Smart Construction Laboratory
智能建造實驗室

THE HONG KONG POLYTECHNIC UNIVERSITY
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Integrating Site Monitoring and Ergonomics into Smart Construction

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Content

1. Automated site management based on IoT, Smart Insole and Computer Vision

2. Establishing traceability chain for quality management based on tool tracking

3. Integrating ergonomics with smart construction

4. Future Plan

- Management focuses on reactive/remedial actions
- Increasing ‘management cost’;

1. Automated site management based on IoT, Smart Insole and Computer Vision

Location-based Technologies for Real-time Site Safety Management System

應用於工地的實時風險警報管理系統

Smart Insole

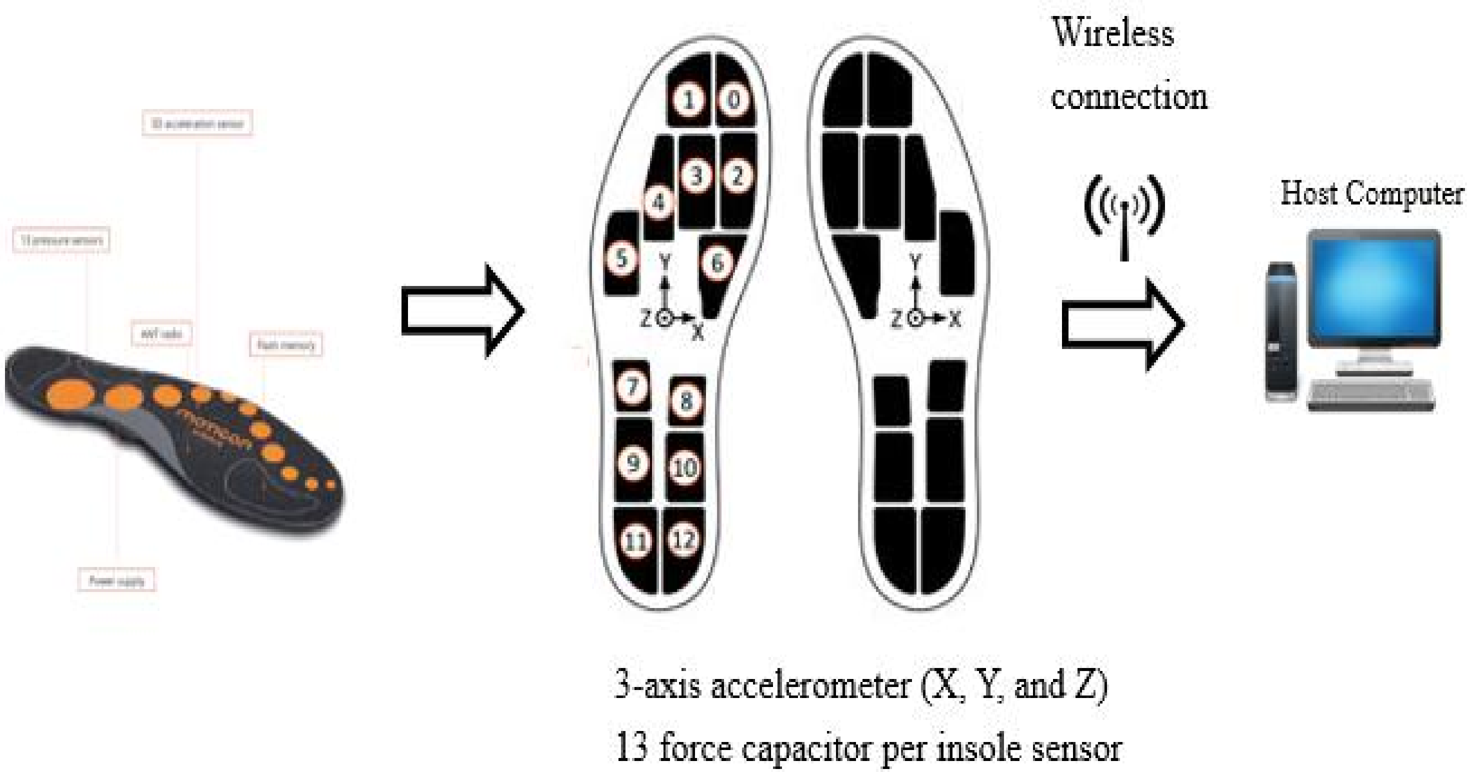
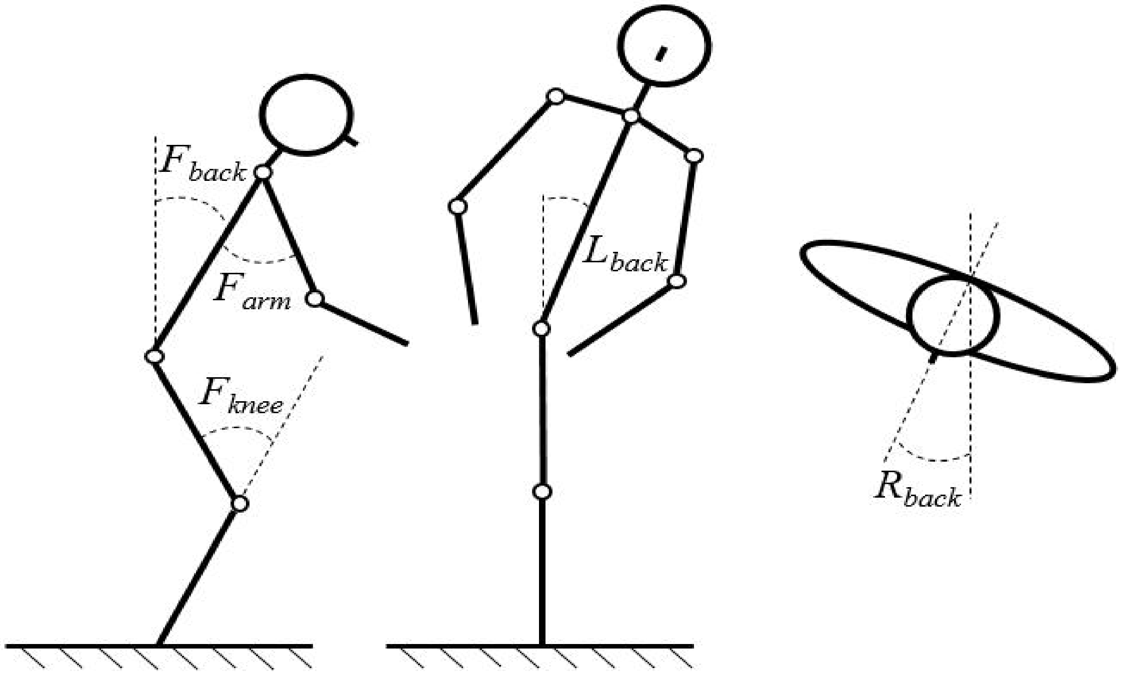


Figure 5: Overview of Foot Plantar Pressure Sensing System

Predicting postures of workers from inverse dyna



Self-power system

❑ **Mini generator integrated with insole system**

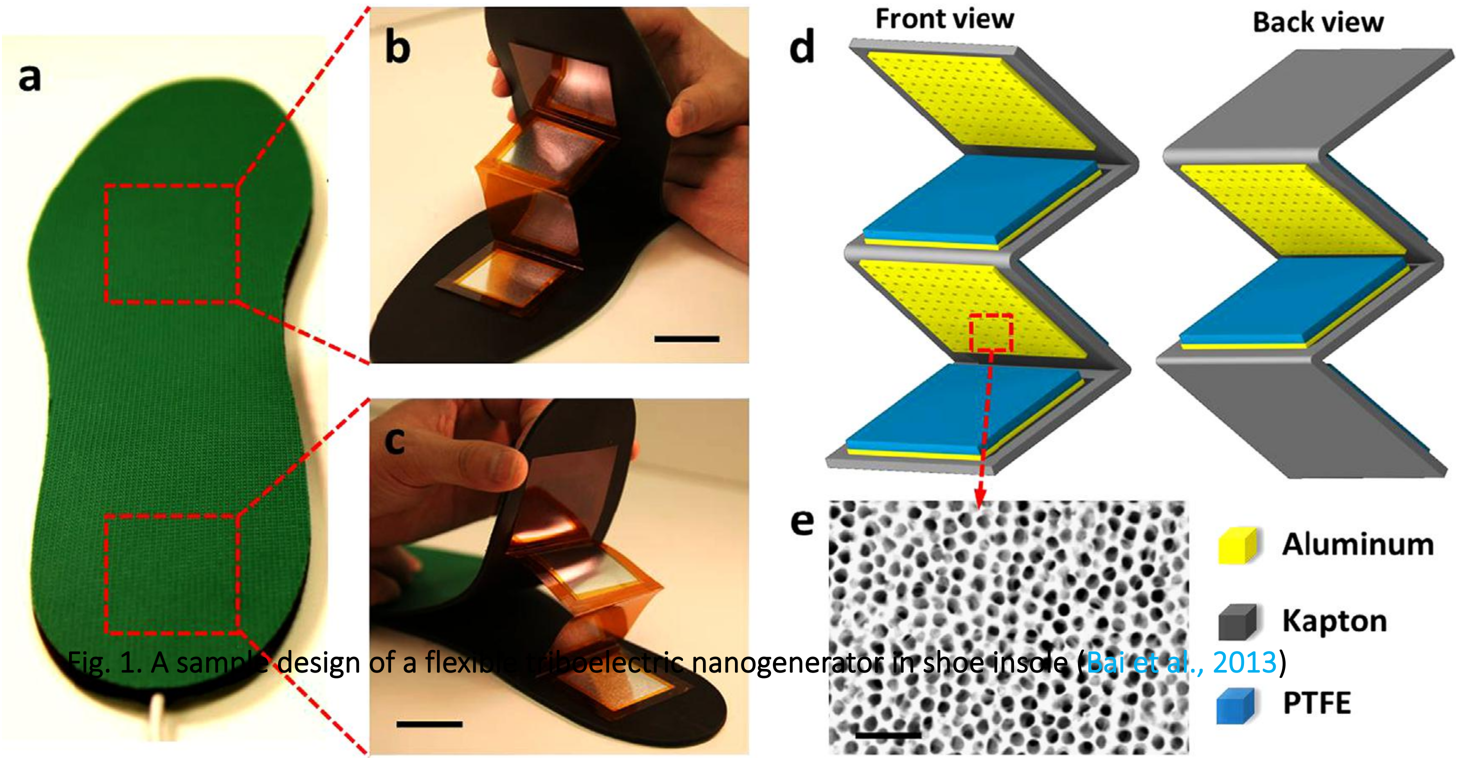
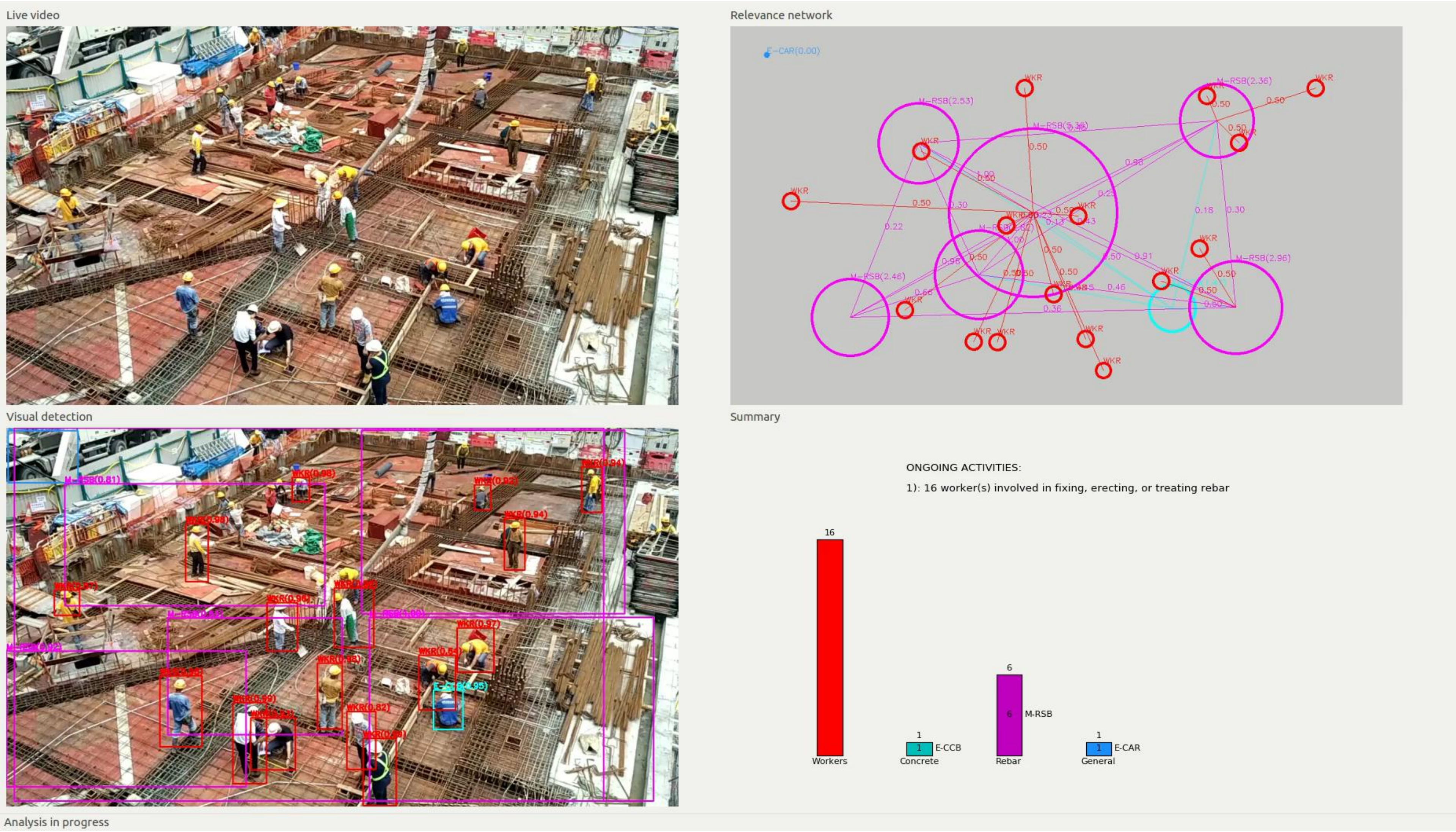


Fig. 1. A sample design of a flexible triboelectric nanogenerator in shoe insole (Bai et al., 2013)

Computer vision and deep learning

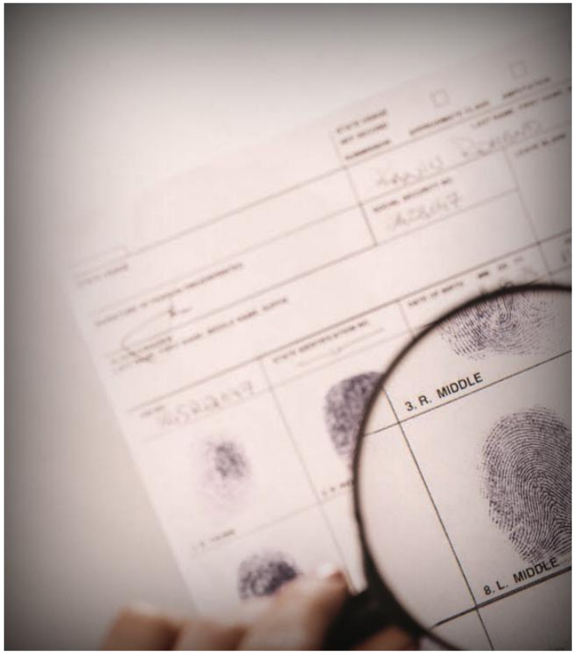

MILL END LOFTS

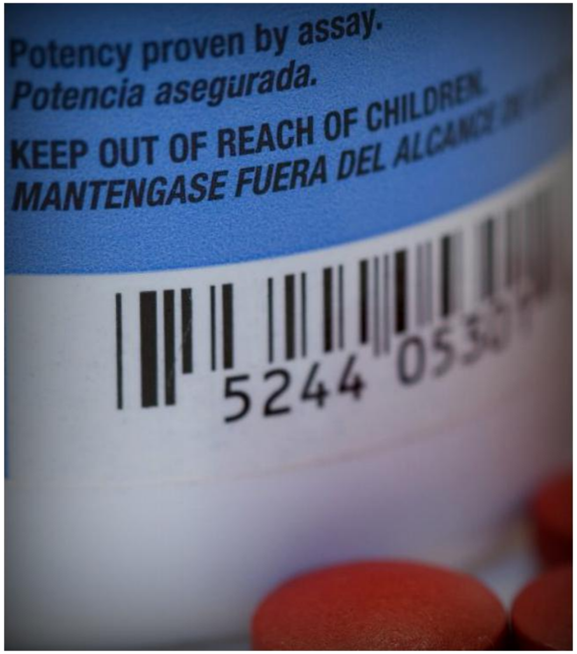
From recognizing action to recognizing activity, to productivity



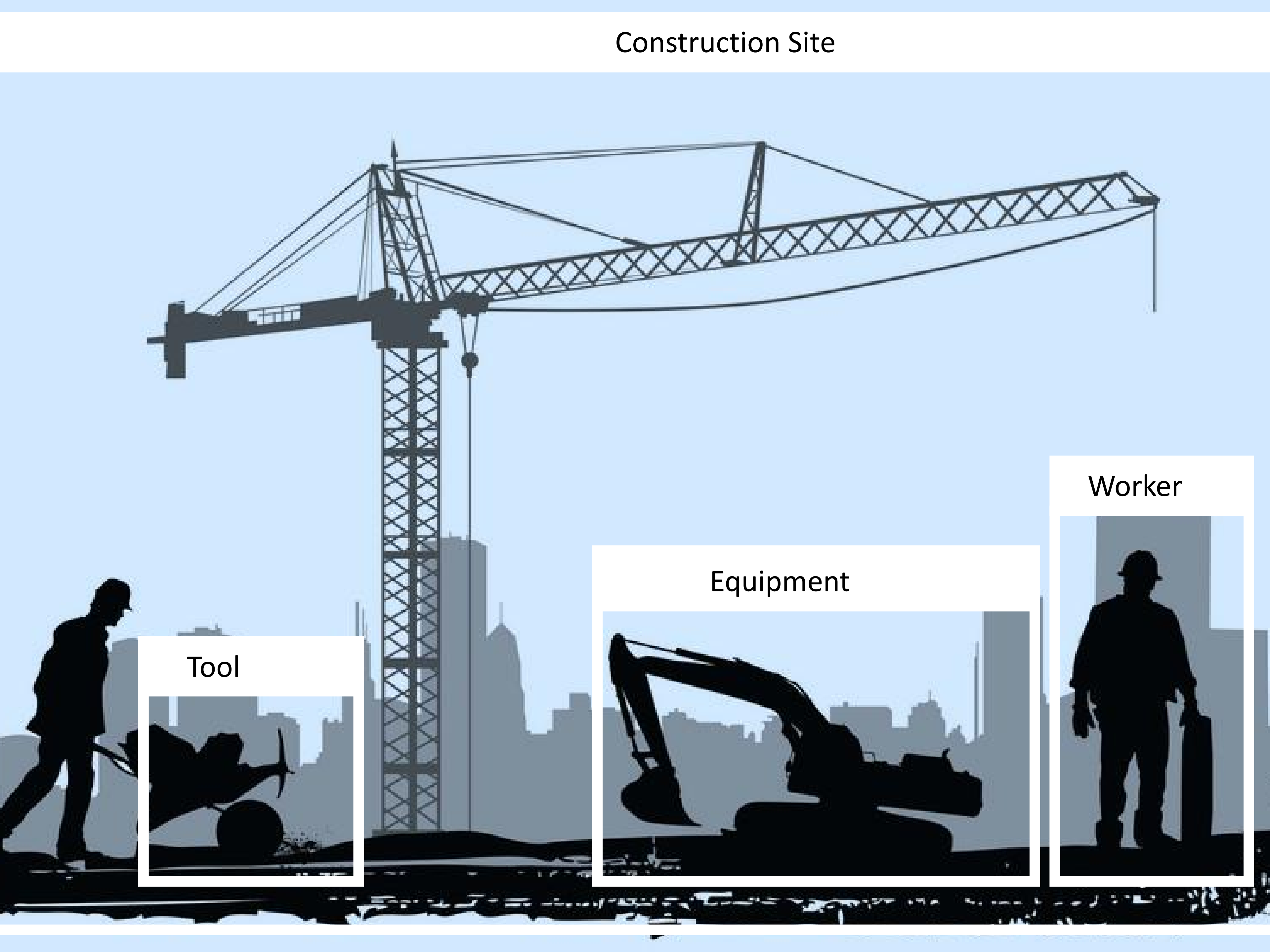
2. Establishing traceability chain for quality management based on tool tracking

A reliable way to record- Traceability





By X.Y.

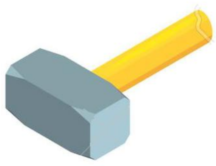

Construction Site
Tool
Equipment
Worker

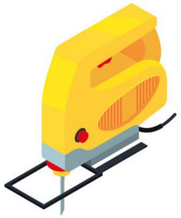

Angle Grinder


Circular Saw


Coping Saw


Drill


Hammer


Jig Saw


Wrench


Orbit Sander


Screwdriver

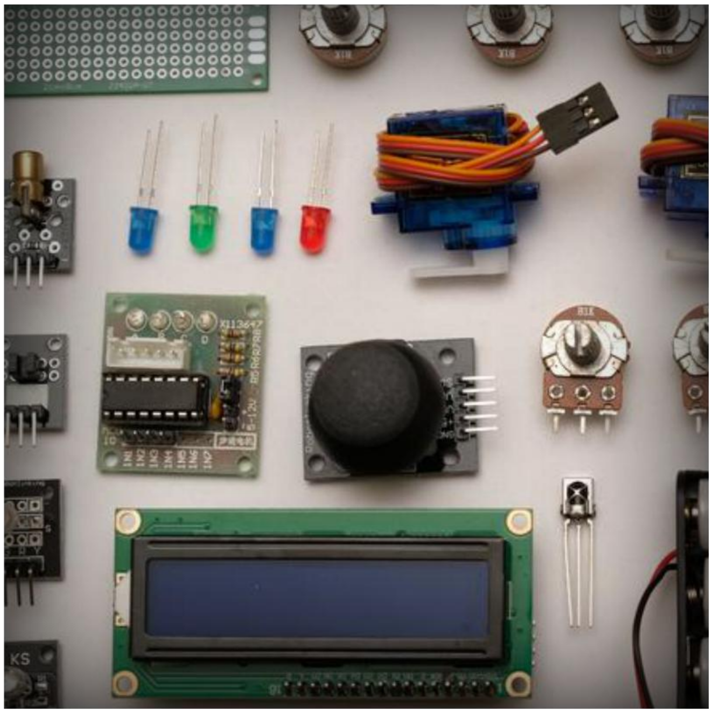

Tape Measure


Torpedo Level


Trowel

By X.Y.

Hardware



System Inertial Measurement Unit

2

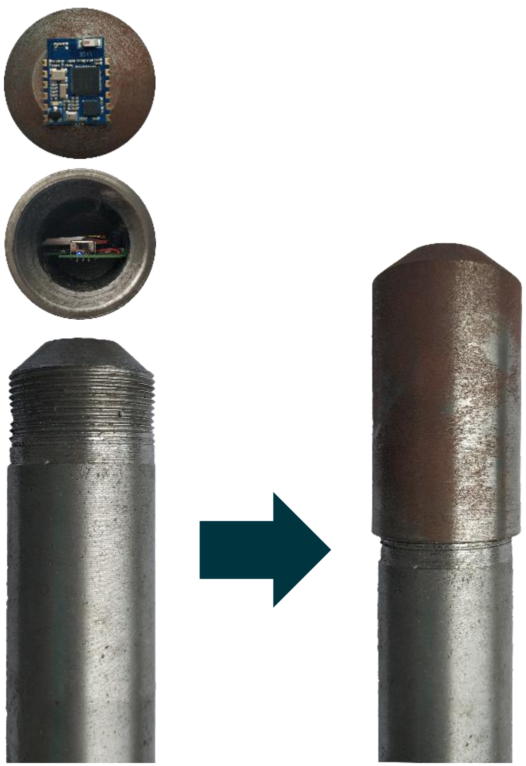
Bluetooth Low Energy 4.2

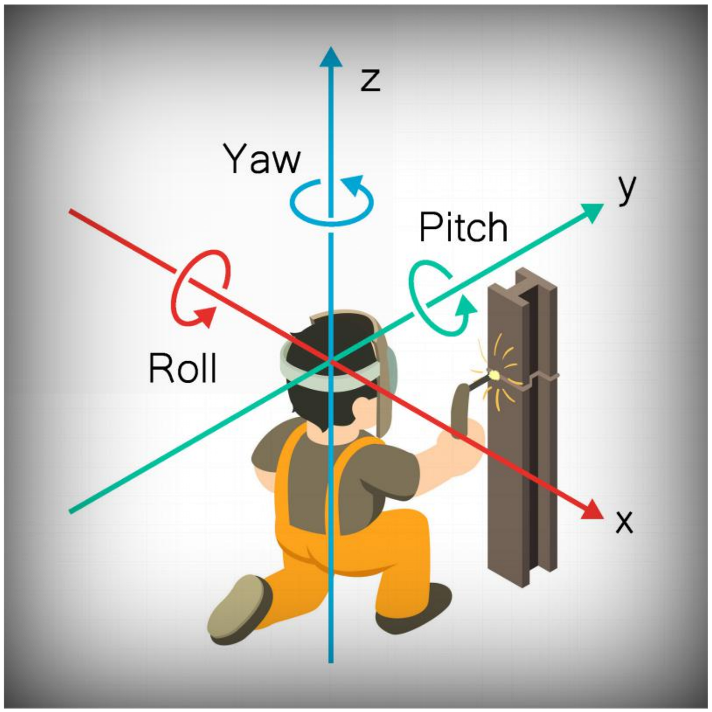
- Communication 4.2 Mbits / s
- Distance 50 m

By X.Y.

IMU based tracking

system





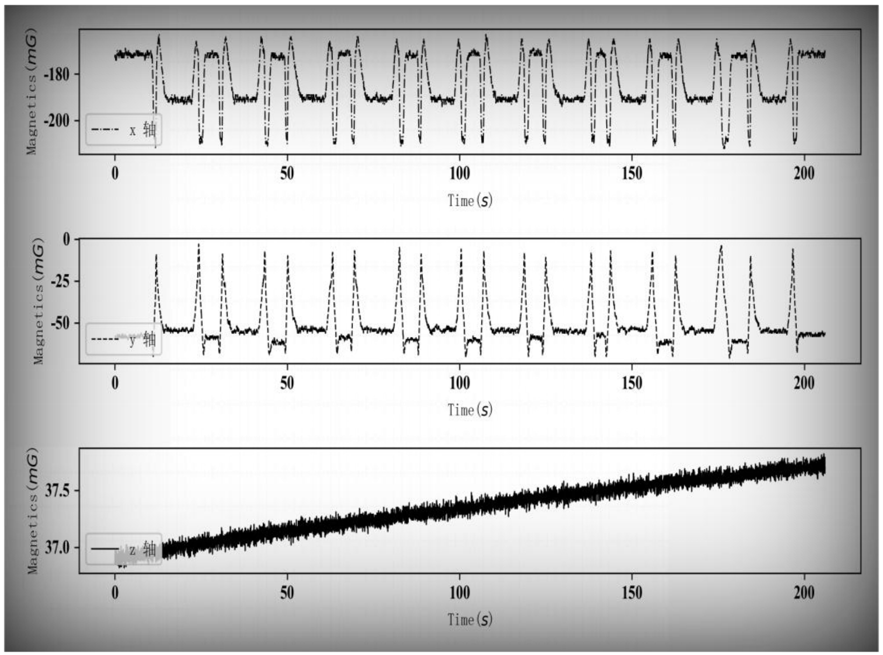
$$\phi = \tan^{-1}\frac{a_y}{a_z}$$

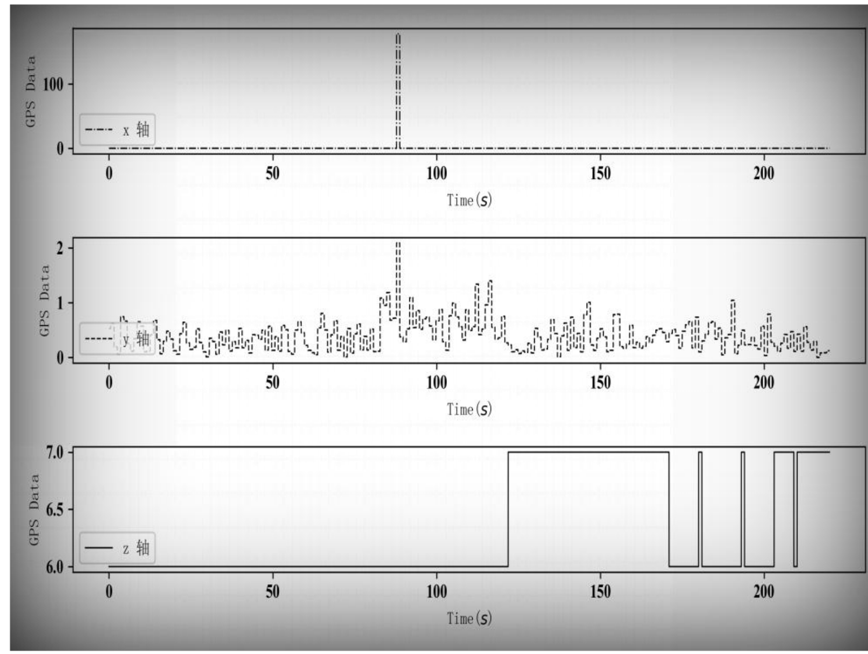
$$\theta = \tan^{-1}\frac{-a_x}{\sqrt{a_x^2 + a_y^2}}$$

$$\psi = \tan^{-1}\frac{-m_x^N}{m_y^N} \pm \Delta\psi$$

$$= \tan^{-1}\frac{-\cos\phi m_y^B + \sin\phi m_z^B}{\cos\theta m_z^B + \sin\phi\sin\theta m_y^B + \cos\phi\sin\theta m_z^B} \pm \Delta\psi$$

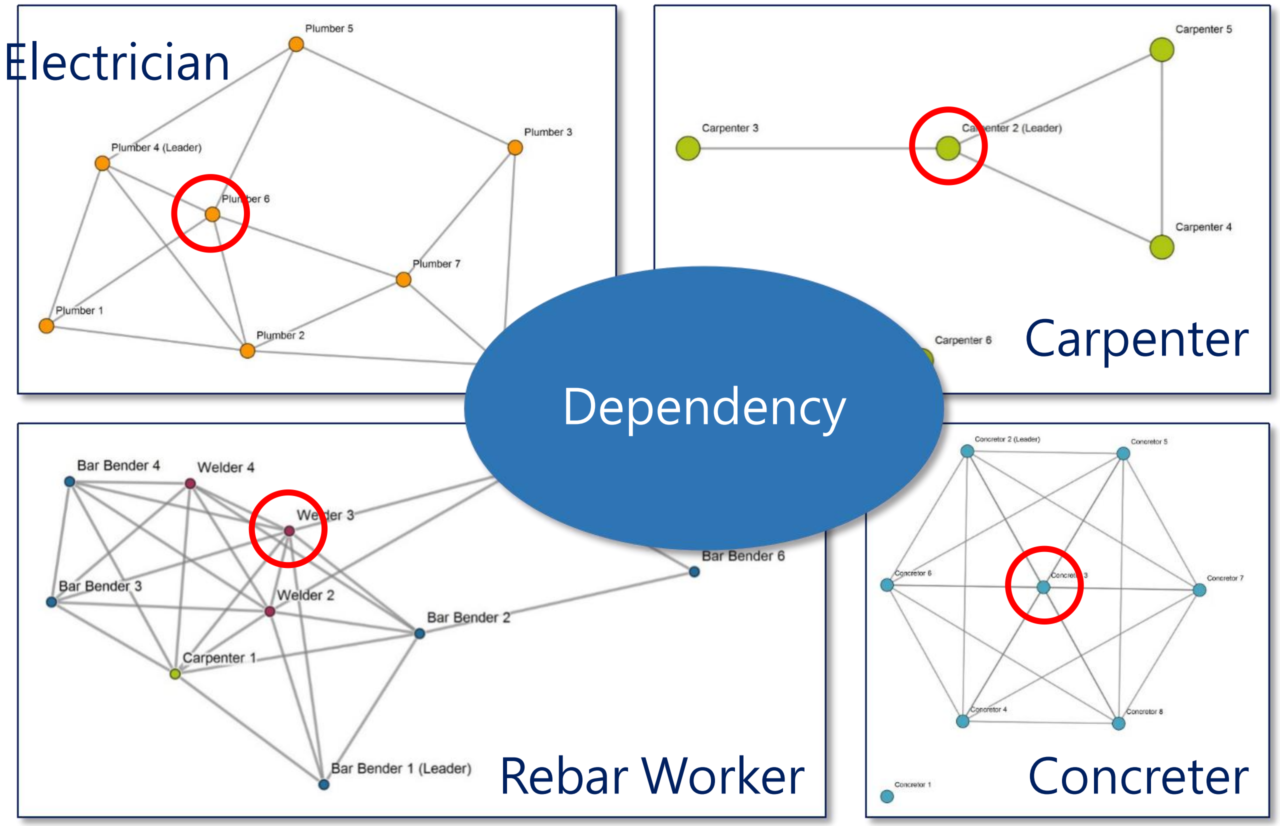
By X.Y.





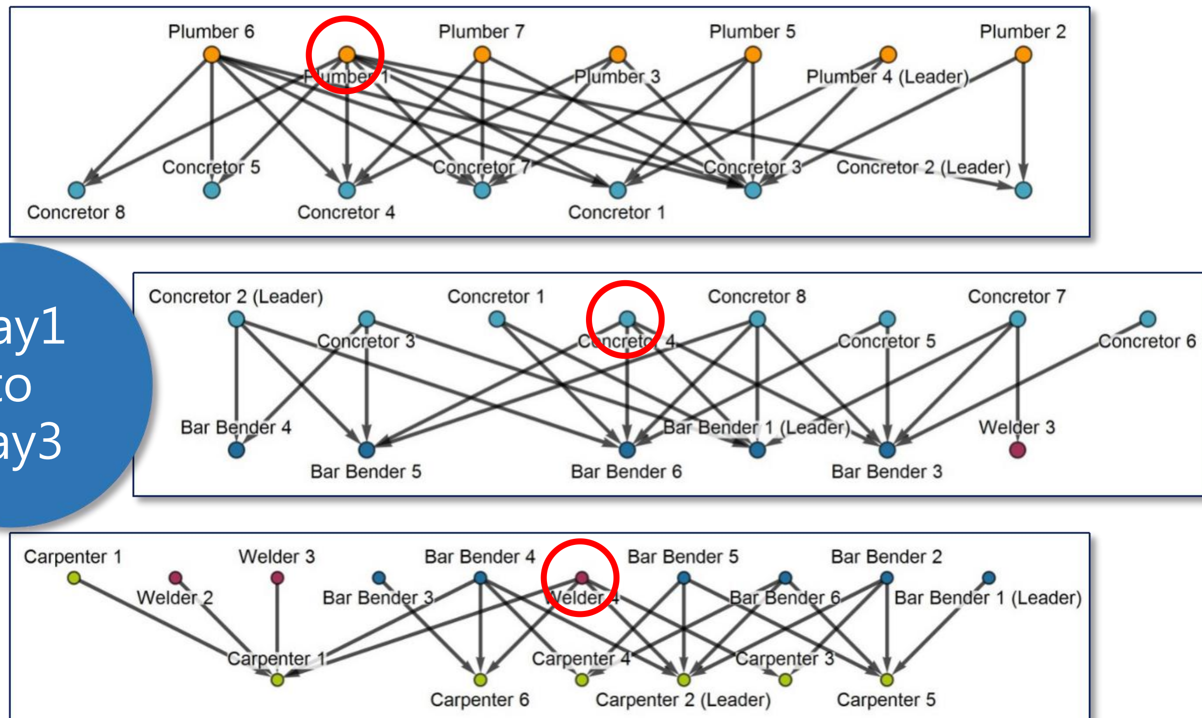
By X.Y.

Dependence network

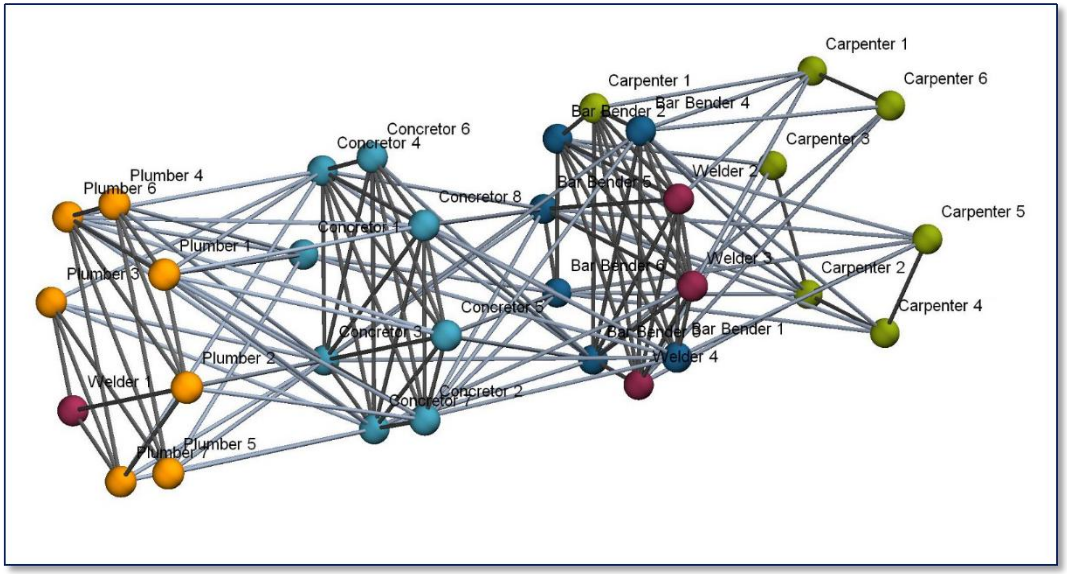


Sequential inter-dependency netweork

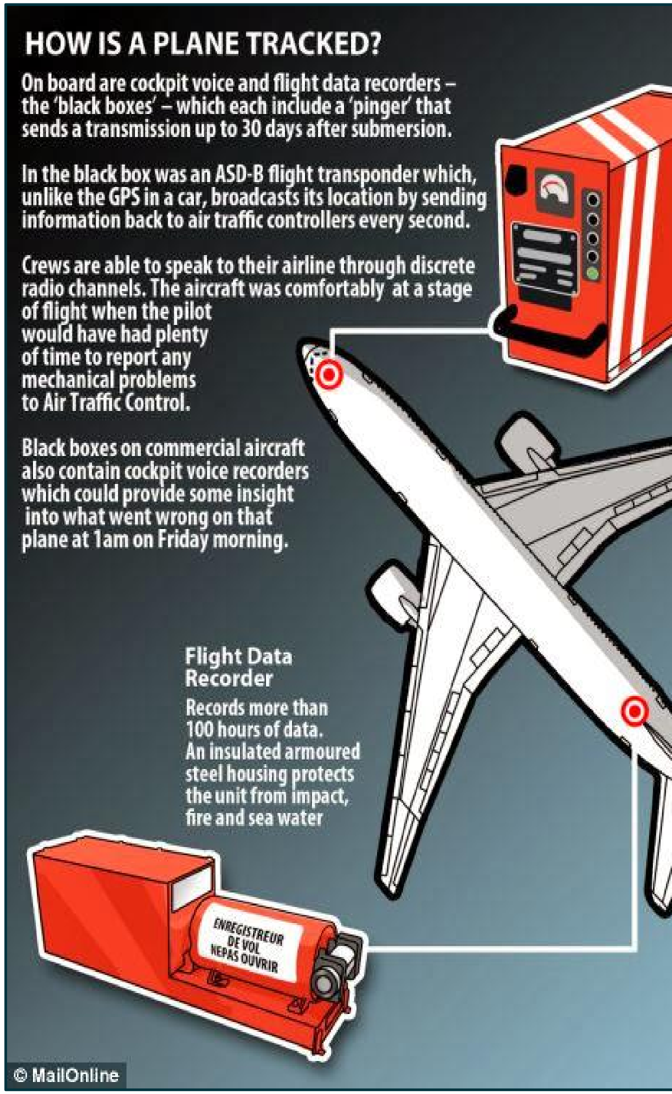
Day1 to day3

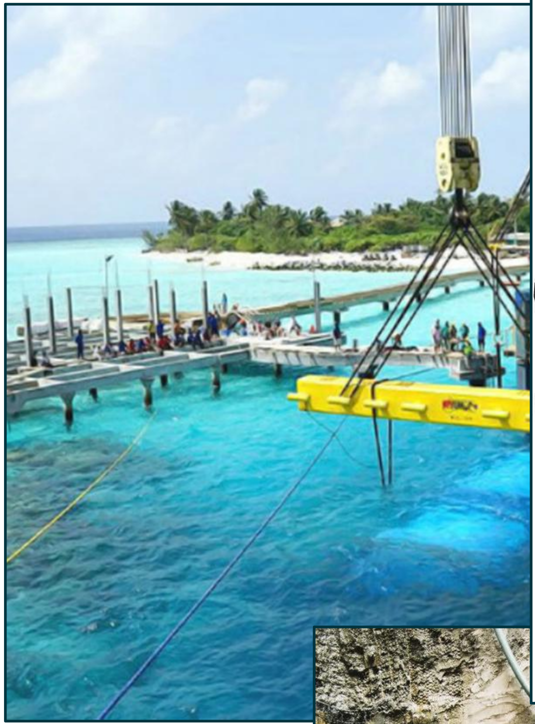


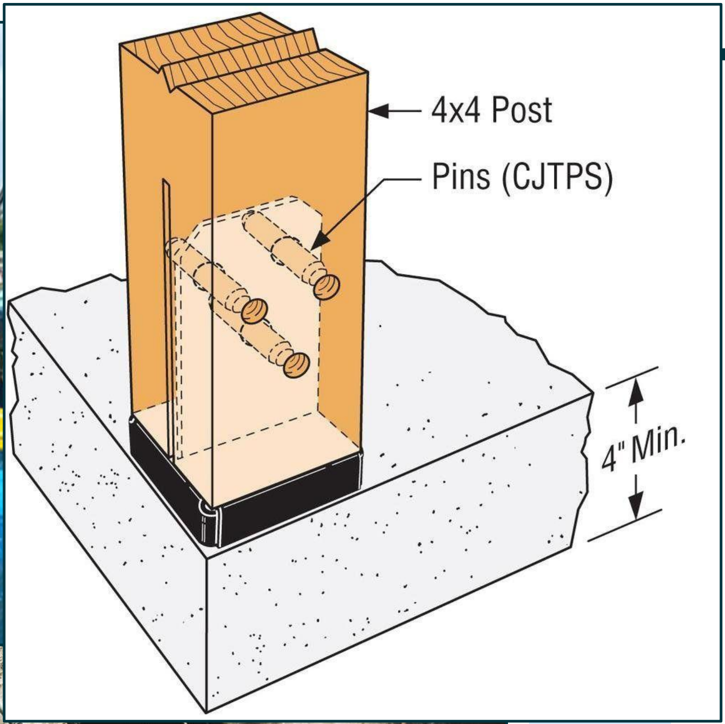
Traceability chain

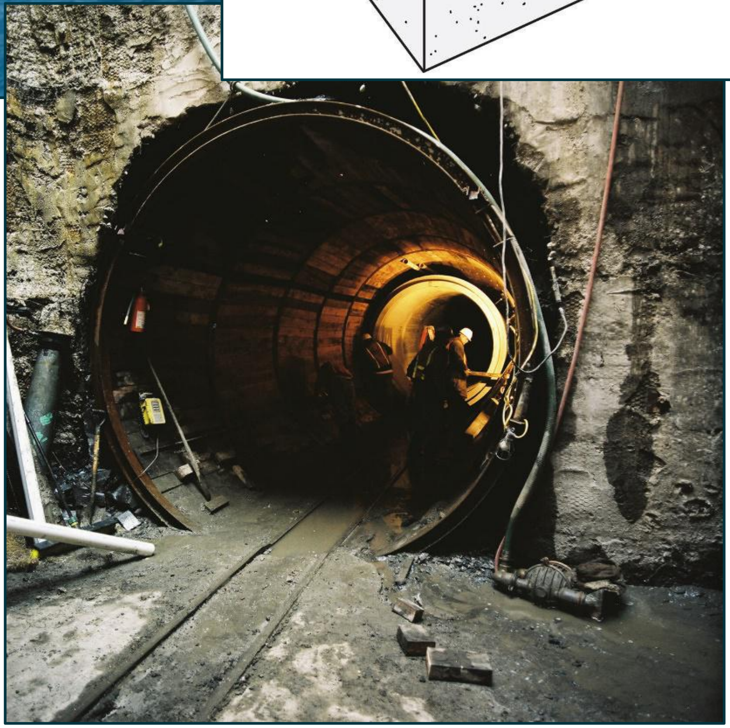


It is possible to develop a traceability chain using the dependency network. This allows to trace "who should be responsible for it, if something goes wrong"









This technology is potentially useful in situations where portions of work are invisible.

3. Integrating ergonomics with smart construction

Study 1: A non-intrusive method for measuring construction workers' physical fatigue
体力疲劳

A non-intrusive method for measuring construction workers' physical fatigue

Research background

Construction workers are faced with high workloads

- Physical demanding
- Confined work space
- **Prolonged duration**
- **Insufficient break**

A non-intrusive method for measuring construction workers' physical fatigue

Research background

Previous fatigue assessment methods

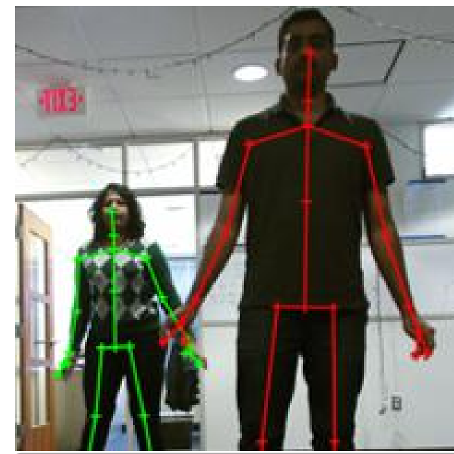
0–10 Borg Rating of Perceived Exertion Scale	
0	Rest
1	Really easy
2	Easy
3	Moderate
4	Sort of hard
5	Hard
6	
7	Really hard
8	
9	Really, really, hard
10	Maximal: just like my hardest race

Manual record

- ✓ Easy implementation
- ✕ Subjective data

Wearable sensors

- ✓ Accurate results
- ✕ Invasiveness



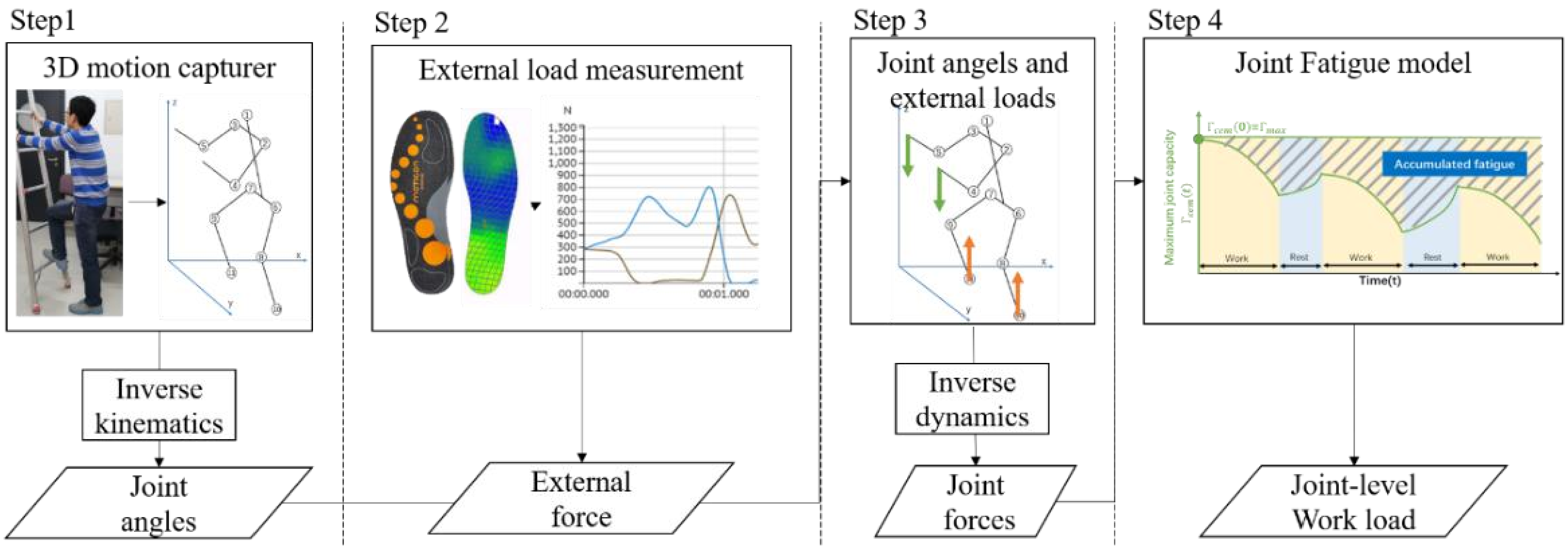
Vision-based methods

- ✓ Accurate results
- ✕ Indoor only

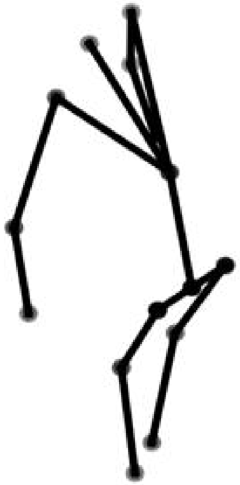
Accurate **Non-invasive** **Outdoor**

A non-intrusive method for measuring construction workers' physical fatigue

Research method



A non-intrusive method for measuring construction workers' physical fatigue



A non-intrusive method for measuring construction workers' physical fatigue

Research method

Task1 3D motion capture from 2D images Residual ANN

- **Fully connected layer**
- Increase the number of neurons in each layer

$$Y^{(l)} = Y^{(l-1)}W + b$$

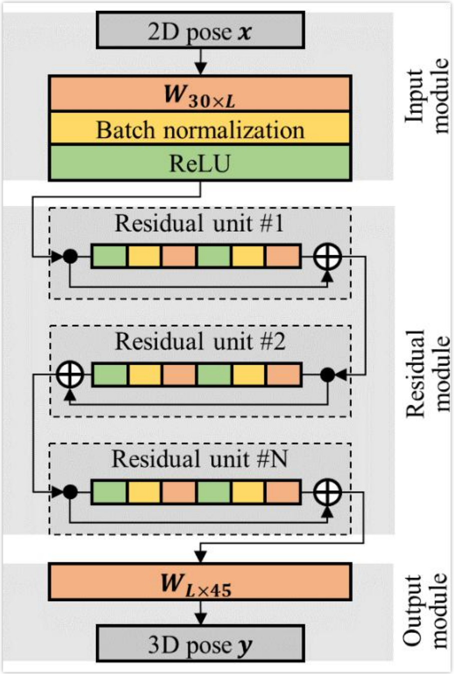
- **Activation layer**
- Increase the non-linearity of a neural network

$$g(y_{ij}) = \max(0, y_{ij})$$

- **Batch-norm layer**
- Improve the stability and consistency

$$\hat{y} = \frac{y - \mu}{\sqrt{\sigma^2 + \epsilon}}$$

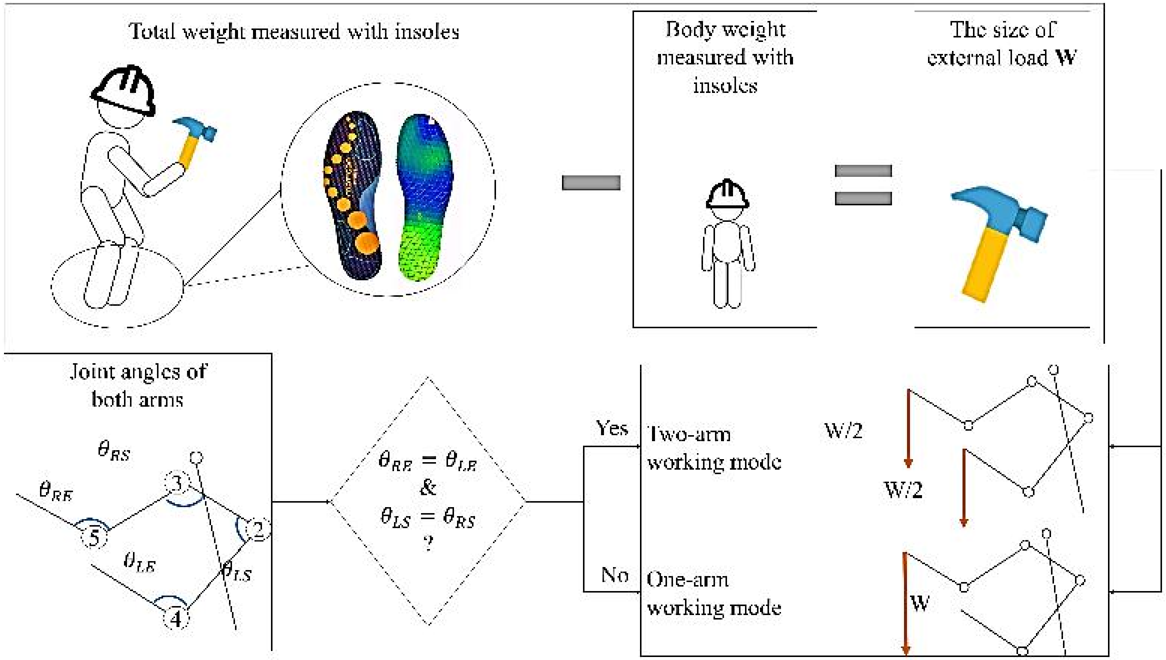
$$y_{BN} = \gamma \circ \hat{y} + \beta$$

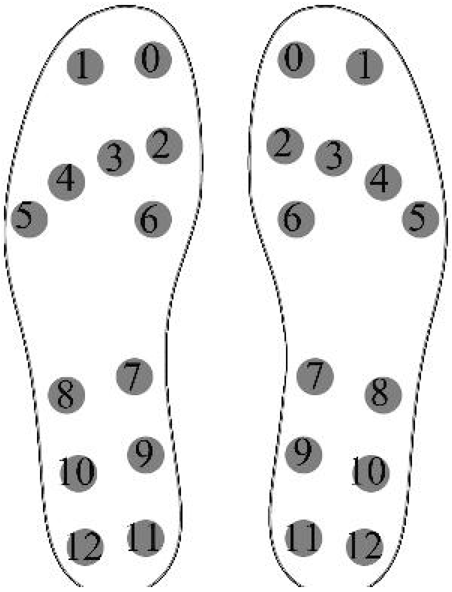


A non-intrusive method for measuring construction workers' physical fatigue

Research method

Task 2 External load estimation with smart insoles



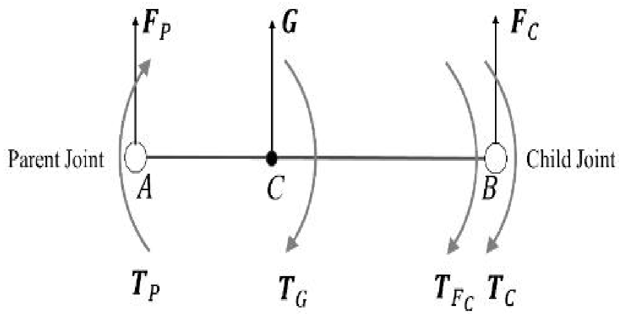


A non-intrusive method for measuring construction workers' physical fatigue

Research method

Task 3 Joint torque calculations

Current joint torques



$$F_{Pr} + F_{Ch} + G = 0$$

$$T_{pr} + T_G + T_{F_{Ch}} + T_{Ch} = 0$$

$$T_G = \overrightarrow{AC} \times G = r\overrightarrow{AB} \times G$$

$$T_{F_{Ch}} = \overrightarrow{AB} \times F_{Ch}$$

Maximum joint torque capacities

Joint capacity regression coefficients

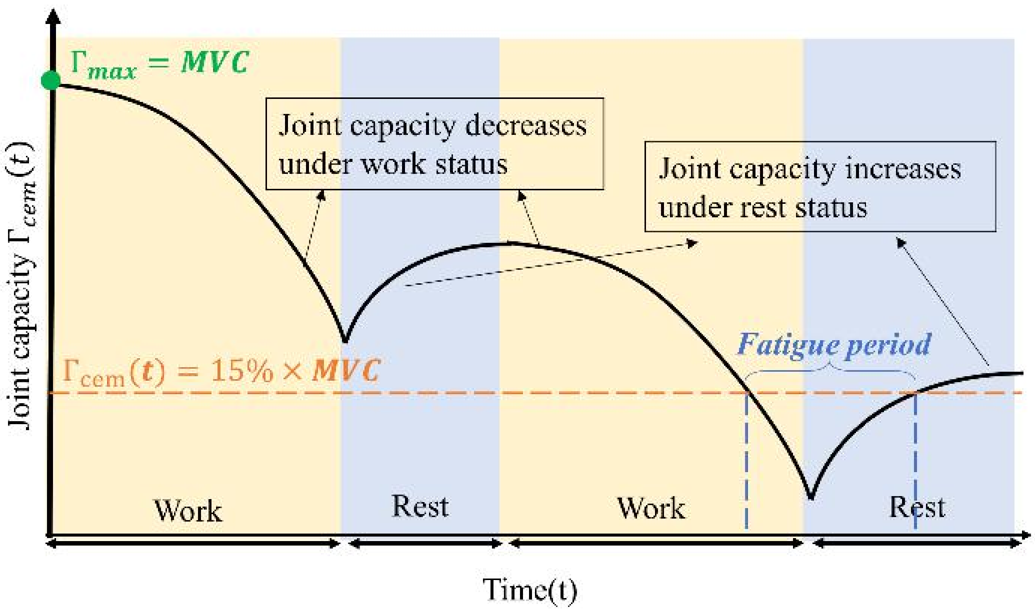
Joint	a	b	c	d
Right shoulder	0.17	16.26	0.17	23.35
Left shoulder	0.18	14.64	0.29	19.59
Right elbow	0.13	11.24	0.07	22.78
Left elbow	0.11	10.63	0.05	19.66
Right hip	0.33	19.19	0.66	34.44
Left hip	0.29	18.75	0.47	36.05
Right knee	0.16	8.78	0.08	22.47
Left knee	0.17	7.67	0.14	21.10

$$T_{\max} = \left(-a \cdot age + b \cdot gender + c \cdot \frac{weight}{height^2} + d \right) \cdot l_{bone}$$

A non-intrusive method for measuring construction workers' physical fatigue

Research method

Task 4 Joint-level fatigue assessments



Joint torque history

$$\Gamma_{cem}(t) = \Gamma_{cem}(t_0)\exp\left(-\frac{k}{\Gamma_{max}}\int_{t_0}^{t}\Gamma(u)du\right)$$

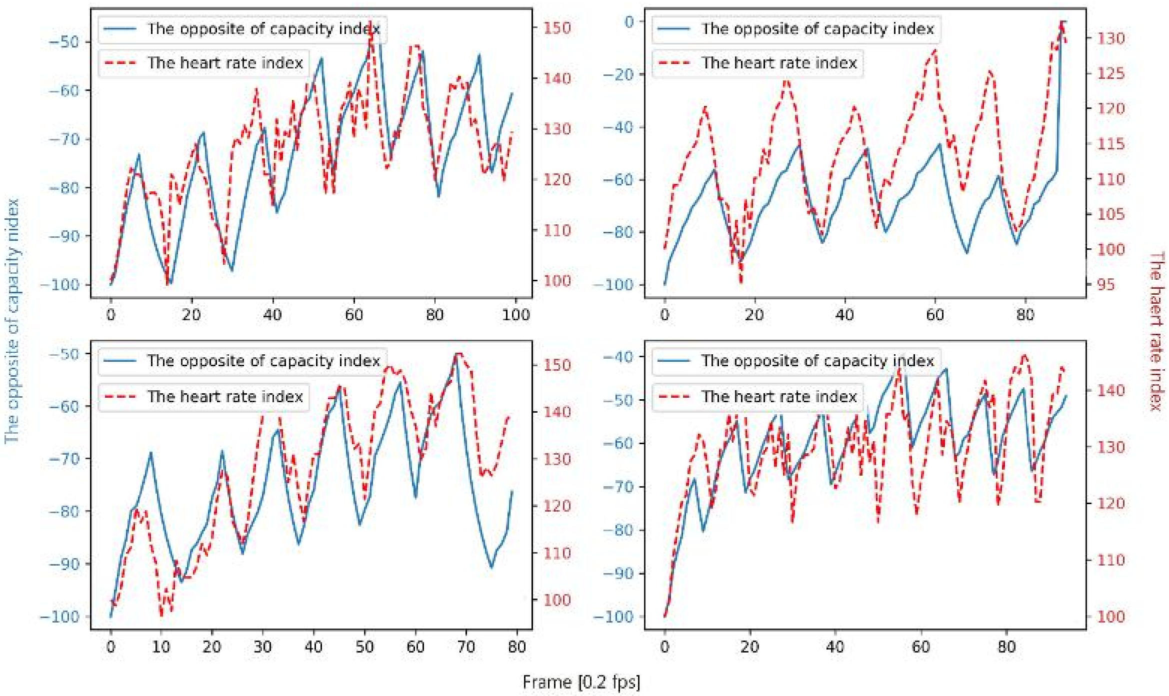
Maximum joint capacities

A non-intrusive method for measuring construction workers' physical fatigue

Results and discussion

The accuracy of the fatigue assessment method

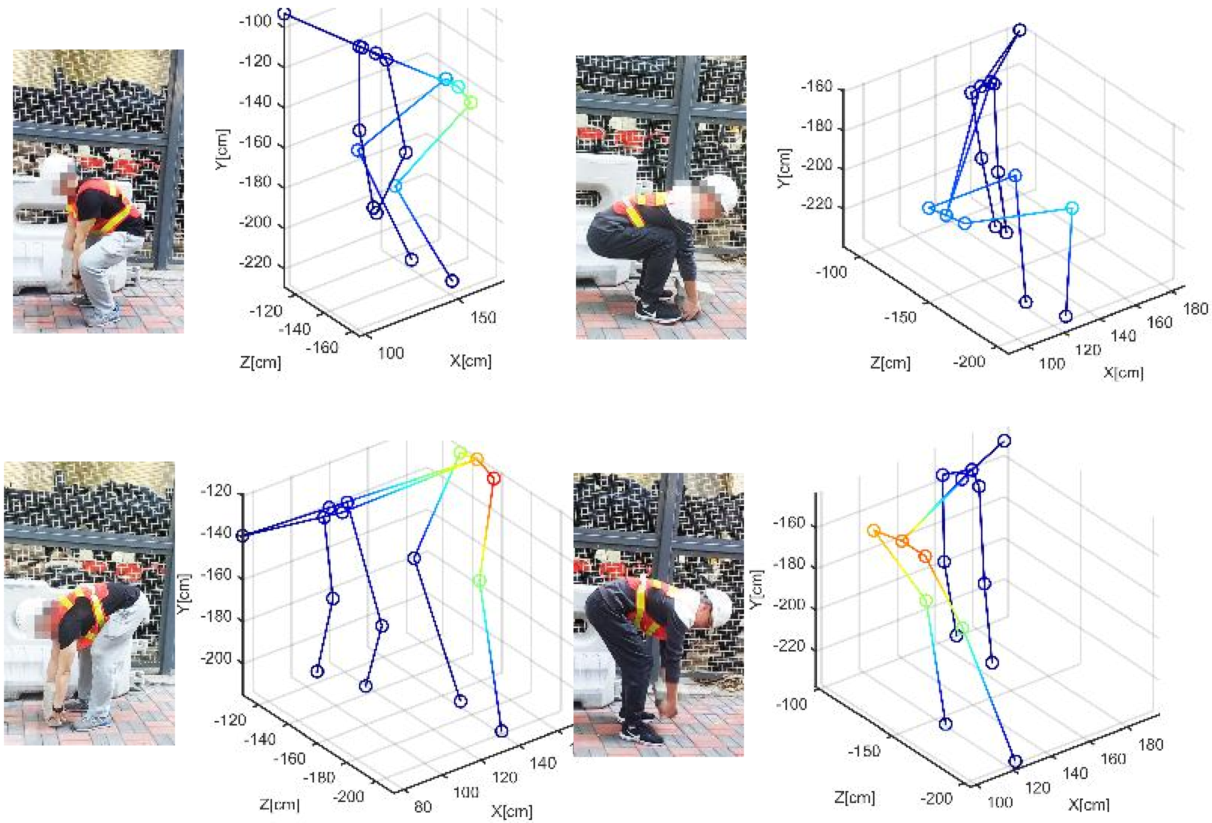
- 4 health subjects
- Heart rate monitor (Equivital™ LifeMonitor, UK)
- Simulated material handling task:
    - A box (6 kg, 37 cm * 33 cm * 26 cm).
    - A working platform (4 m * 3m * 1m);
    - Repeat the above steps for three times and rest for 5 seconds to start another round.
    - 10 rounds in total



A non-intrusive method for measuring construction workers' physical fatigue

Results and discussion

Comparison between different work postures



- Squatting lifting is a better posture for material handling than bending lifting

- Latency time: **0.5s** for each frame on one **GTX 1080Ti** GPU.

Study 2: A multicomponent and neurophysiological intervention for the emotional and mental states of high-altitude construction workers
心理疲劳

A multicomponent and neurophysiological intervention for the emotional and mental states of high-altitude construction workers

Research background

Aimed object: High-altitude construction workers (e.g., Scaffolders)

Scaffolders working at height

Two main accidents: Falling from height and object strikes

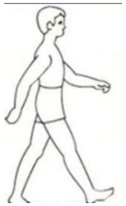
Four requirements:

1. Technical requirements

2. Physical requirements

3. Regulation requirements

4. Emotion and mental status requirements——the causal relationships are as below.



Workers' emotional states (e.g., pleasure, displeasure, excitement, and relaxation)	→	(1)cognitive status (e.g., attention and motivation), (2) decision making and behaviors (e.g., risk-taking behaviors affecting unsafe actions), (3) mental and physical health (e.g., stress, sleep disorder, and headache)	→	Work performance, such as safety, health, quality, and productivity

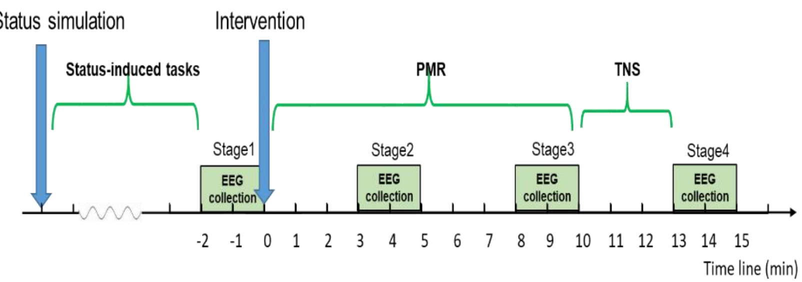
A multicomponent and neurophysiological intervention for the emotional and mental states of high-altitude construction workers

Research method

Step 1: Status simulation

Part 1—— Induce mental fatigue
Through a modified stroop color-word interference task (30min)

Part 2——Induce certain negative emotions of scaffolders
Through a VR mission simulating the high-altitude walk site (10min)



An online stroop test

VR mission simulating the high-altitude walk

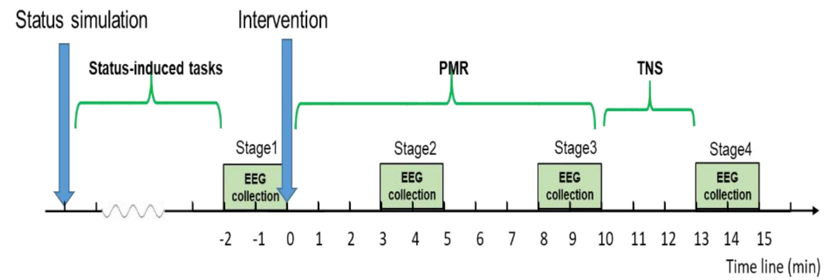
A multicomponent and neurophysiological intervention for the emotional and mental states of high-altitude construction workers

Research method

Step 2: Intervention

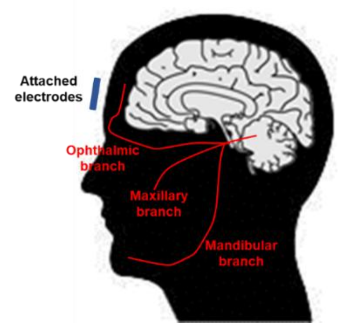
Part 1——Progressive muscle relaxation (PMR) （10min）

Part 2——Trigeminal nerve stimulation (TNS)（3min）



Progressive muscle relaxation in a lounge environment

The medical and portable external pulse generator

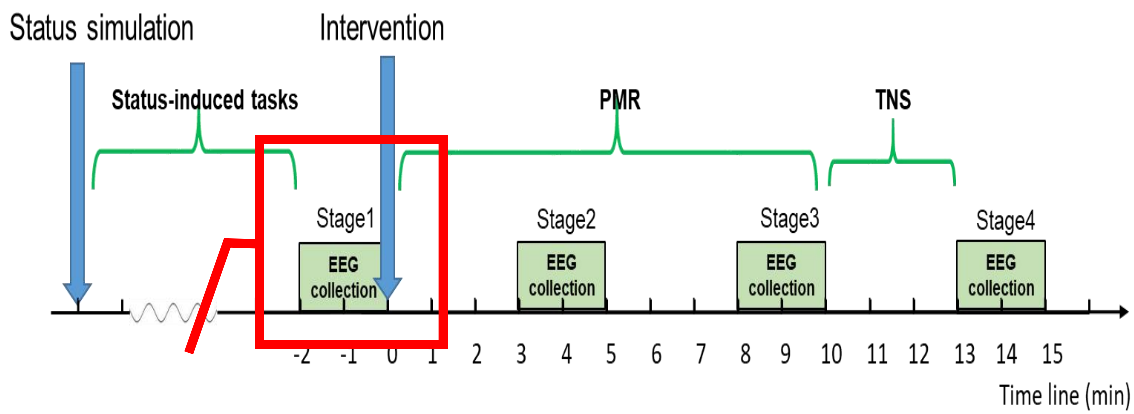


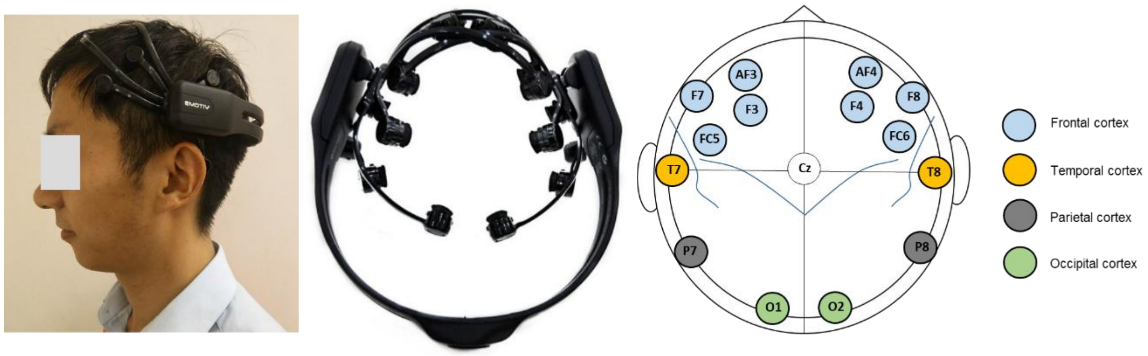
Two adhesive rubber electrodes placed corresponding to the ophthalmic branch of the trigeminal nerve

Waveform	Frequency1 (Hz)	Frequency2 (Hz)	Frequency3 (Hz)	Note
Continuous wave	10	30	50	-----
Discontinuous wave	10	30	50	3s on/3s off
Disperse-dense wave	10/30	30/40	40/50	2s disperse/4s dense

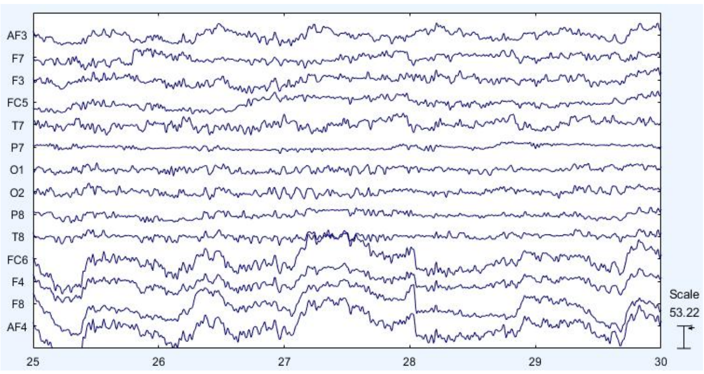
A multicomponent and neurophysiological intervention for the emotional and mental states of high-altitude construction workers

Research method: Data collection for method evaluation





A subject with the wearable EEG device (EMOTIV EPOC+ 14 Channel Mobile EEG) and 14 objective electrode channels in four cortical regions

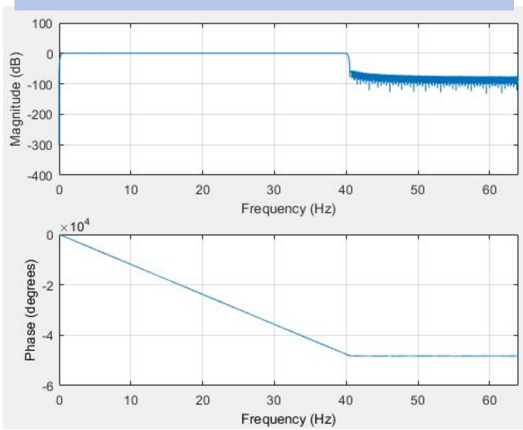


Raw EEG data

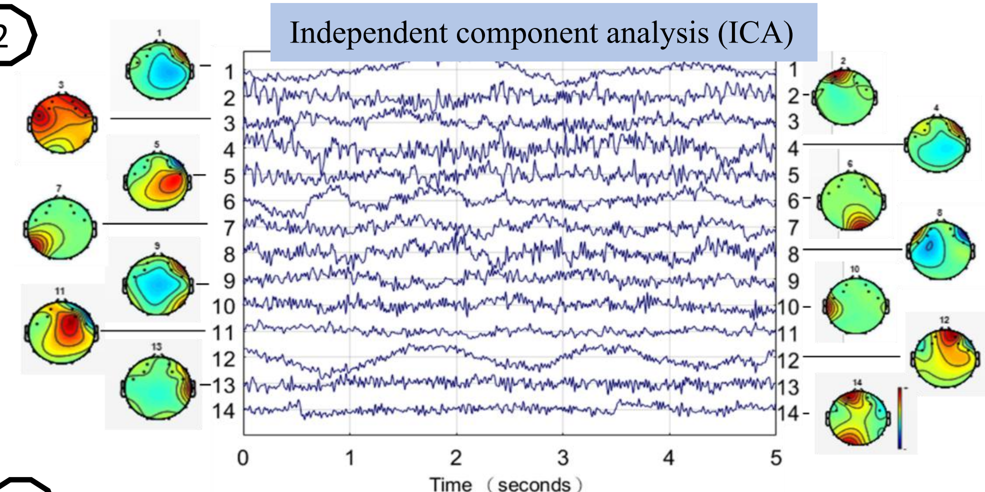
A multicomponent and neurophysiological intervention for the emotional and mental states of high-altitude construction workers

Research method: Data processing

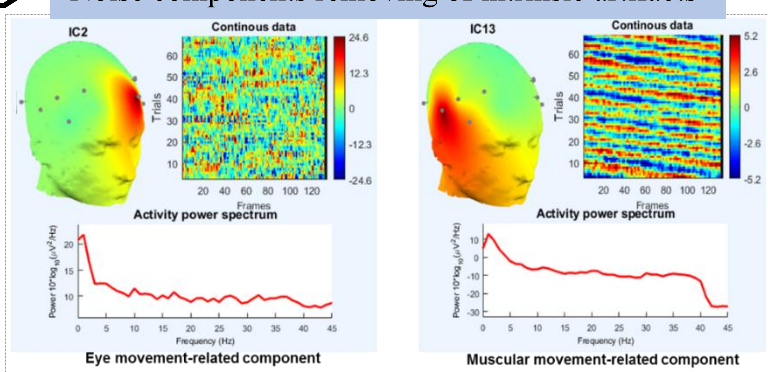
① Hamming windowed sinc FIR filter



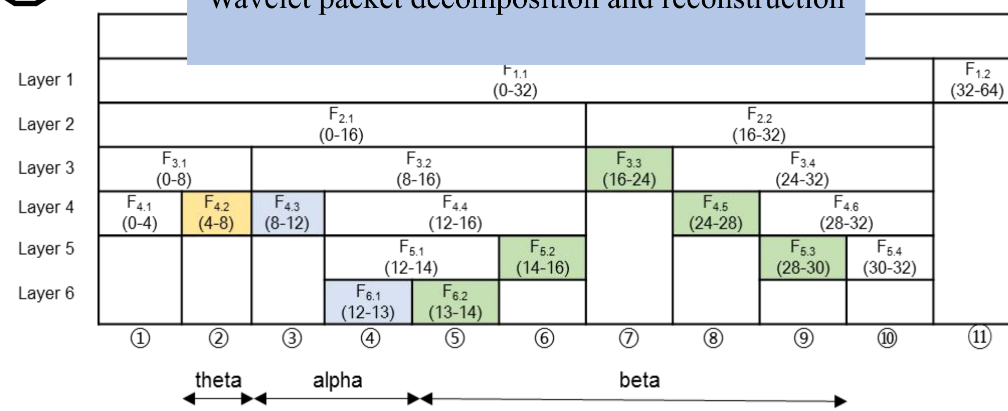
② Independent component analysis (ICA)



③ Noise components removing of intrinsic artifacts



④ Wavelet packet decomposition and reconstruction



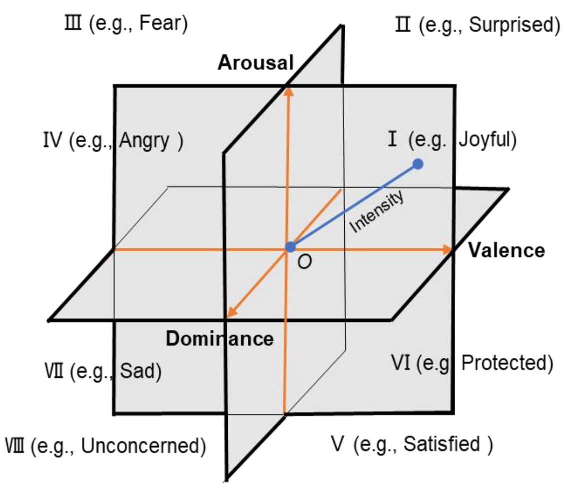
A multicomponent and neurophysiological intervention for the emotional and mental states of high-altitude construction workers

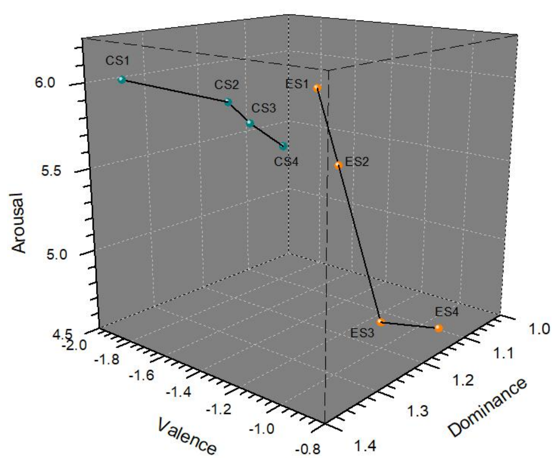
Results and discussion

Statistical analysis based on processed EEG signals

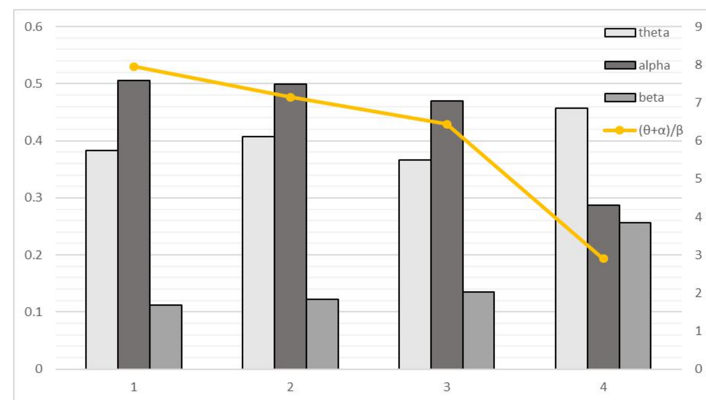
Emotional state regulation

Mental fatigue regulation





VDA (Valence-Dominance-Arousal) model



Trend of mental fatigue adjustment of the experimental group through intervention sessions

After this multicomponent and neurophysiological intervention, the emotional state of high-altitude construction workers tend to be mitigated to **a relatively pleased, autonomous, and excited level.**

The multicomponent and neurophysiological intervention **reduces the mental fatigue** of high-altitude construction workers.

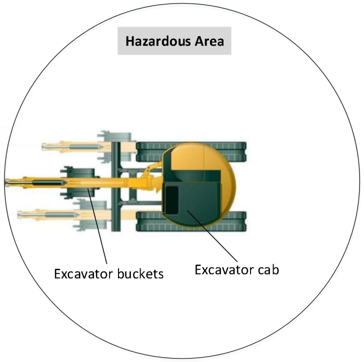
Study 3: Evaluating the impact of mental fatigue on construction equipment operators' ability to detect hazards using wearable eye-tracking technology
体力疲劳和心理疲劳的相互作用

Evaluating the impact of mental fatigue on construction equipment operators' ability to detect hazards using wearable eye-tracking technology

Research background

- **Mobile construction equipment and safety**
  - 50% fatal accidents are related to construction equipment (Marsh and Fosbroke,2015; OSHA 2018)
  - The contact collision between pedestrian workers and equipment accounts for a large portion of construction-equipment-related accident (Shen et al., 2016, CFOI, 2014, Kazan and Usmen, 2018)

- **What caused the accident ?**
  - Operator's faliure in attention is one of the leading cause (Shapira and Lyachin, 2009, Hinze and Teizer, 2011, Fang and Cho, 2017)
  - Mental fatigue can easily lead to poor hazard perception performance of construction equipment operations and accidents in the worst case scenario



Evaluating the impact of mental fatigue on construction equipment operators' ability to detect hazards using wearable eye-tracking technology

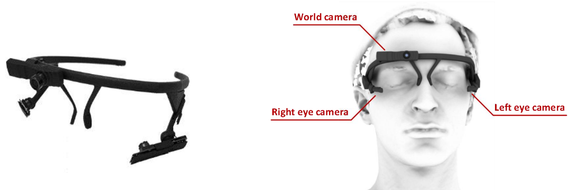
Research method

- **Participants**

  12 males between the ages 24 and 35.

- **Apparatus and measurement**

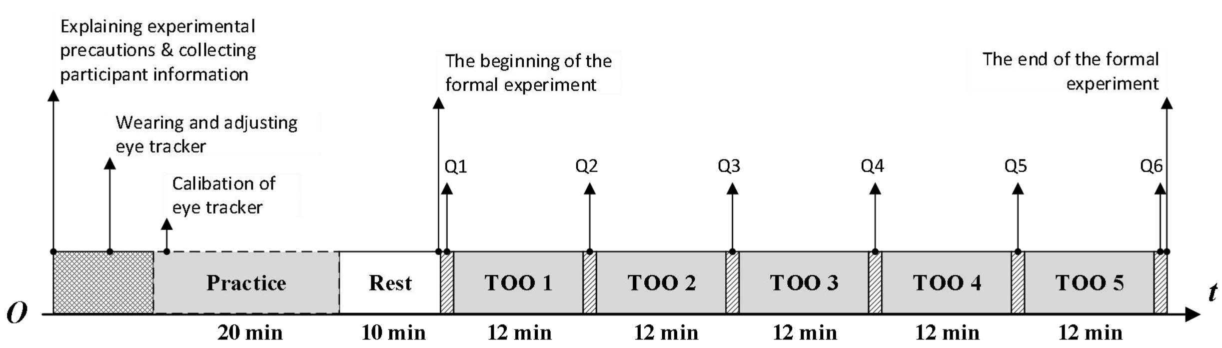
  Wearable eye-tracker and excavator operating simulation system.

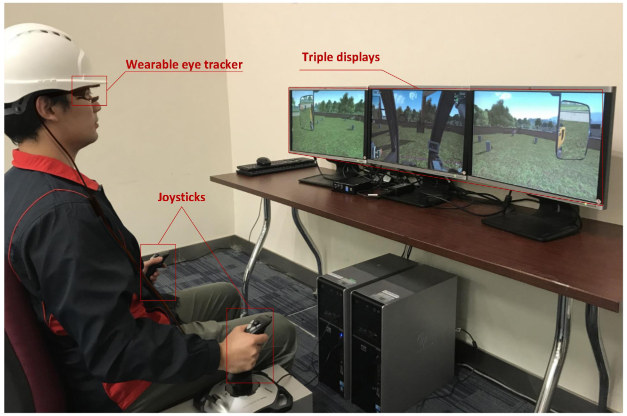


Typical simulated experiment situations

- **Experiment design**

A Time-On-Task procedure considering an excavate-discharge task and a hazard detection task:



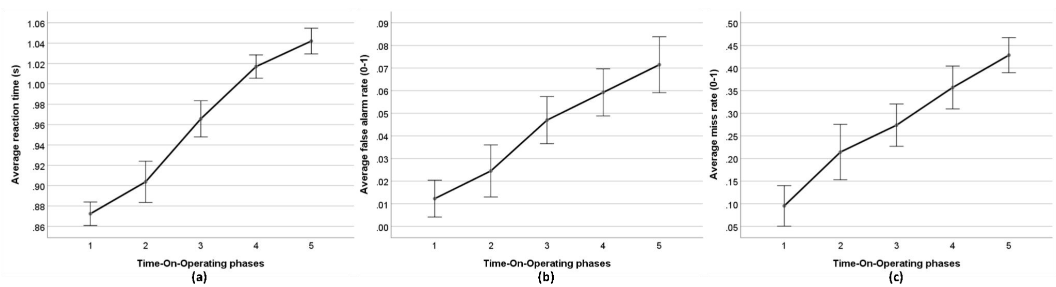


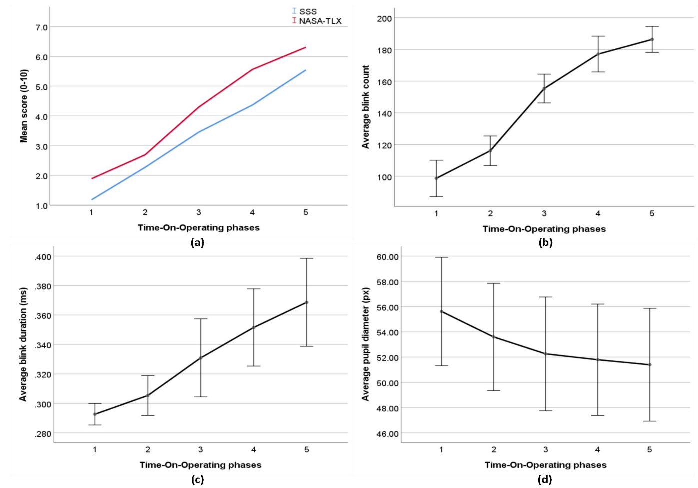
THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

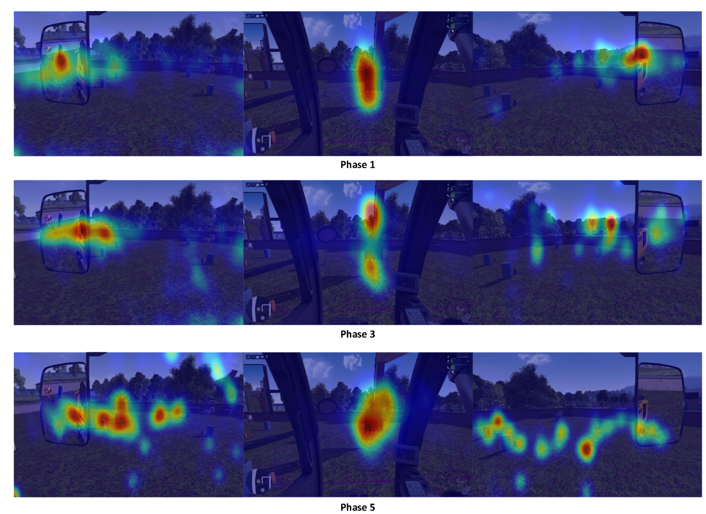
Evaluating the impact of mental fatigue on construction equipment operators' ability to detect hazards using wearable eye-tracking technology

Results and discussion

- ❑ Operator` hazard detection performance decreased when they experienced mental fatigue
- ❑ Operators` hazard detection rate decreased to 70% of the initial performance after 36 min of operating and to 60% after a 60 min task:







- ❑ The findings indicated that the decrement of operators' hazard detection ability results from the changes in his visual attention allocation with increasing mental fatigue
- ❑ The feasibility of eye-tracking technology applied to monitor and quantify construction equipment operators` mental fatigue and hazard detection decrement was demonstrated

DEPARTMENT OF
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3. Future Plan

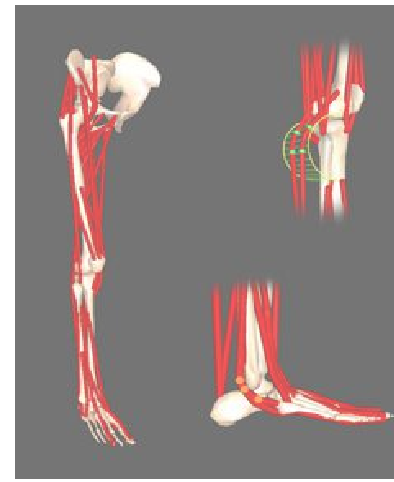
PolyU

Future project 1: Wearable artificial muscles for reducing the risk of muscle fatigues

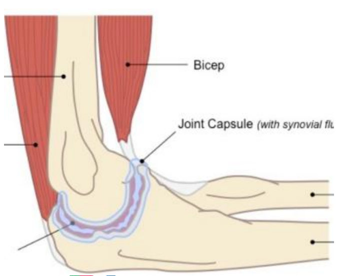
Task 1. Identifying Muscle Capacity Gap

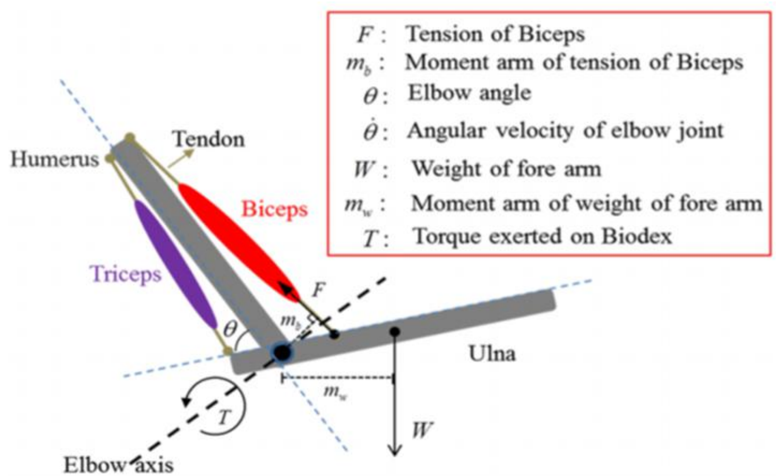
❖ *Identifying and modelling of fatigue-prone muscle groups*

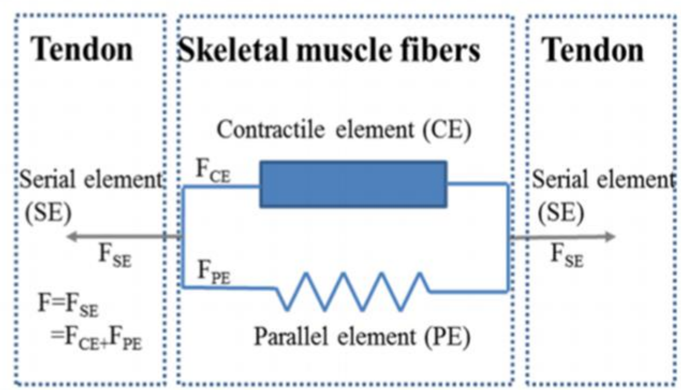
- Calculating the stress of each muscle group through biomechanical analysis
- Identifying the fatigue-prone muscle fatigue with a muscle fatigue model
- Calculating and modeling the muscle capacity gap



Example model for elbow joint:



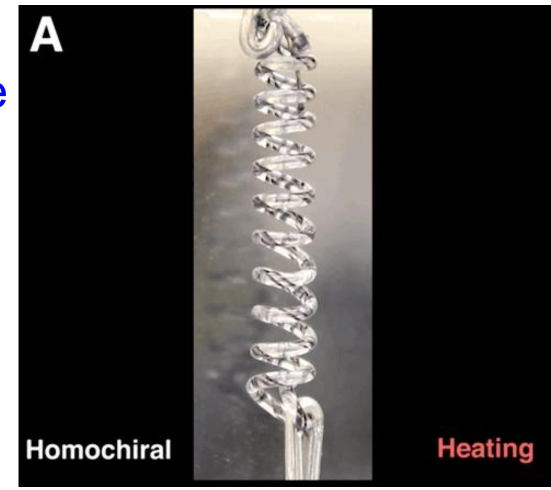




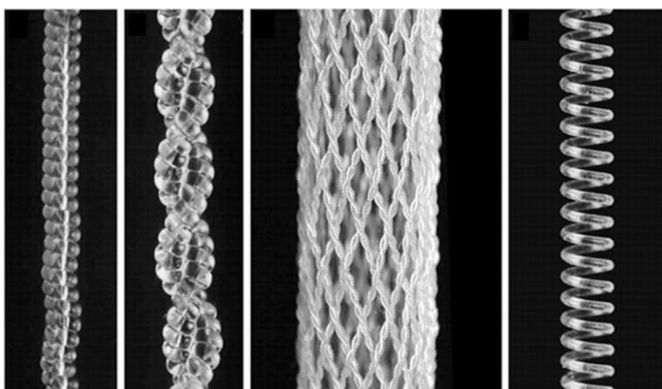
Task 2. Design and fabrication of artificial muscle actuators

- Fabrication of supercoiled fiber/polymer-based artificial muscle actuators
- Synthesize high performance electrolyte to enhance the stroke of actuators
- Produce various electrothermally driven and electrochemically driven actuators

Thermal driven coil polymer fiber actuator

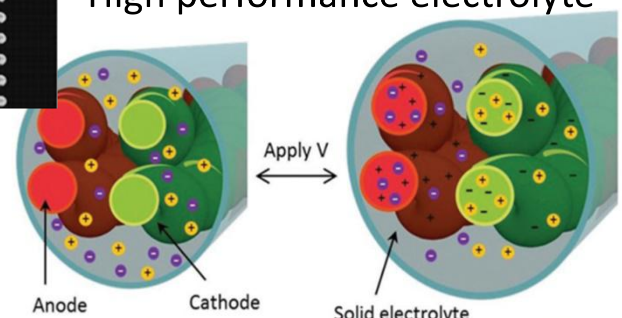


Large current driven actuator



Supercoild yarn fabrication

High performance electrolyte

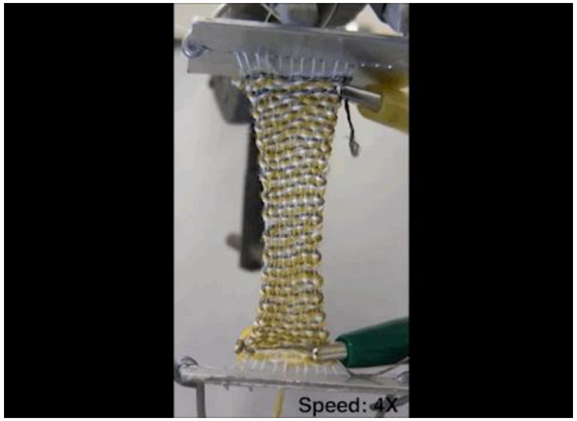


Task 3. Developing Wearable Artificial Muscle Apparati

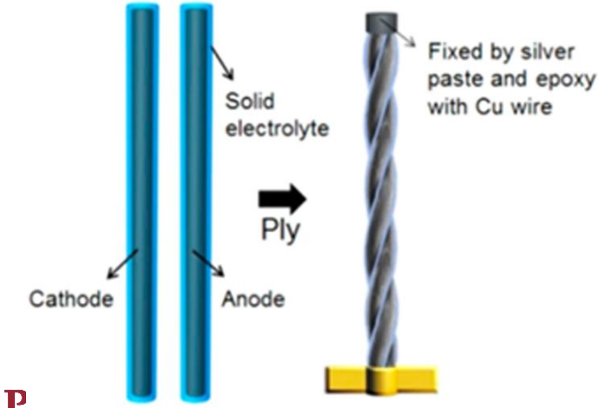
❖ *Optimizing artificial muscle performance to support fatigue-prone muscles*

- Relationship between processing parameter and artificial muscle performance
- Optimizing performance based on the property of fatigue-prone muscles
- Encapsulating and Integrating towards wearable devices

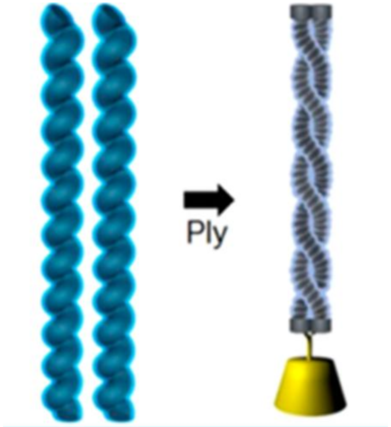
Integrate into fabrics



Rotational artificial muscle



Tensional artificial muscle

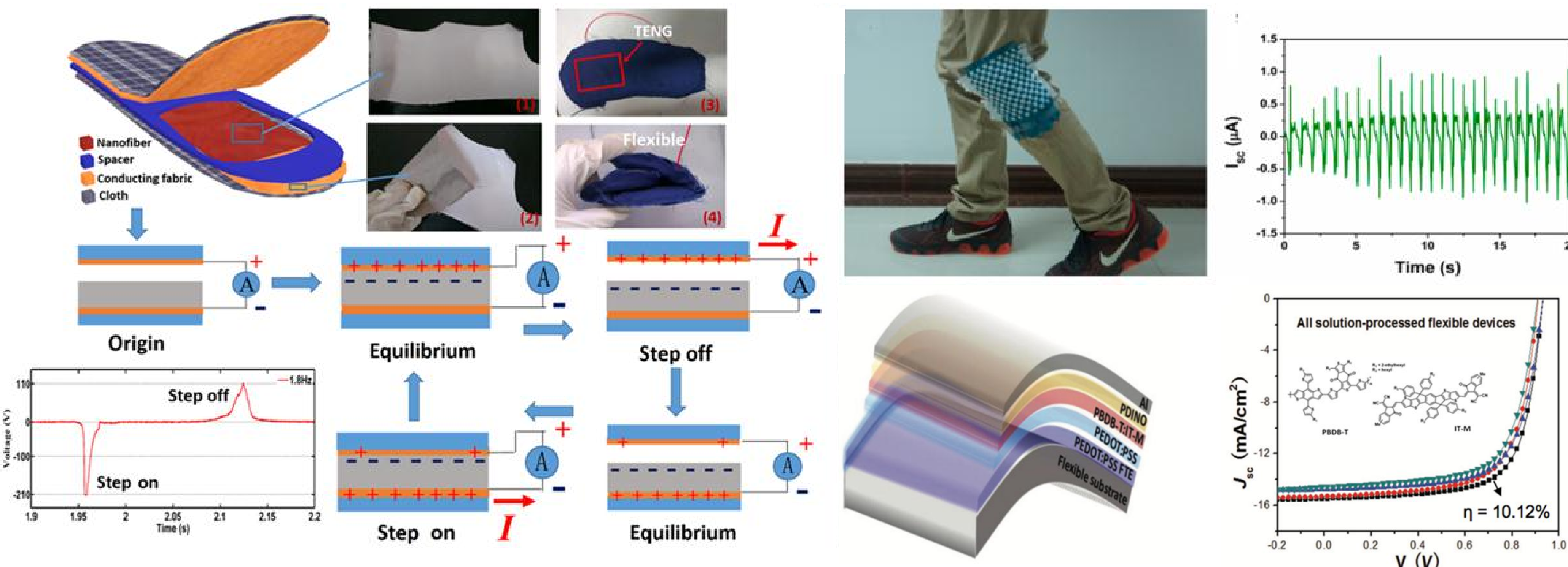


Potential diverse applications

Task 2. Designing green energy harvesting system to power artificial muscles

- Integrate triboelectric nanogenerators to harvest mechanical energy of works
- Integrate flexible organic solar cells to gain energy from sunlight exert on works
- Develop power management unit to control sustainable power supply for artificial muscles

Harvesting mechanical and solar energy

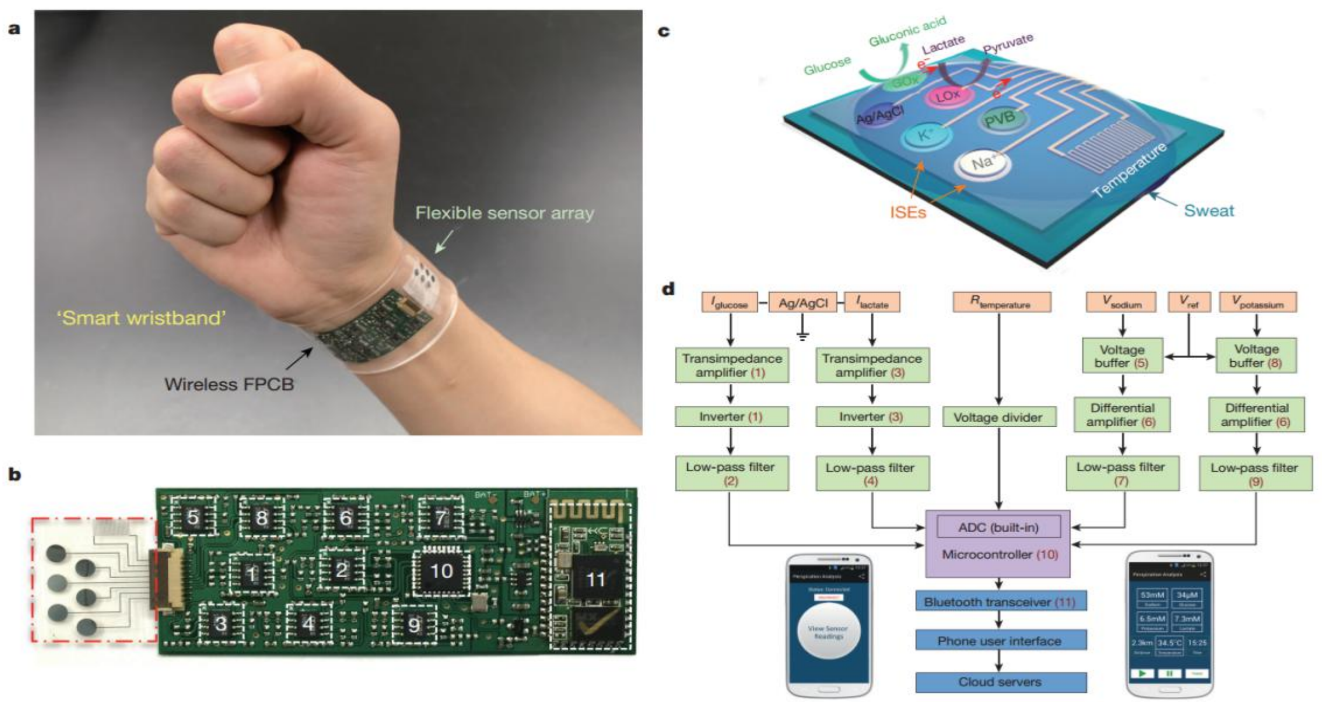


Future project 2: Tele-operated
and machinery, and robots

A pilot project: construction waste recycling robot for nails and screw (funded by Environment and conservation Fund)

- Path planning algorithm for complete coverage search
- Grasping algorithms for robotic hands

Future Project 3: Measurement of physical and mental stress based on psychophysiological measurements



Ground truth of physical and mental fatigue measures

Portable blood lactate analyzer (Lactate Plus)

Portable saliva based cortisol monitoring system, VerOFy

Conclusions

Construction activities are complex due to interactions between man, machine and material

Site safety is important and it needs hi-tech.

Thanks