, in-operation monitoring of fatigue crack on bogies and wheel axles.



### 3. Sensory systems for rail application (7)

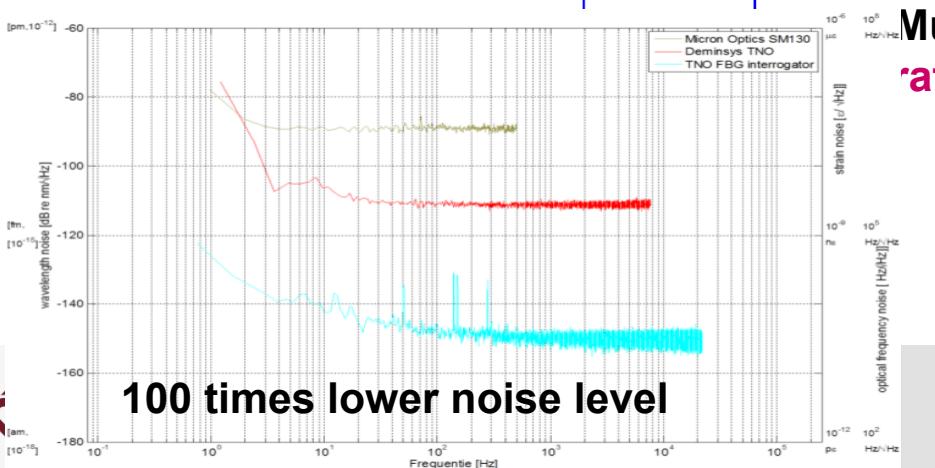
- A joint team from TNO (Netherlands Organization for Applied Scientific Research), HK Polytechnic University and Southwest Jiaotong University is developing a fiber optic based ultrasonic guided wave technique (with ultrasensitive interrogation system) for online monitoring of rail tracks.



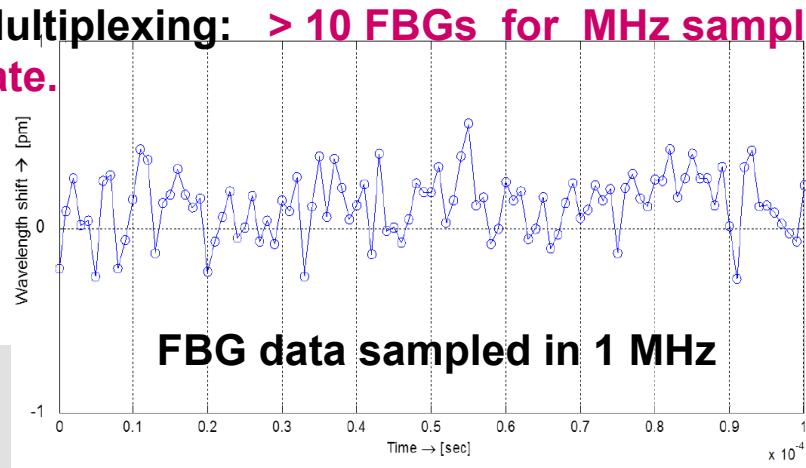
#### Target Specifications:

- Sampling frequency: **MHz to GHz**;
- FBG bandwidth: **About 0.1 nanometer**;
- Detectable wavelength shift: **1 picometer ( $10^{-12}$  m)**;

**Multiplexing: > 10 FBGs for MHz sampling rate.**



100 times lower noise level



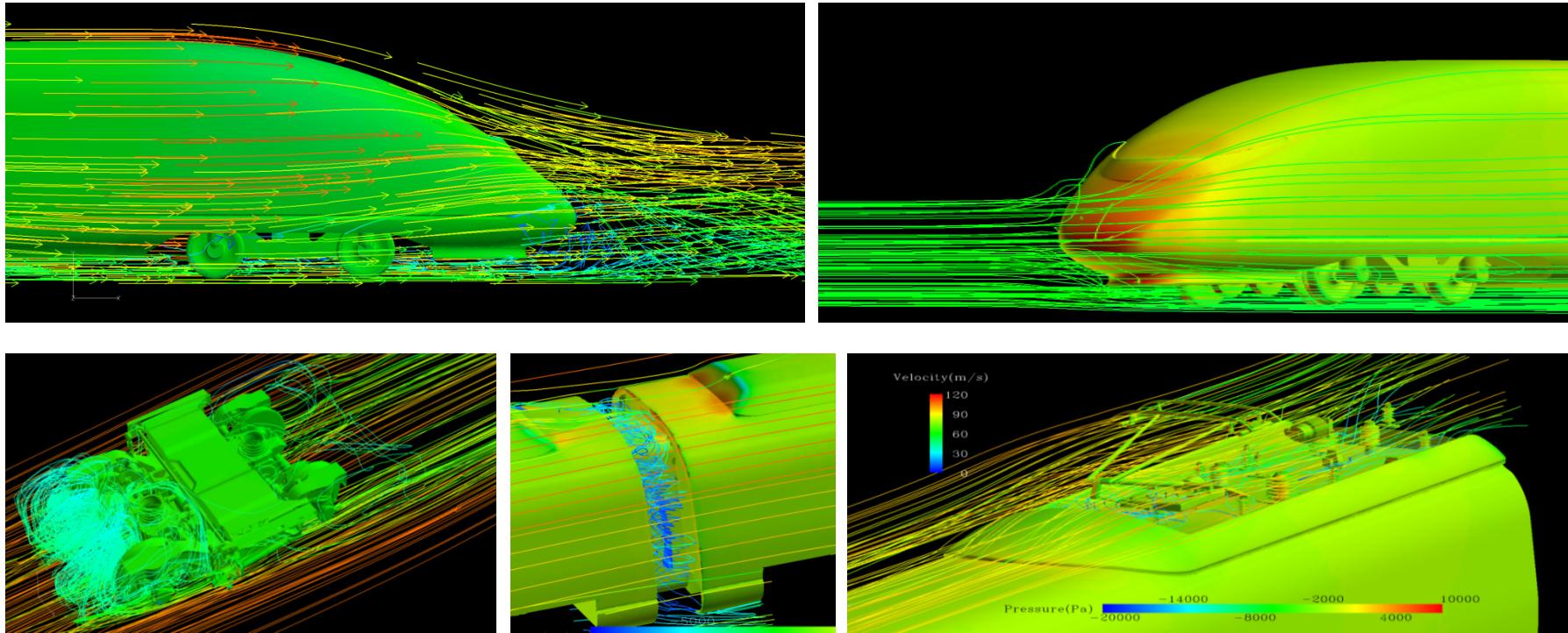
### 3. Sensory systems for rail application (8)

#### □ Interconnectivity and trackside online monitoring:

- **Online monitoring of contact force between the pantograph and catenary.** The monitored contact force can serve as feedback to an active control or variable stiffness system equipped to suppress excessive contact force fluctuation;
- **Fault detection of dampers in suspensions** to prevent the failure caused by malfunction of the dampers;
- **Online or offline monitoring of rail axial stress of continuously welded rail** as an indicator of track system's condition;
- **Online monitoring of obstruction** to early alert drivers to the presence of an obstacle or abnormality in the front of the running train;
- **Earthquake early warning system enabled by wireless sensor network.**

### 3. Sensory systems for rail application (9)

- ❑ How about the feasibility to develop PZT or piezoresistive skins, films, coatings, or patches for online and distributed monitoring of aerodynamic forces acting on four surfaces of an in-service high-speed rail vehicle?



# 4. Predictive modelling tools (1)

- **Predictive modelling tools would be able to**
  - harness the **highly heterogeneous data** (physical and non-physical data) acquired from different sensor types;
  - cater for the **uncertainties** associated with changing operational and environmental conditions and stemming from measurement noise;
  - identify **false positives** resulting from **sensor fault**;
  - formulate **data-driven models** for defect diagnosis; and
  - develop **evolutionarily updatable models** for prognosis of breakdown before its occurrence and prediction of structural and system deterioration/ degrading over time or mileage.

# 4. Predictive modelling tools (2)

## □ Predictive modelling tools in a Bayesian framework

- The **Bayesian modelling approach** is straightforward and powerful in dealing with the heterogeneous and uncertain monitoring data;
- The **Bayesian updating and inference approaches** are perfect in formulating models for successive evaluation and updating the models with progressively cumulated monitoring data;
- The **Bayesian source separation technique**, which enables blind source separation from noisy and nonstationary signals, would be competent to identify a specific subsystem with fault and discriminate between true defect and false-positive;
- The **Bayesian forecasting and dynamic modelling method** is feasible for the development of time-dependent evolutionary models purposed for prognosis of possible breakdown upon minor symptom and prediction of degrading or deterioration in component or system level.

# 5. Looking into the Future (1)

1. The SHM-enriched smart railway system is more than providing merits to the existing HSR. Capitalizing on the living laboratory of HSR networks, the 'mobile' sensors which move on vasty railroads provide the most authentic and comprehensive data to facilitate optimal design of the next-generation HSR;
2. If looking ahead, a more imaginative step forward is to blend climatic- and environmental-related sensors into this global-mobile-enabled sensing environment, collecting spatio-temporal data for the research of grand issues such as global sustainability, energy efficiency, carbon footprint and climate change.

# Thank You for Your Attention !



**Two postboxes in Taipei, Taiwan become cute when being damaged during Typhoon Soudelor on August 8th, 2015.**

**For most of us, it is enjoyable to work with recognizing a new pattern.**