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A Novel IoT Application System Using Wearable PPG Heart Rate Monitoring Devices to Improve Safety Management for Shield Tunnel Construction Projects

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OUTLINE

1. Introduction
2. Literature Reviews
3. Development and Validation of the Heart Rate Monitoring System
    - System Development
    - System Validation
4. Experiment Results and Discussions
5. Future Work

1. INTRODUCTION

- There are more than **60 thousand of casualties** happened in 2016. (Yi, W., Chan et al., 2016). Construction workers are involved in the highest casualty rate industry, which has 3 to 4 times higher casualty rate compared to other industries (Yilmaz, F. et al., 2015).
- According to statistics published by International Labor Organization (ILO), **33.7 million accidents** happened around the global with **USD1.2 trillion** lost accordingly. Due to such a high casualty rate happened in construction projects, safety management has been included by the Project Management Body of Knowledge for years.
- NIOSH has been promoting **Total Worker Health (THW)** to inspire and encourage construction companies and workers to be more cautious and vigilant to safety related matters including off-duty times.

2. LITERATURE REVIEWS

- **HRR:** The cause of human's fatigue has two types, physical and psychological. Measuring human's fatigue based on heart rate, Heart Rate Variability (HRV) and its related parameters, is mostly seen in many research papers. Resting Heart Rate (RHR), Maximum Heart Rate (MHR), the percentage of Heart Rate Reserve (%HRR), Heart Rate Recovery (HRR), etc. are commonly used as the index to assess human's fatigue. (Abdelhamid & Everett, 2002)(Miyake et al., 2009) (Liu, Gao, & Freedson, 2012) (Thomson et al., 2016).
- **HRV:** It has been proven that high frequency HRV (01.5Hz<HRV<0.4Hz) is closely related to psychosocial workload and continuous working time (Fumiharu Togo et. al., 2009). To measure physical fatigue needs continuous heart rate collection devices with a data sampling resolution up to mini-second level.
- **Light-weight wearable heart rate monitoring devices and application system are needed for measuring workload and fatigue.**

3. SYSTEM DEVELOPMENT AND VALIDATION

No.	Management Requirements	Specifications	Descriptions
1	Full range detection of heart rate	Sampling rate >500 times/second	Heart rate detection range from 30 to 200bpm.
2	Continuous detection	Heart rate detection and transmitting rate >10 times/second	Heart rate data can be received by application system at least in every second.
3	Full working hour power duration	Battery life before next charge>12 hours	A full operation period of one shift.
4	Environment sustainability	IP67 Standard	Water, dust, and shock proof.
5	Mobility	Bluetooth Low Emission version 4.x	Full coverage of heart rate senor network in tunnel construction site.

3. SYSTEM DEVELOPMENT AND VALIDATION

Key System Components

- **PPG Heart Rate Monitor**: Nordic SoC with Green LED senor.
- **BLE Gateway:** Raspberry Pi 3B platform
- **IoT Application System:** Developed on AWS IoT software platform

KEY PRODUCTS

Product Name	Specifications	Product Feature
Bluetooth PPG Heart Rate Wristband	1.PPG heart rate detection 2.RFID MiFare M1 3.Support BLE 4.0 4.Up to 24hr power duration 5.IP67	
BLE Gateway	1.Support BLE 4.X 2.Support concurrent 20 BLE clients 3.100Mpbs Ethernet interface 4.Support Wifi 803.11a/b/n 5.DC5V/2A	

HEART RATE RESERVE THEORY

$$HRR = MHR - RHR \quad [1]$$

$$L\% = \triangle HR / (MHR - RHR) \quad [2]$$

$$WHR = RHR + \triangle HR$$

$$= RHR + (MHR - RHR)*L\%$$

$$L\% = (WHR- RHR) / (MHR - RHR) \quad [3]$$

$$MHR = 206.9 - (0.67 \times Age) \quad [4]$$

- HRR, Heart Rate Reserve
- MHR, Maximum Heart Rate
- RHR, Resting Heart Rate
- WHR, Working Heart Rate

SYSTEM VALIDATION ARRANGEMENT

- 6 volunteers involved aged form 24 to 28
- 20 minutes exercise for 3 times with a 10 minutes rest between each exercise.
- A wireless ECG tag(FDA approved) attached on each volunteer and PPG wristband worn on his left wrist.

PPG VS ECG

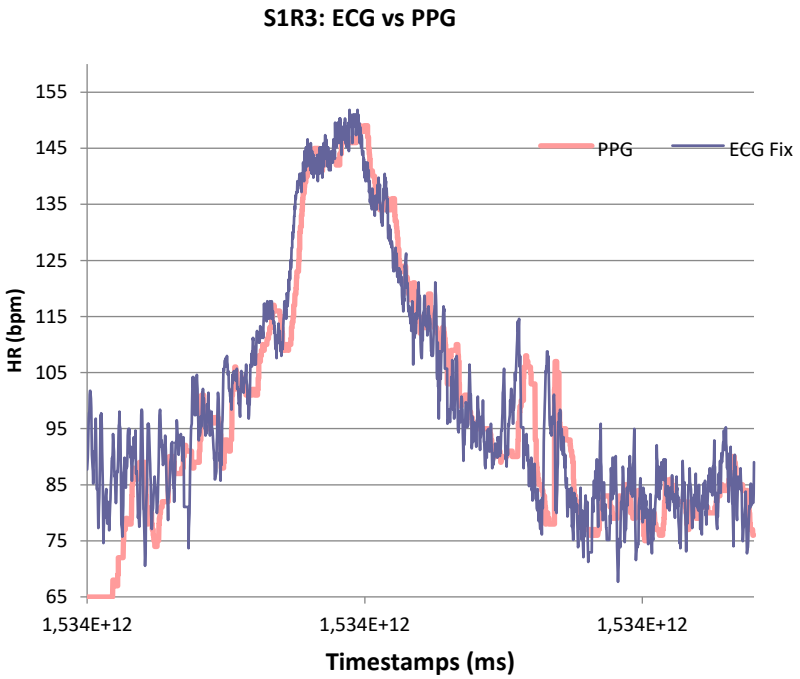


Figure 1. ECG vs. PPG from the first subject

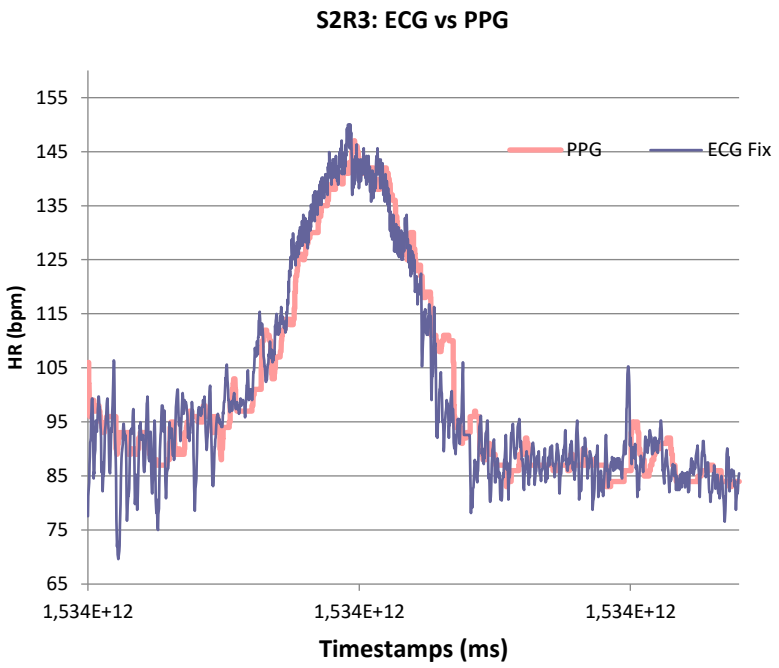


Figure 1. ECG vs. PPG from the second subject

RESULT OF SYSTEM VALIDATION

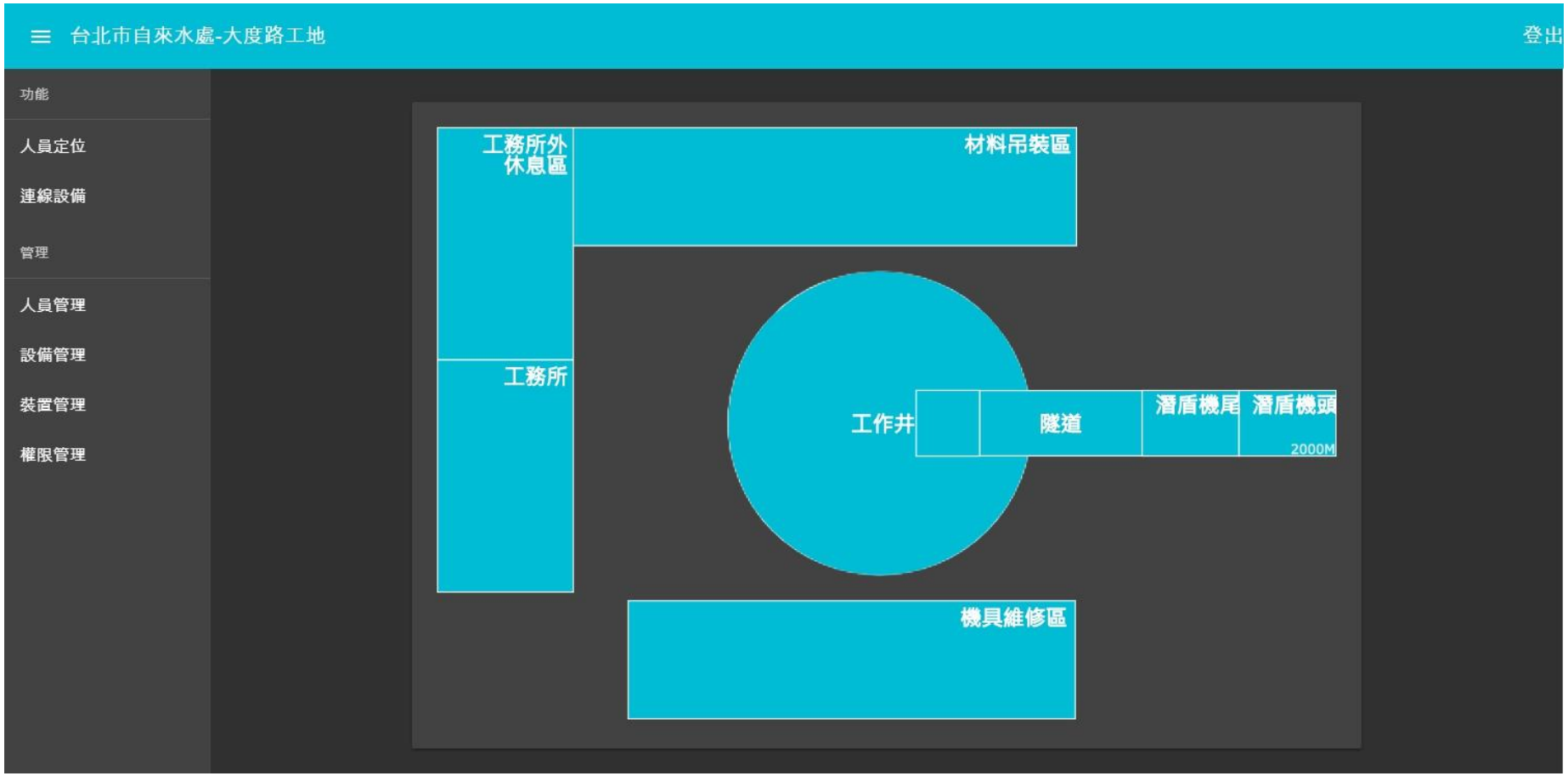
Validation Index	Round	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Average
Sensor Coverage	Round 1	95.88%	100.00%	100.00%	100.00%	100.00%	99.18%
	Round 2	98.00%	95.75%	92.26%	92.35%	100.00%	95.67%
	Round 3	100.00%	100.00%	100.00%	100.00%	100.00%	100%
R (R>0.7)	Rest	0.8128	0.8408	0.9029	0.9764	0.8848	0.8835
	Walking	0.9785	0.9857	0.9090	0.9337	0.9942	0.9602
	Running	0.9905	0.9945	0.9461	0.9772	0.9947	0.9806
MEAP% (±5%)	Rest	2.73	-0.51	1.89	0.83	-0.03	+0.98
	Walking	0.68	0.08	-0.55	4.50	0.72	+1.09
	Running	-0.29	-0.12	-0.92	-0.73	-0.10	-0.43
Time lag (seconds)		16	15	15	14	14	14.8

4. EXPERIMENT ARRANGEMENT

- Construction site: shield tunnel construction project selected with a tunnel of 2KM in distance, and 2.8M in tunnel's diameter, two shaft of 30M in depth and 15M in diameter.
- 16 volunteer workers involved in two teams of 8 people for each team.
- Data collection for 12 hours in the day shift form 6am-6pm.
- Pre-experiment conducted from March to May 2018, and justification work taken in July and August 2018.
- Second experiment starting from 16 September to 16 November 2018

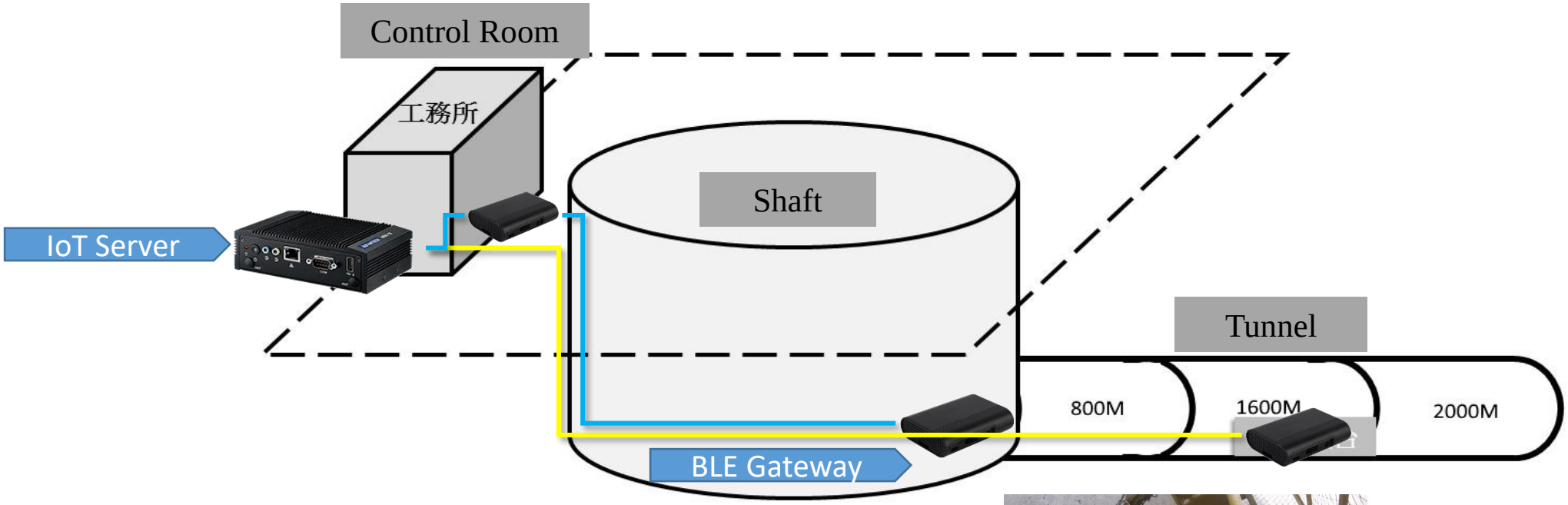
LOCATION-BASED APPLICATION

Location-based dashboard used for worker tracking in the construction site



SYSTEM INSTALLATION

Installation and arrangement of the hardware and network



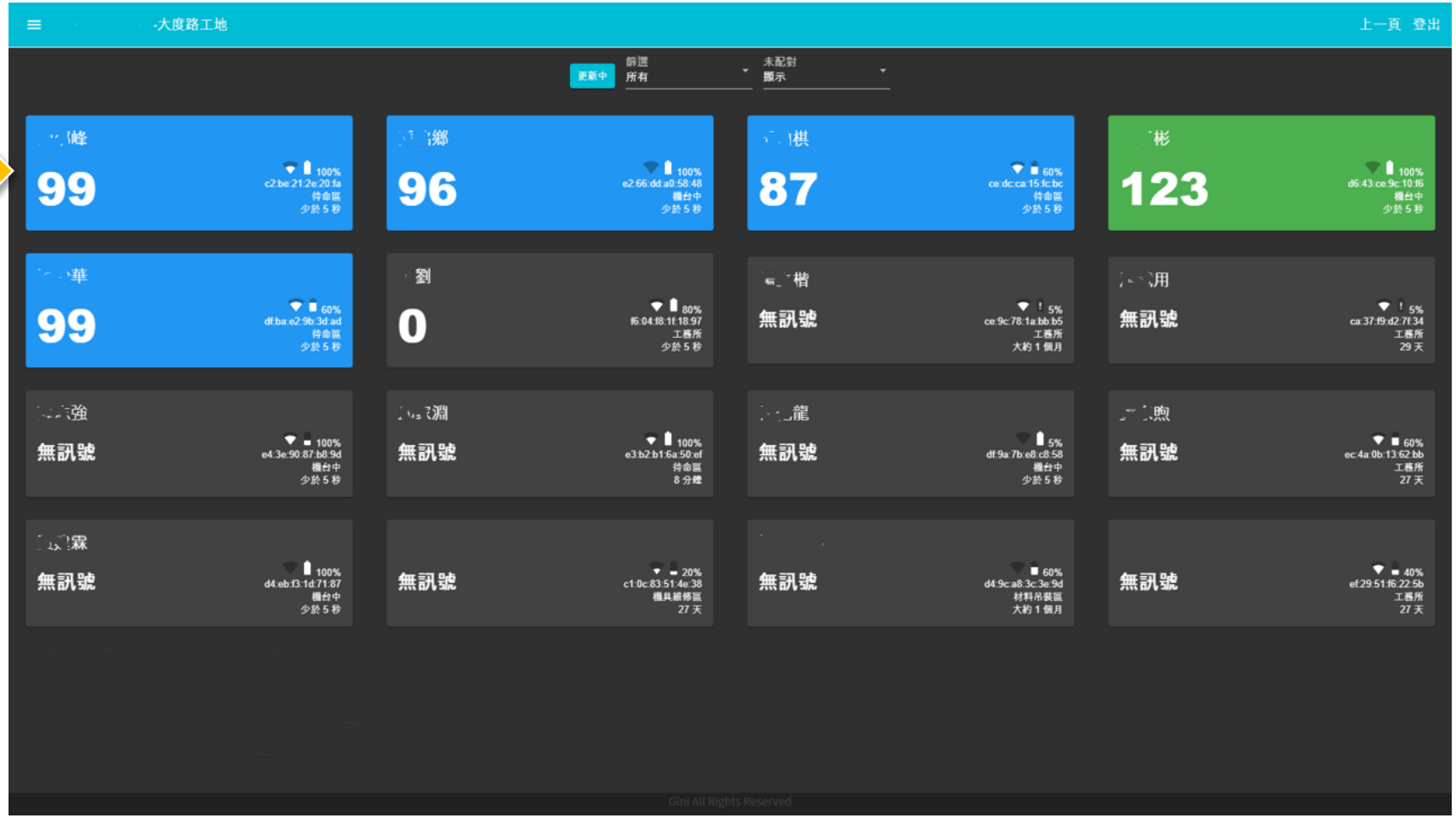
Cat. 6 ethernet cable

Optical Fiber

DASHBOARD OF WORKER'S STATUS

Dashboard of worker's health condition

Real-time heart rate



REAL-TIME WORK'S HEART RATE RECORD

Dashboard of worker's heart rate record

Real-time heart rate

FIELD EXPERIMENT

國立臺灣大學
行為與社會科學研究倫理委員會

Research Ethics Committee
National Taiwan University
No. 1, Sec. 4, Roosevelt Rd., Taipei, Taiwan 10617, R.O.C
Phone: 3366-9956 Fax: 2362-9082

審查核可證明

核可日期：2017 年 9 月 11 日

倫委會案號：201707HM016
計畫名稱：隧道環境勞工生理監測策略及管理
校/院/系/計畫主持人：國立臺灣大學/工學院/土木工程系營建管理組/曾惠斌 教授
計畫文件版本日期：【研究計畫書，2017 年 7 月 6 日】、【知情同意書， 2017 年 7 月 10 日】、【問卷，2017 年 7 月 1 日】、【招募文宣， 2017 年 8 月 4 日】

上述計畫業經 2017 年 9 月 11 日 國立臺灣大學行為與社會科學研究倫理委員會同意，符合研究倫理規範。本委員會的運作符合本校行為與社會科學研究倫理準則與規範及政府相關法律規章。

本案需經研究經費補助單位核准同意後，該計畫始得執行。

本審查核可證明之有效期限自 2017 年 9 月 11 日 起至 2018 年 7 月 31 日 止。若有需要，計畫主持人最遲應於本核可證明到期前的 6 週，提出持續審查申請表，方可繼續執行。

在計畫執行期間，若有計畫變更或嚴重不良反應事件，計畫主持人須依國內及本校相關法令規定通報本委員會。

行為與社會科學研究倫理委員會主任委員 謝世忠

Ethical Review Approval
National Taiwan University

Date of approval: September 11, 2017

NTU-REC No.: 201707HM016
Title of protocol： Strategies and Management of Worker's Physiological Status Monitorting in Tunnel Worksite
University/ College/ Department/ Principal Investigator： National Taiwan University Civil Engineer Department Construction Engineer/ Professor Hui-Ping Tserng
Version date of documents：【Research Protocol, July 6, 2017】、【Informed Consent Form, July 10, 2017】、【Questionnaires, July 1, 2017】、【Recruitment Advertising, August 4, 2017】

The protocol has been approved by Research Ethics Committee of National Taiwan University and has been classified as expedited on September 11, 2017 . The committee is organized under, and operates in accordance with, Social and Behavioral Research Ethical Principles and Regulations of National Taiwan University and governmental laws and regulations.

Approval by funding agency is mandatory before project implementation.

The duration of this approval is from September 11, 2017 to July 31, 2018 . Continuing Review Application should be submit to Research Ethics Committee no later than six weeks before current approval expired.

The investigator is required to report protocol amendment and Serious Adverse Events in accordance with the National Taiwan University and governmental laws and regulations.

Chairperson Shih-chung Hsieh
Research Ethics Committee

Project approved by the Research Ethics Committee, National Taiwan University
Case No. 201707HM016, dated on 9 September 2017

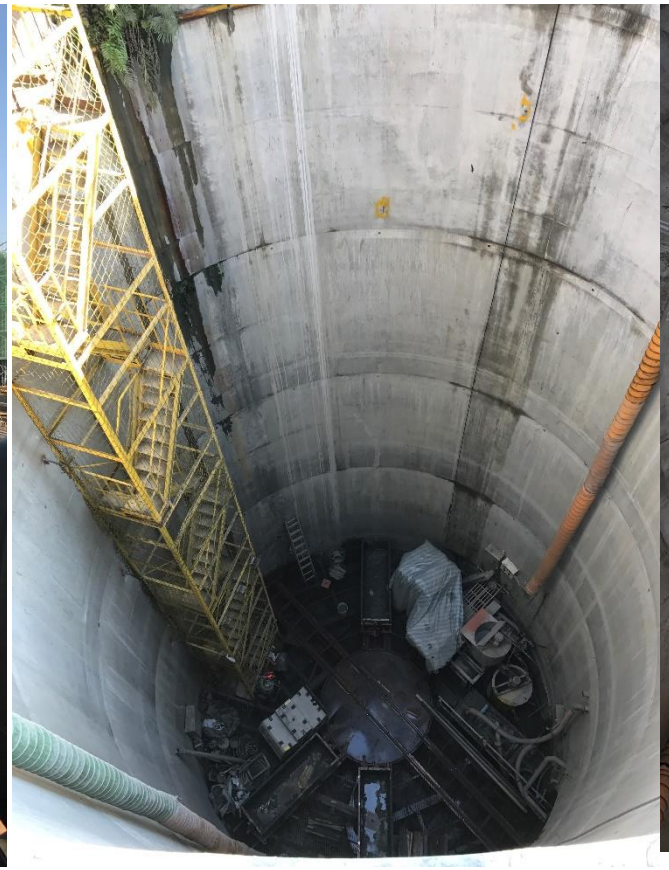
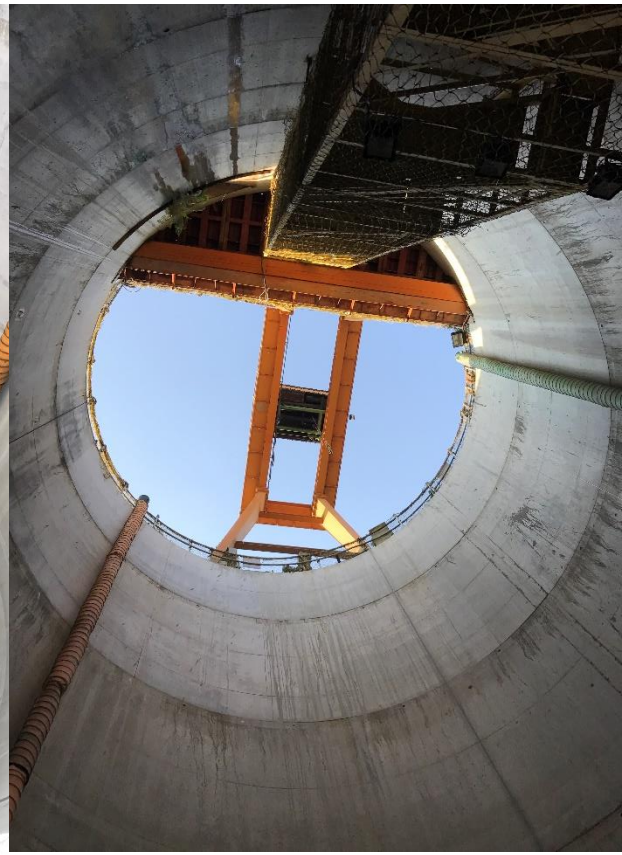
Authors conducting site survey, on the left is Wei-Cheng Chen and on the right is Jia-Sheu Huang

Toolbox meeting before daily work

FIELD EXPERIMENT

Shield tunnel construction site-ground and shaft



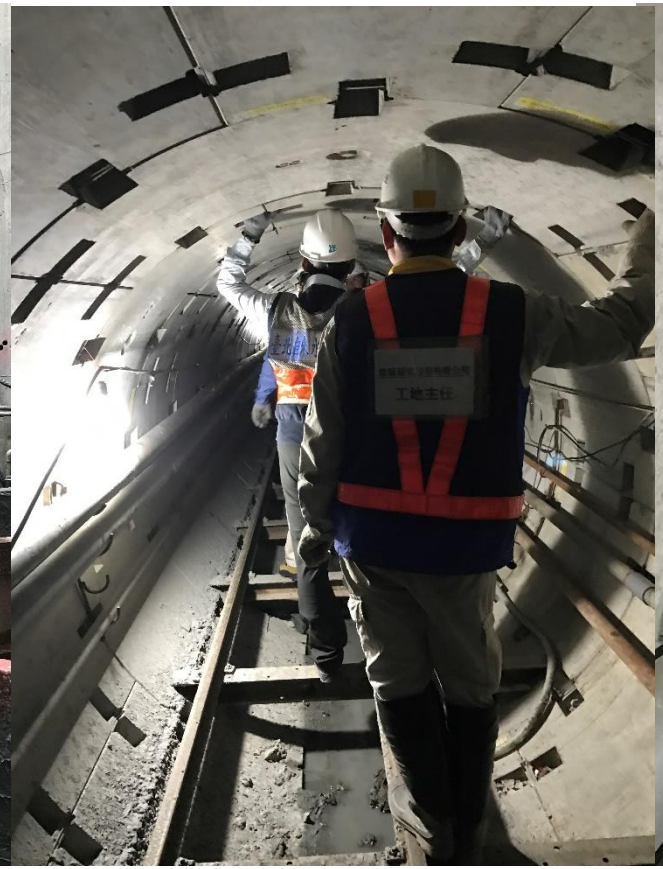



FIELD EXPERIMENT

Shield tunnel construction site- drill and shield tunnel

FIELD EXPERIMENT

Shield tunnel construction site-tunnel operation



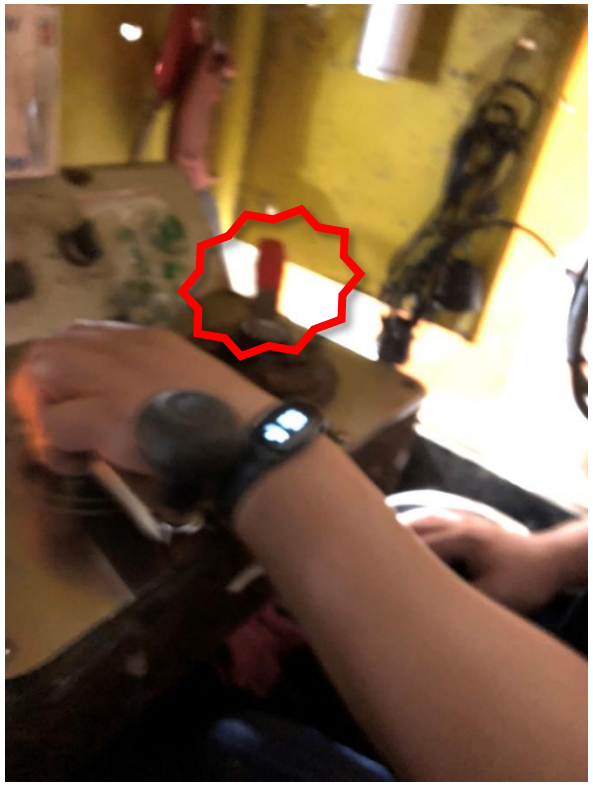
FIELD EXPERIMENT

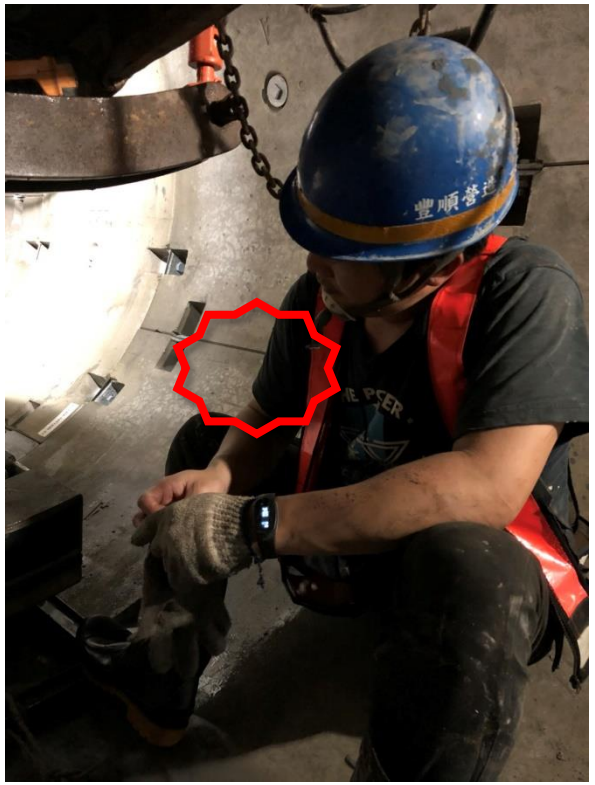
Data sent from the PPG heart rate monitor wristbands is received by BLE gateway installed at each working section

PPG Heart Rate Monitor Wristband

FIELD EXPERIMENT

PPG heart rate monitor wristbands worn on each on construction worker





EXPERIMENT RESULTS

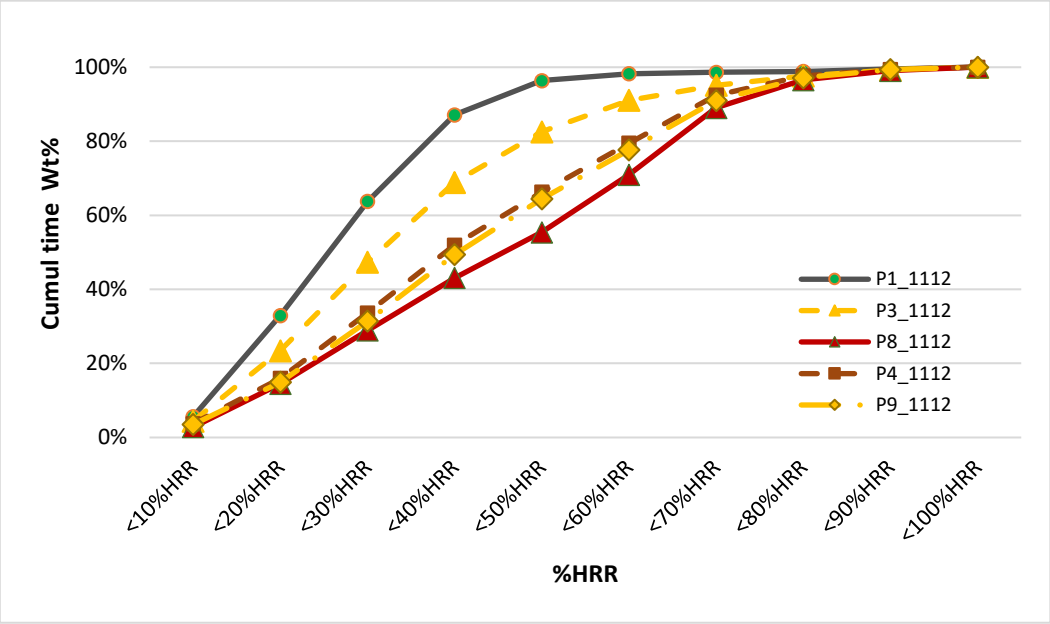


Figure: 5. Workload (%HRR) difference between tunnel construction workers

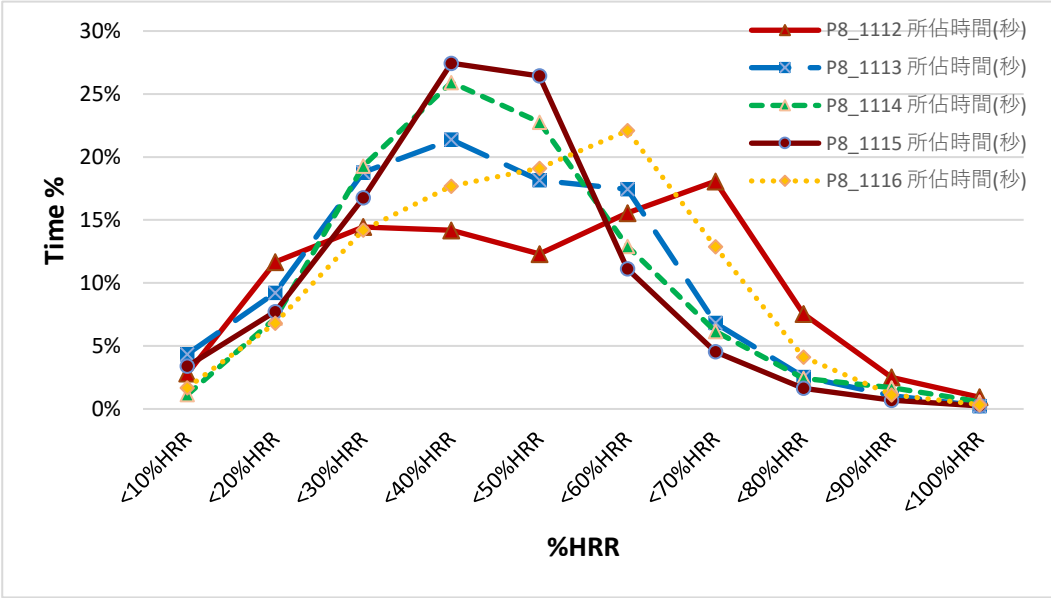


Figure 6. Workload (%HRR) distribution of No. P8 workers in one week

CHALLENGES AND ACHIEVEMENTS

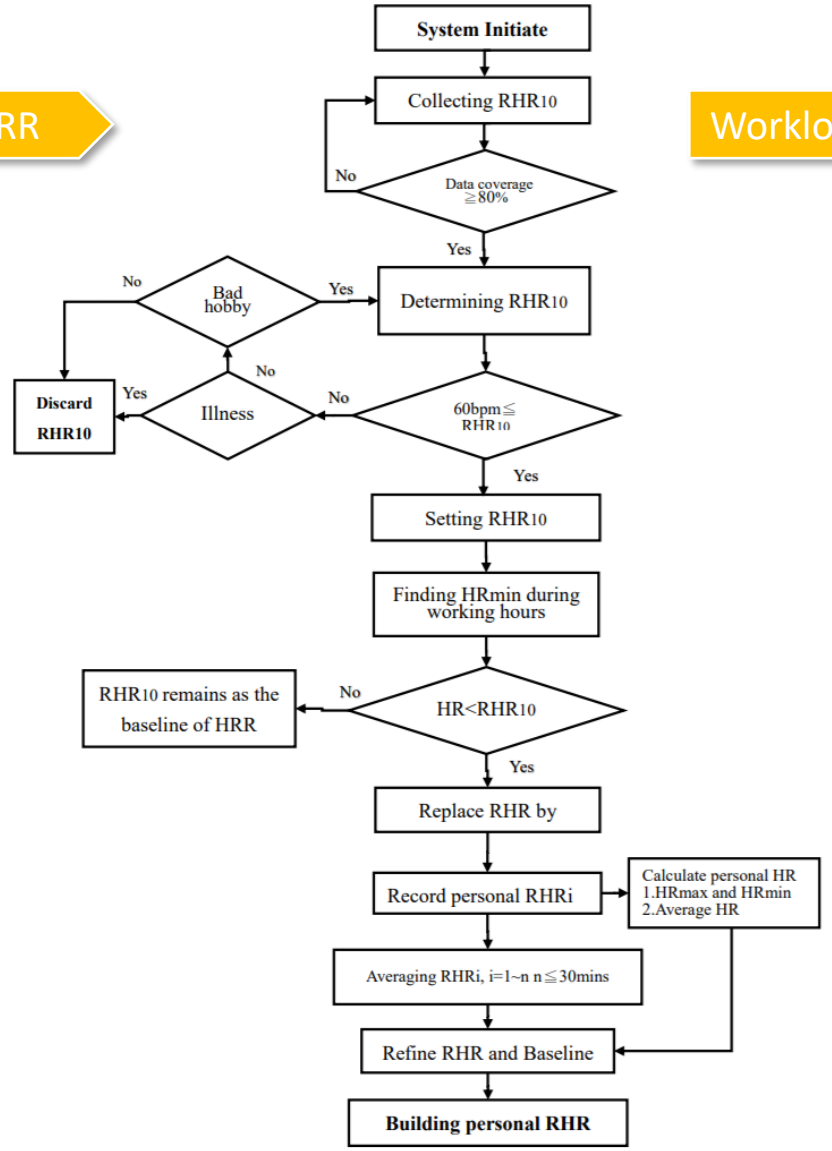
- System development: technical challenge of infrastructure, hardware and software.
- Construction site: workers' compliance and top management support.
- Data processing and analysis: lacks of software tools and references.

5. FUTURE WORK

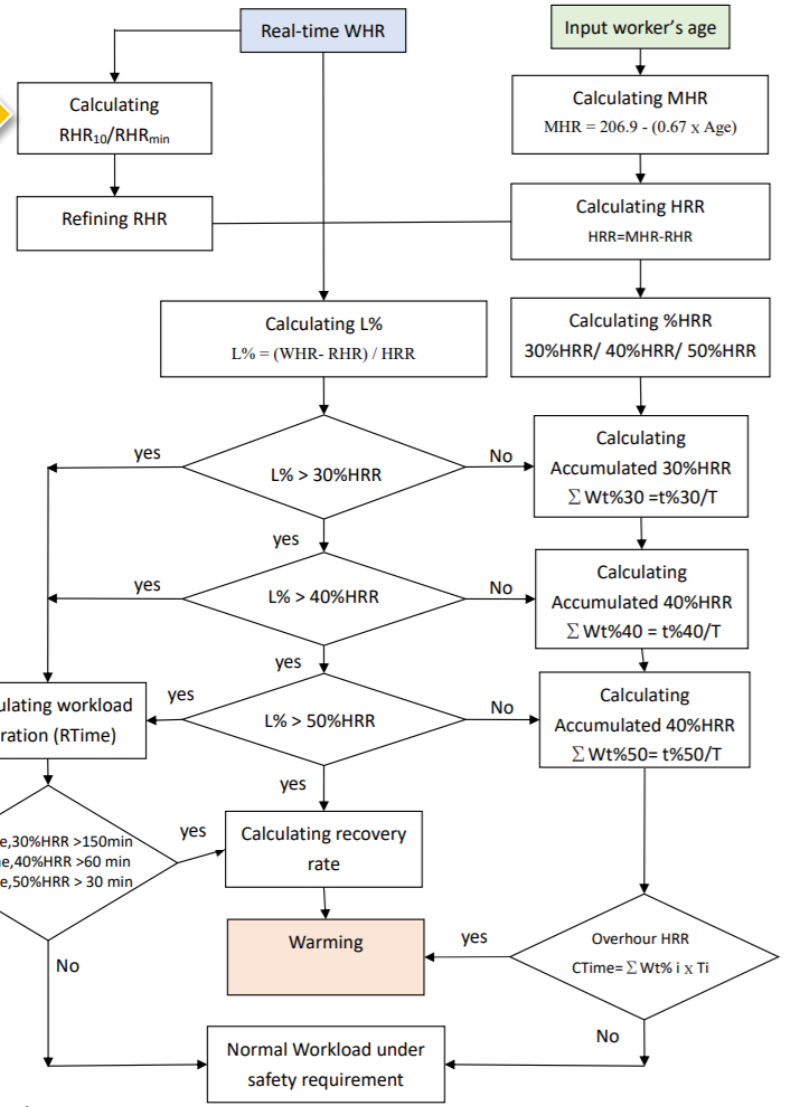
- Real-time workload calculation and fatigue modeling.
- Developing fatigue prediction model and prevention method.
- Finding worker's stress(HRV) and its relation with %HRR.
- Developing safety management system based on worker's workload(%HRR) and stress(HRV).

5. FUTURE WORK

Real-time %HRR

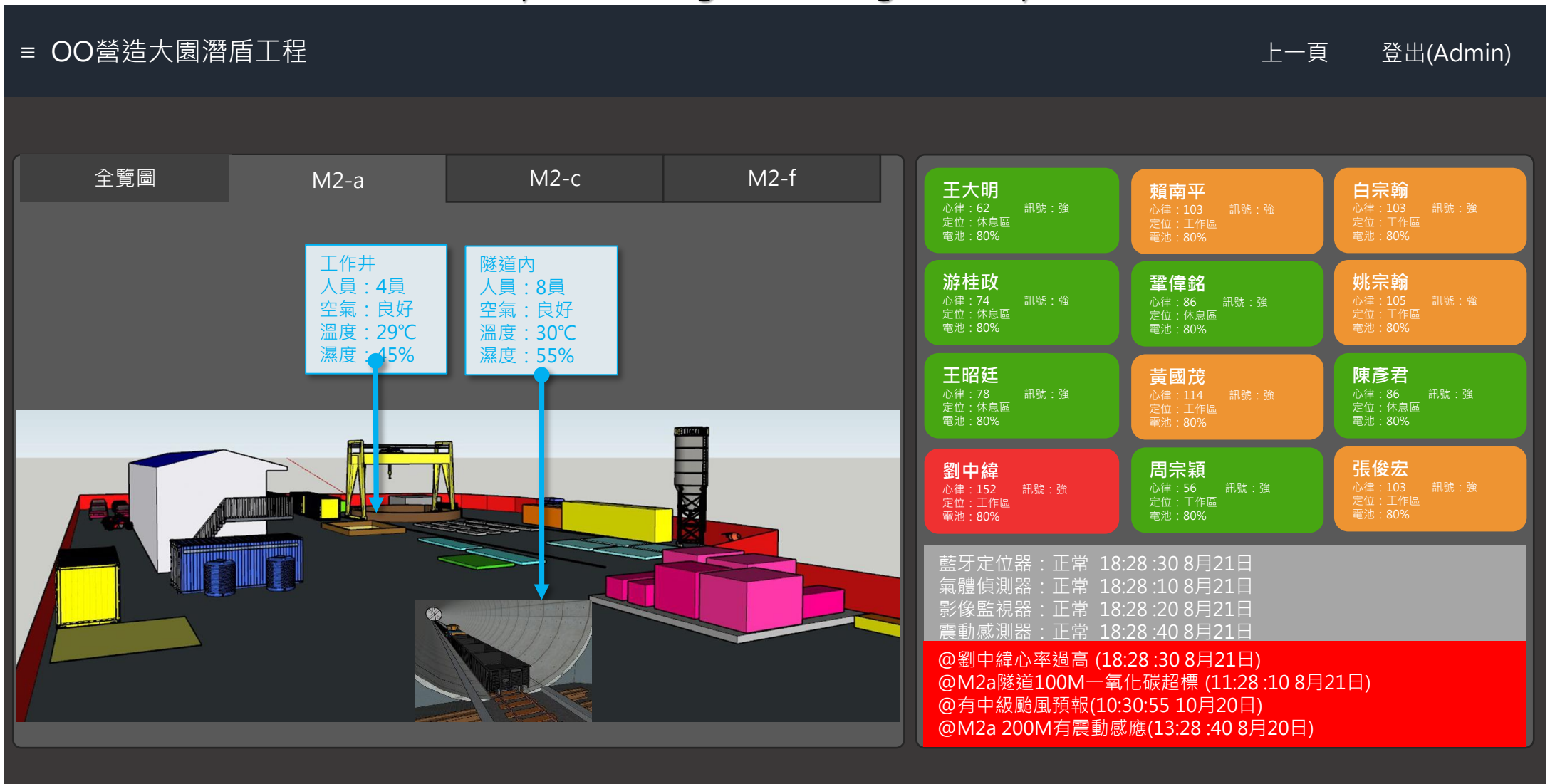


Workload monitoring



5. FUTURE WORK

Safety Monitoring and Management System



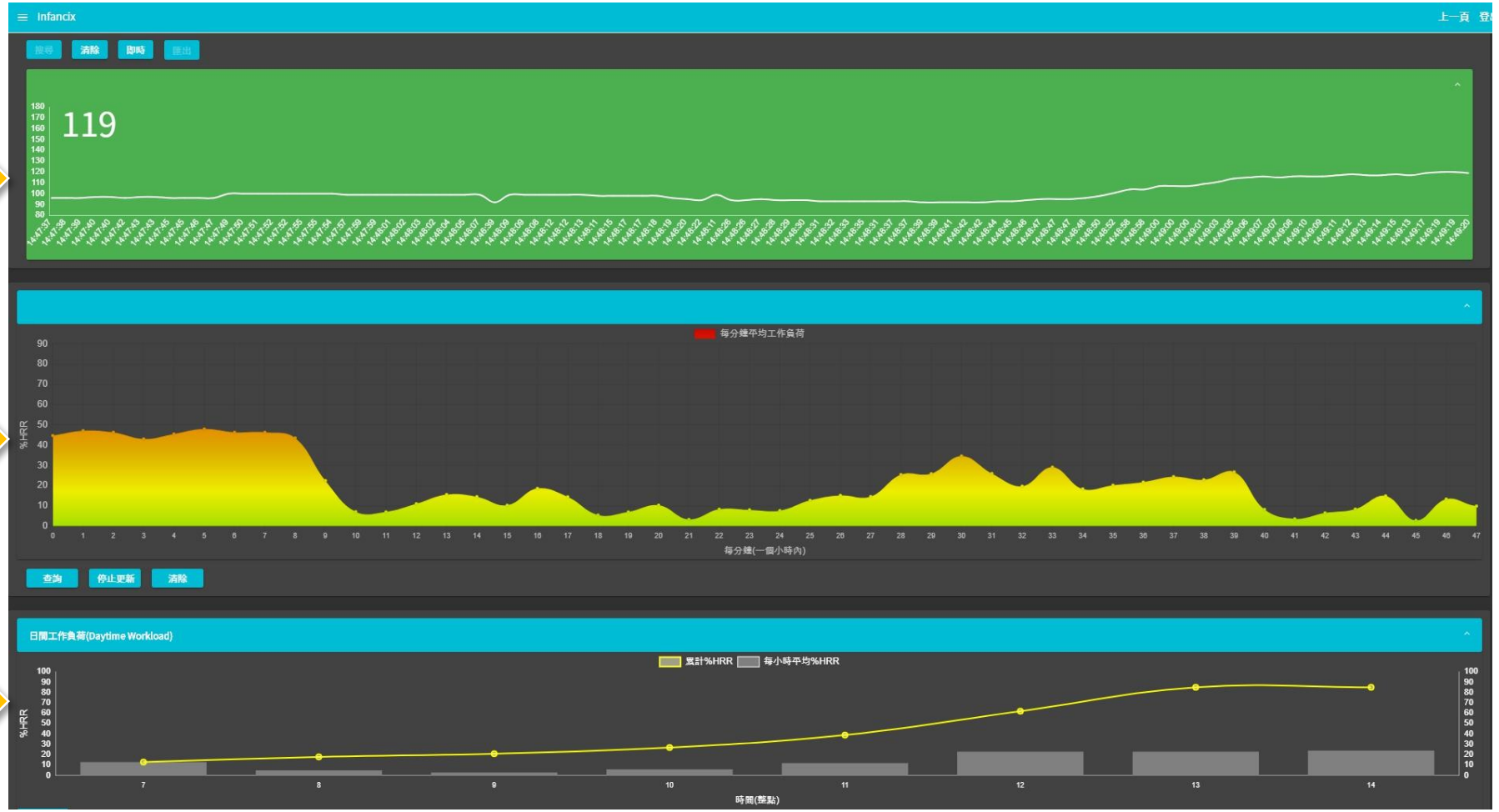
5. FUTURE WORK

Monitor of worker's hear rate, %HRR, and workload

Real-time heart rate

Real-time %HRR

Hourly workload



Thank you for listening
.....Questions?