Engineering Response to COVID-19

Faculty of Engineering
April 29, 2020

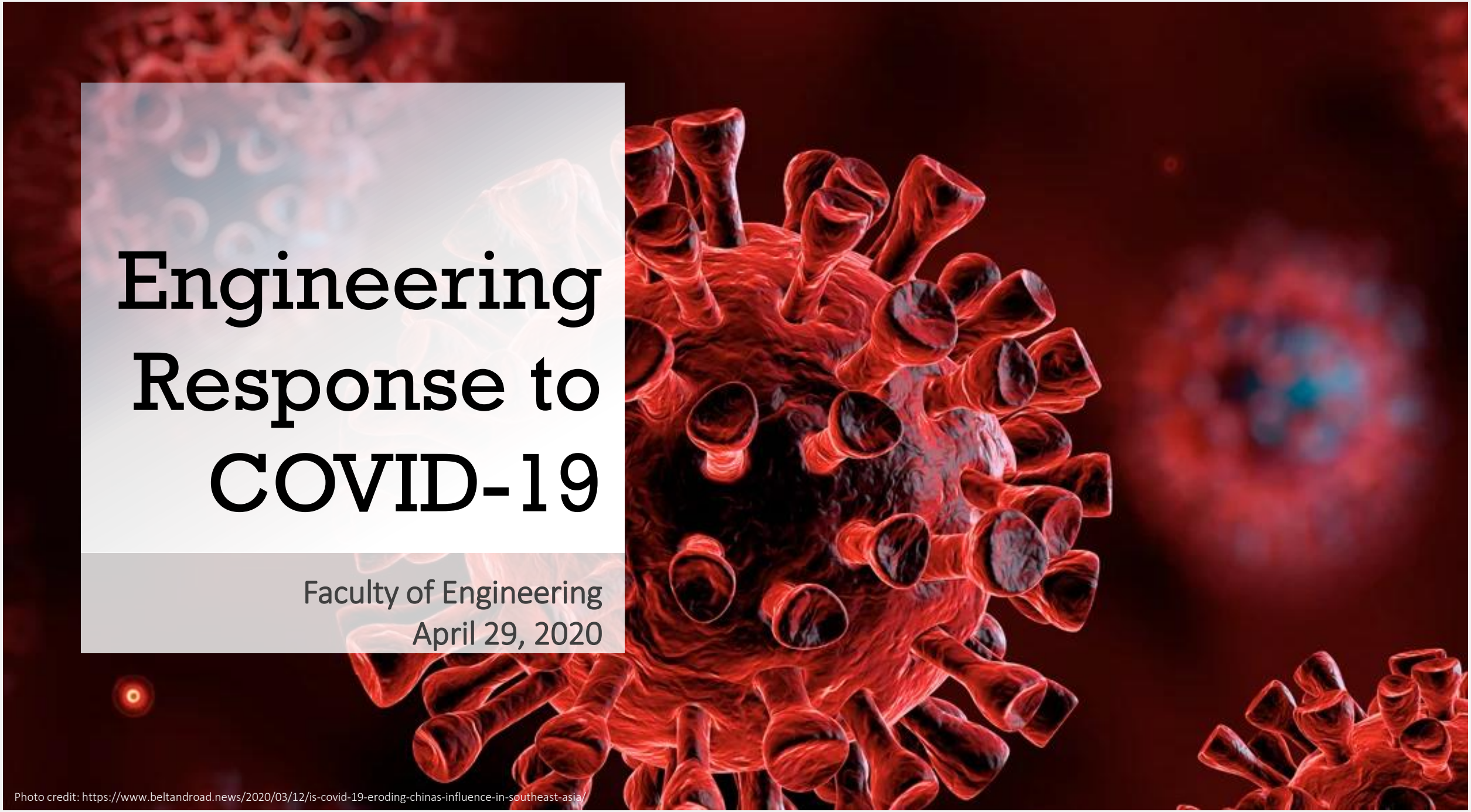


Photo credit: https://www.beltandroad.news/2020/03/12/is-covid-19-eroding-chinas-influence-in-southeast-asia/

Photo credit: https://www.scmp.com/news/hong-kong/health-environment/article/3079222/coronavirus-hong-kong-records-lowest-daily-count

Transmission Pathway and Indoor Environment

Professor Yuguo Li,
Dr. C.H. Liu and
Professor Christopher Chao

Photo credit: https://www.worldpropertyjournal.com/real-estate-news/hong-kong/hong-kong-real-estate-news-jll-residential-market-monitor-report-march-2020-coronavirus-impact-on-hong-kong-property-industry-hong-kong-covid-19-property-report-11892.php

Roles of surface and air in SARS-CoV-2 transmission (Professor Yuguo Li, ME)

Our aims:

1. Understand roles of indoor environments and non pharmacological intervention;
2. Understand the possible roles of airborne and fomite routes

Findings so far

- Nearly all identified outbreaks in non-Hubei cities occurred in indoor environments
- In a hospital with patients of mild symptoms, toilet aerosols dominate (see left figure)
- Drainage stack and vent transported toilet aerosols in one high-rise apartment building block
- The roles of poor ventilation and crowding in 2 outbreaks
- Central air-conditioning seemed not play a role in transmission in one cruise ship outbreak.

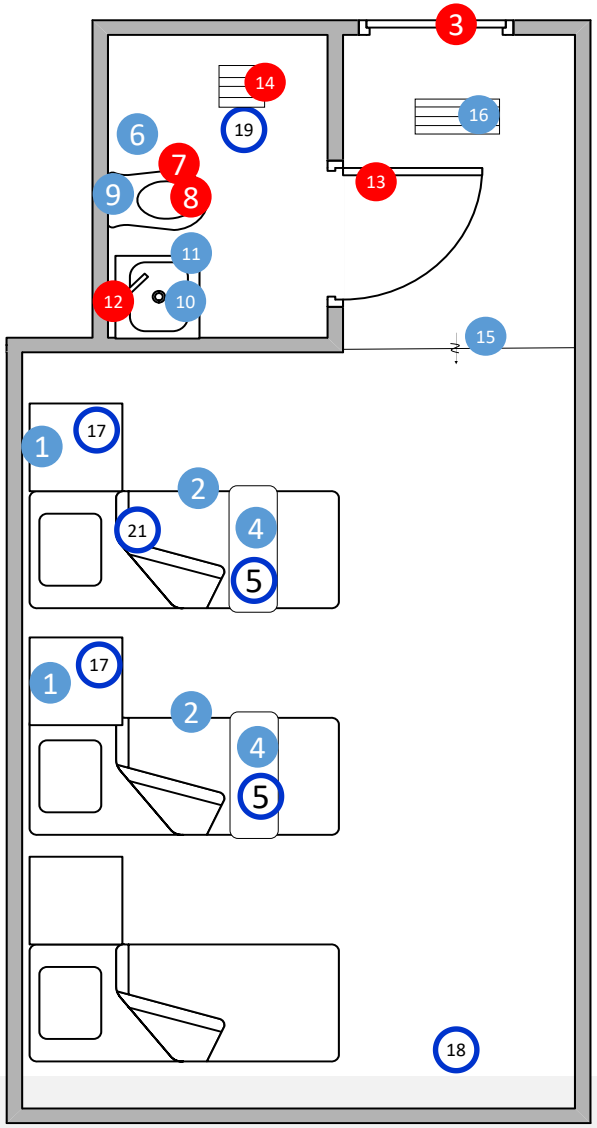
1 Negative surface

1 Positive surface

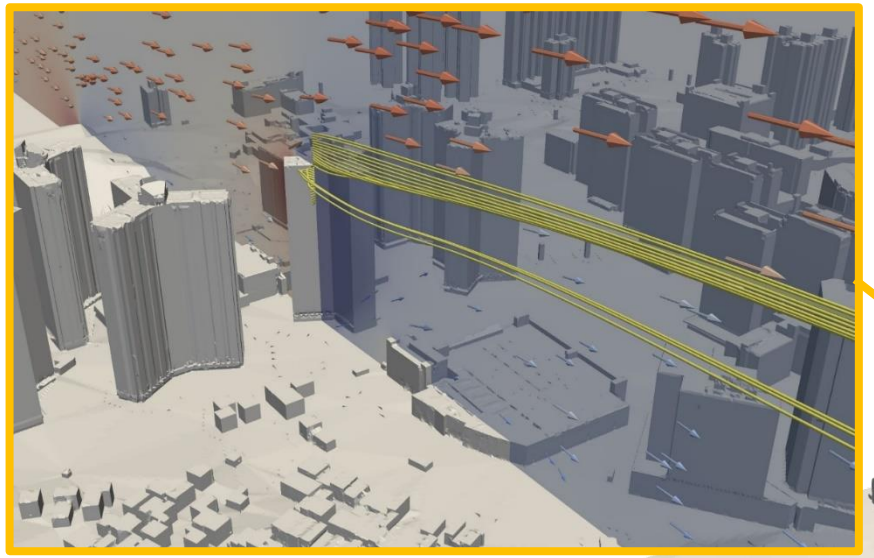
1 Negative air

1 Positive air

1.bedside table
2.bedrail
3.ward door handle (ward side)
4.bedtable
5.bedtable (air)
6.toilet bowl
7.toilet seat
8.toilet seat cover (lower surface)
9.flushing button
10. washbasin sink
11. washbasin flange
12. washbasin faucet lever
13. bathroom door handle
14. bathroom ceiling-exhaust louvre
15. fan-coil supply louvre
16. fan-coil return filter
17. bedside table (air)
18. close to window (air)
19. bathroom (air)

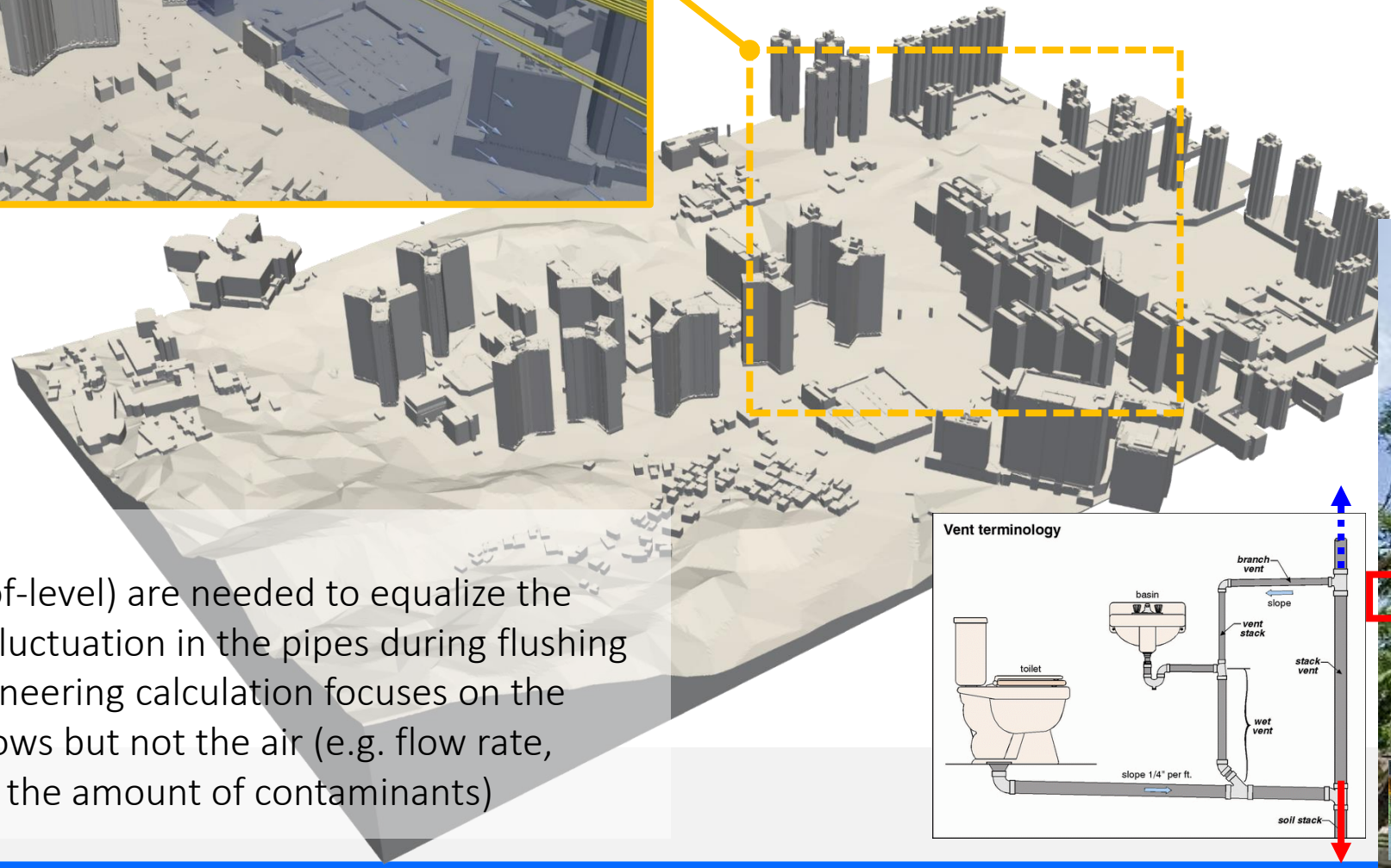


Numerical study on the transmission path in Heng Tei House (Dr. C.H. Liu, ME)



We're interested in two scientific questions:

- Dynamics of airflows in the pipe system during flushing (hydraulics & two-phase flows)
- Neighborhood-scale dispersion processes & the influence on the buildings/apartments nearby (atmospheric flows/turbulence)



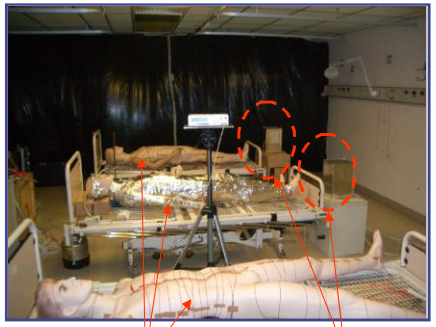
Background

- Vents (roof-level) are needed to equalize the pressure fluctuation in the pipes during flushing
- Most engineering calculation focuses on the sewage flows but not the air (e.g. flow rate, velocity & the amount of contaminants)

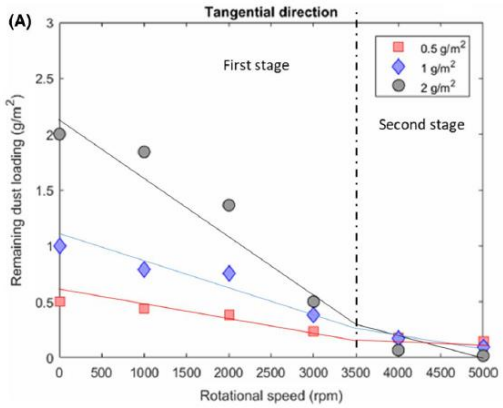
Disease transmission - from emission to infection (Professor Christopher Chao, ME)

Our aims: 1. Understand the role of Bio-aerosol deposition and resuspension on disease transmission;
2. Study the protective role of personalized ventilation (PV) against airborne transmissible disease

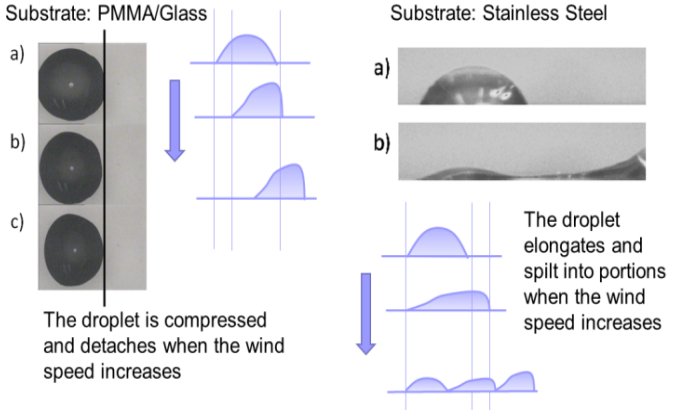
- Deposition
  - Dust could greatly reduce the particles adhesion on surfaces
  - Adhesion varies >3 times depending on separation direction
- Aerosol resuspension
  - Due to human movement and turbulence
  - Secondary source of indoor air pollution
  - >90% of viable E.coil was found in detached droplet
- Personalized ventilation (PV)
  - Sinusoidal airflow PV can reduce inhaled PM1 by 69% to 98%
  - Probability of infection decreased by 27%-65%

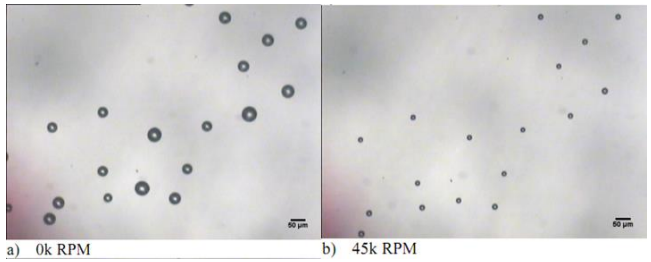


Chao et al. (2008) AS&T



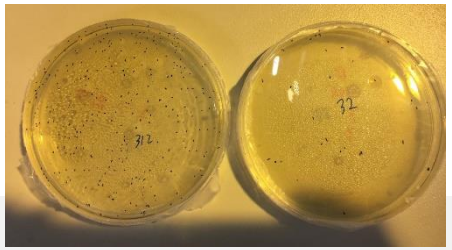
Fu and Chao et al. (2013) J. Fluids Eng.
Lee and Chao et al.(2019) Indoor Air
Wang and Chao et al. (2020) JAS





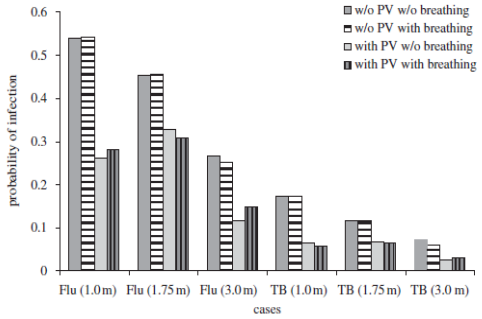
Aerosol resuspension by various forces

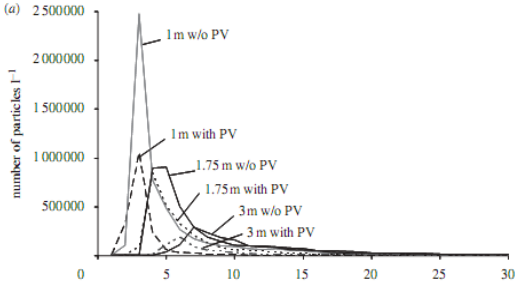
Leung and Chao et al. (2013) Indoor Air; Han and Chao et al. (2014) BMC Infect. Dis.
Leung and Chao et al. (2016) AS&T; Fu and Chao et al. (2018) AS&T

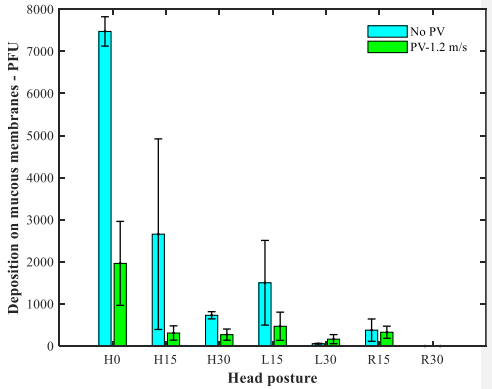


CFU on detached droplet CFU on remained droplet

Leung and Chao et al. (2019) Asian Aerosol Conference







Reduced exposure level by PV

Pantelic and Chao et al. (2009) J.R. Soc. Interface
Xie and Chao et al. (2018) Indoor Built Environ
Xu and Chao et al. (2018) ISIAQ Indoor Air Conference

Virus Detection Technologies

Researchers from CIV and ME

Photo credit: https://www.worldpropertyjournal.com/real-estate-news/hong-kong/hong-kong-real-estate-news-jll-residential-market-monitor-report-march-2020-coronavirus-impact-on-hong-kong-property-industry-hong-kong-covid-19-property-report-11892.php

Fast response organic transistor sensor – virus sensing (Dr. Paddy Chan, ME)

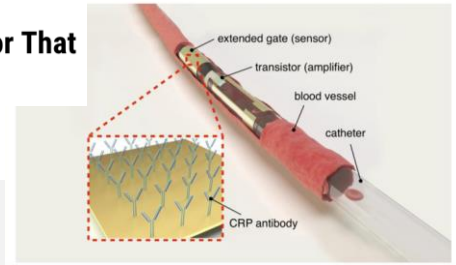
Previous work

Protein sensor for inflammation sensing

港大研發超薄感應器快速檢測炎症

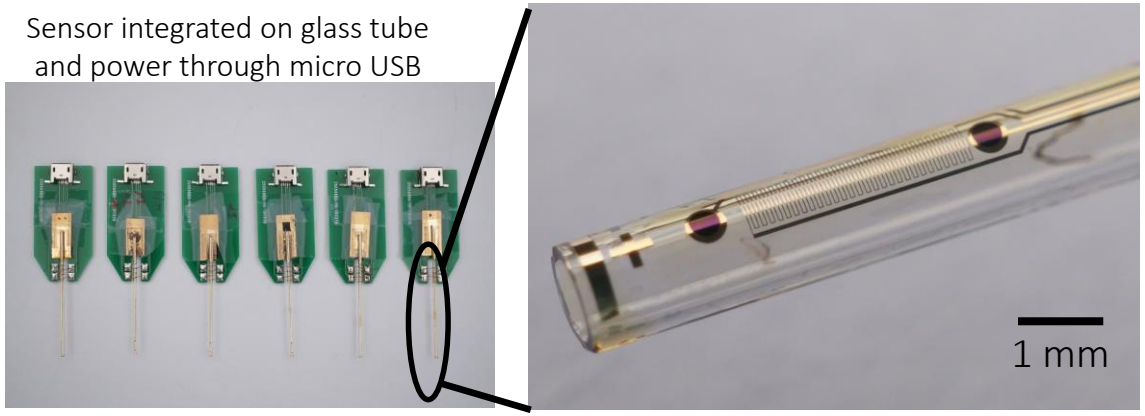
ASIANSCIENTIST

A Real-Time Inflammation Sensor That Fits In A Catheter

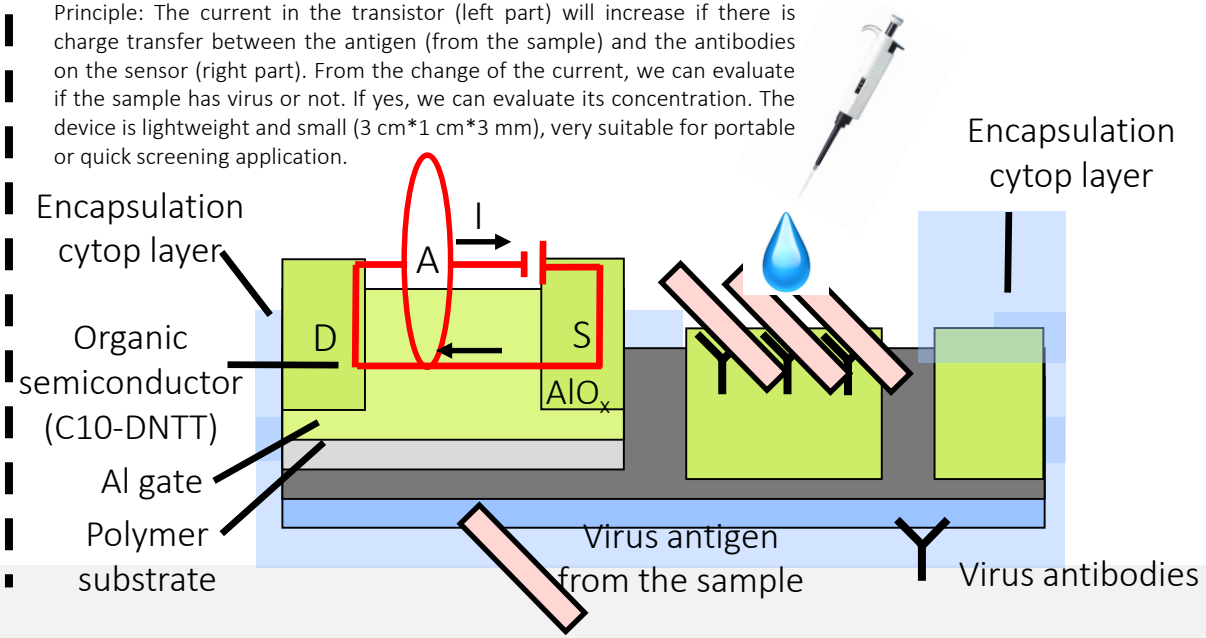


Current work on virus sensor

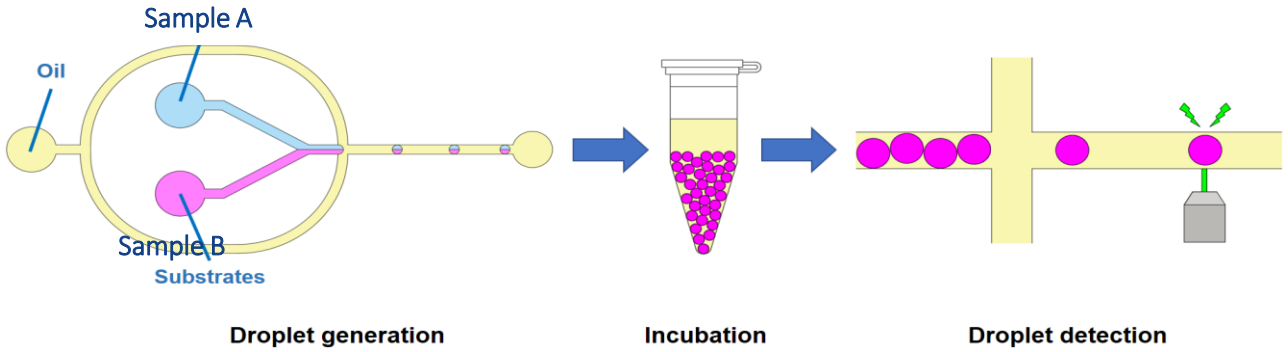
Sensor integrated on glass tube and power through micro USB

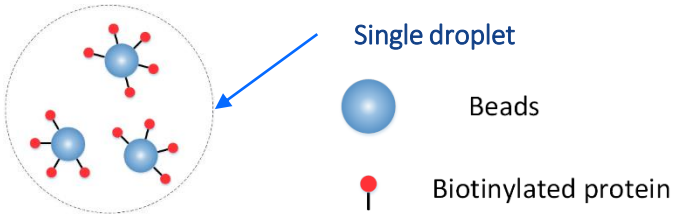


Principle: The current in the transistor (left part) will increase if there is charge transfer between the antigen (from the sample) and the antibodies on the sensor (right part). From the change of the current, we can evaluate if the sample has virus or not. If yes, we can evaluate its concentration. The device is lightweight and small (3 cm*1 cm*3 mm), very suitable for portable or quick screening application.



High-throughput and ultra-sensitive detection using droplet microfluidics to enhance detection (Professor Anderson Shum, ME)

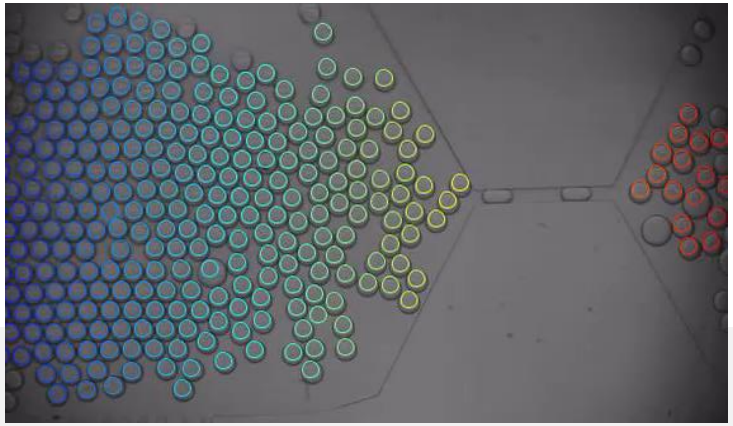


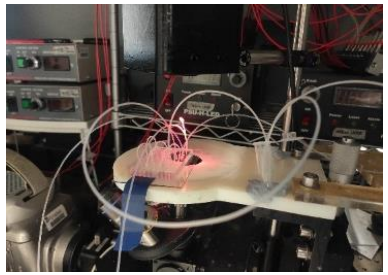


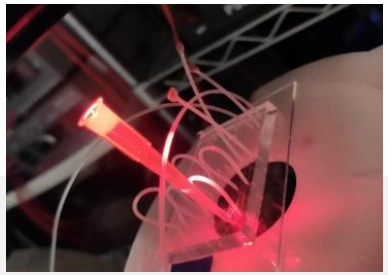
signal amplification inside microdroplet

Confinement in droplet containers leads to

- Reduced sample volume
- Shortened detection time
- Increased throughput
- Enhanced sensitivity



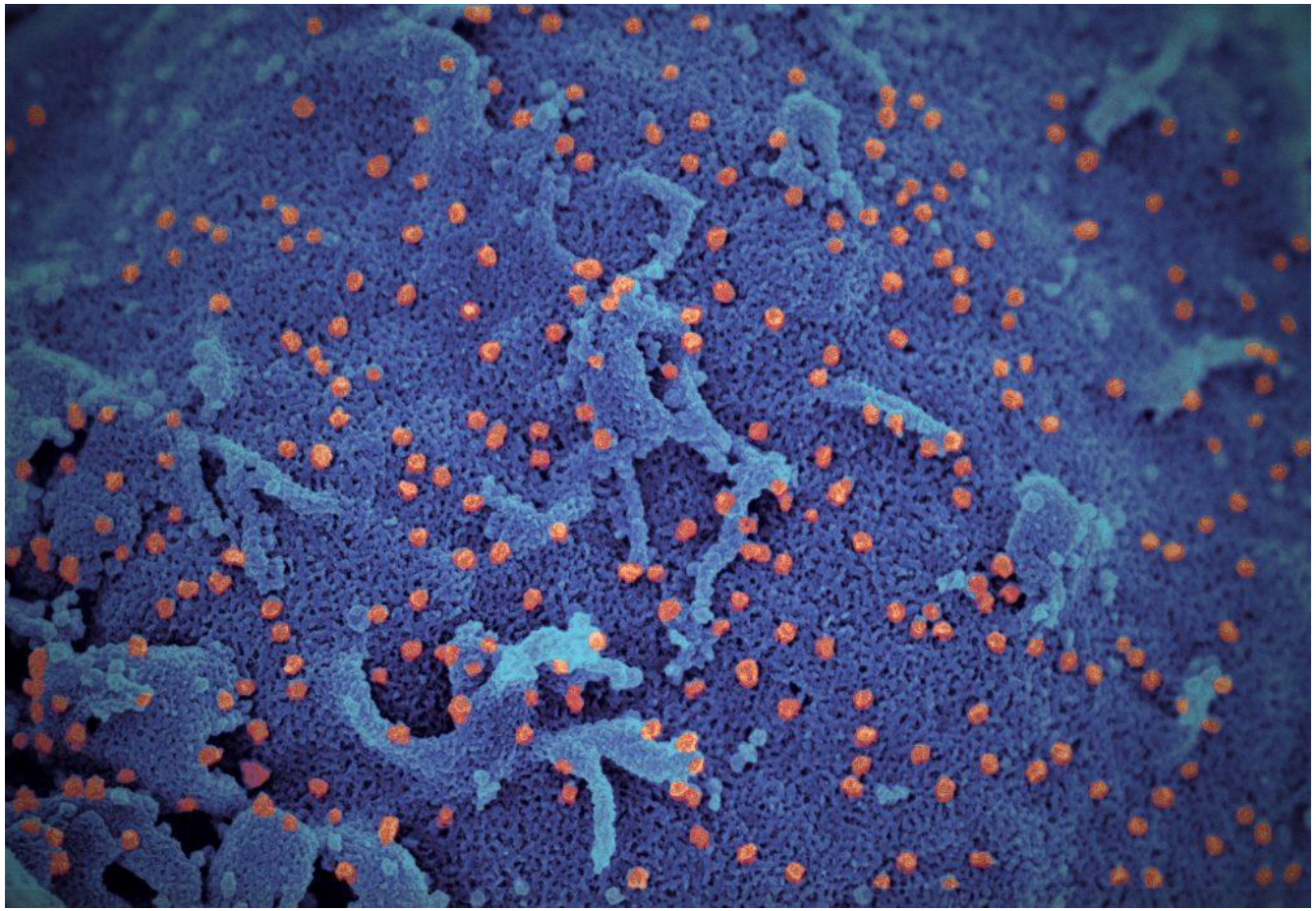




Techniques (patented and/or concept-proof) for

- Integration with COVID-19 detection methods, such as
  - ELISA (*Enzyme Linked Immunosorbent Assay*)
  - PCR (*Polymerase Chain Reaction*)
- Development of portable devices or instruments for Point-of-Care testing of COVID-10
- Isolation of single targets (e.g. coronavirus or virus-infected cells) for further analysis and culture

Processing electron microscope images of SARS-CoV-2 virus infected cells (Dr. Kevin Tsia, EEE)



Diagnosis

Researchers from CIV, CS, EEE and ME

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Low-cost portable thermal imaging fever detection system

Dr. S.C. Fu (ME), Professor Dennis Leung (ME), Professor Chris Chao (ME) and Dr. Kenneth Wong (CS)

Fever is one of the key symptom of COVID-19

A non-intrusive system for rapid screening and sieving out suspected people is necessary

e.g. before entering hall for events, if the screening is not fast enough, it will easily gather people for queuing and increase the risk of cross-infection.

Thermal imaging systems are excellent tools for fast mass screening and keeping distance in screening

Infrared thermometer (requires a very close distance for checking) can be used for confirmation after screening

We are developing a low-cost portable system

Advantages:

Non-Contact
Alarm and alert
Low-cost (only $3~4k HKD)
Portable (no fixed installation)
Face detection speed up the screening

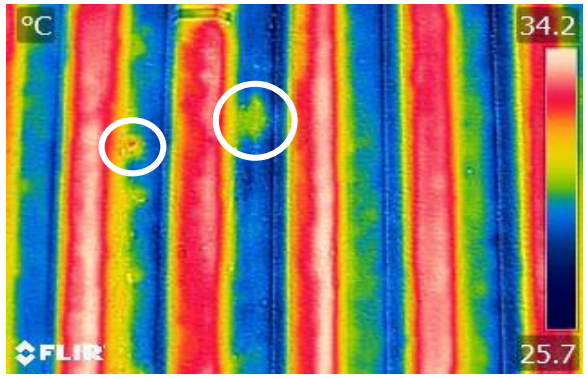
The system can detect a number of people simultaneously, even wearing mask.

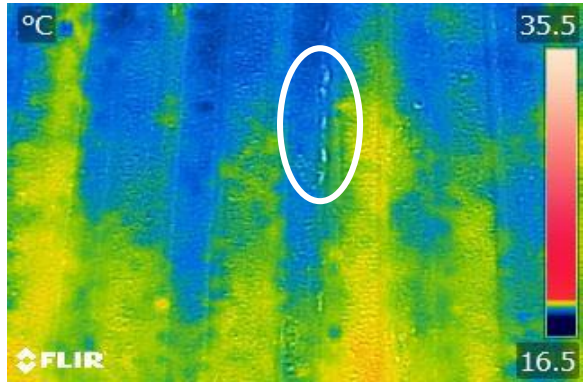
Health and safety inspection of building structures

Dr. Ray Su (CIV), Professor Edmund Lam (EEE) and Mr. Y.S. Wong (CIV)

Digital and infrared cameras were used for drone imaging of deteriorations on external walls of buildings, including water leakage, stains, delamination and cracks.

Water leakage (infrared image)





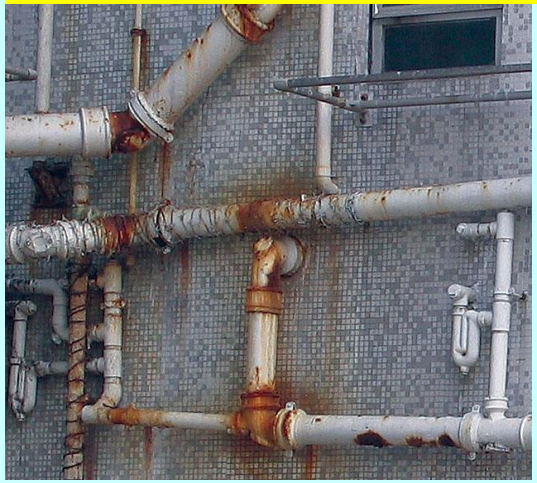
Water leakage (digital image)

Test on external wall of Fresh Water Service Reservoir

Health and safety inspection of building structures

Dr. Ray Su (CIV), Professor Edmund Lam (EEE) and Mr. Y.S. Wong (CIV)

Drain pipe leakage



Steel corrosion & concrete delamination

Rust stain

Concrete delamination

Delamination of tiles

Concrete spalling

Crack on external wall

Tong Zhang's slide

Reynold’s slide

Disinfection and Control

Researchers from CIV, ME and SPH

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Anti-viral materials to cut the two transmission routes (Professor L.Q. Wang, ME)

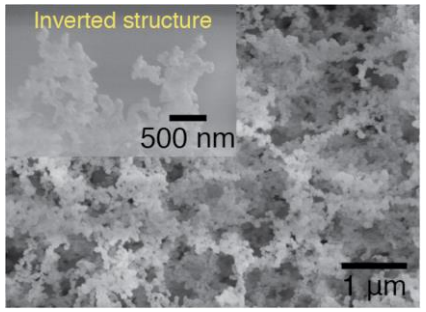
Two Routes of Transmission

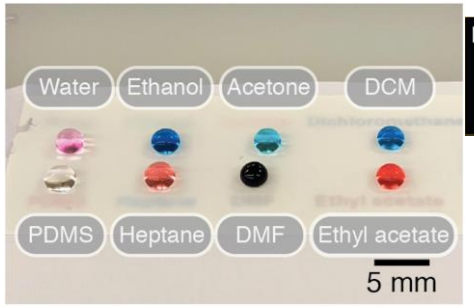
- Droplet contact transmission

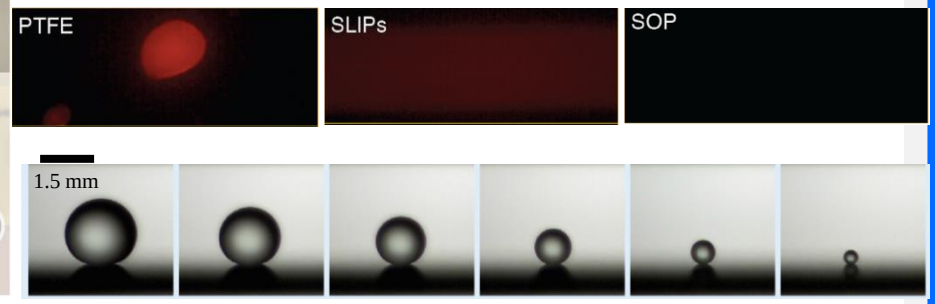
- Contaminated surfaces

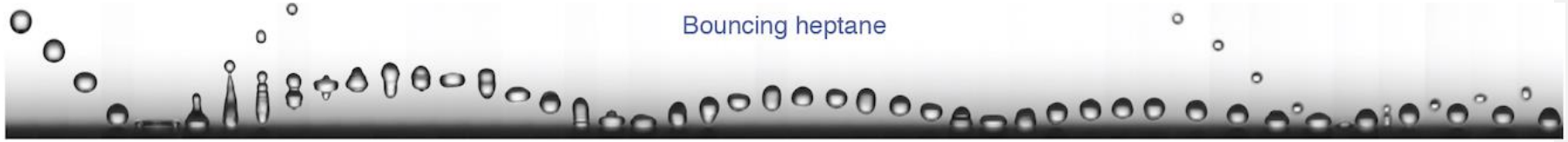
BusinessInsider

Self-cleaning surfaces repel diminutive droplets from sneeze or cough

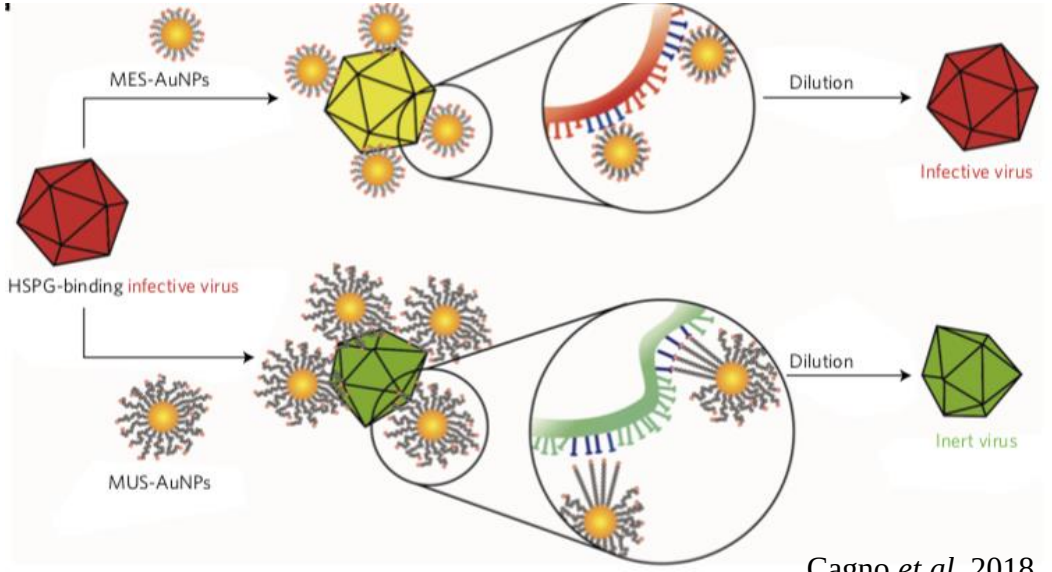








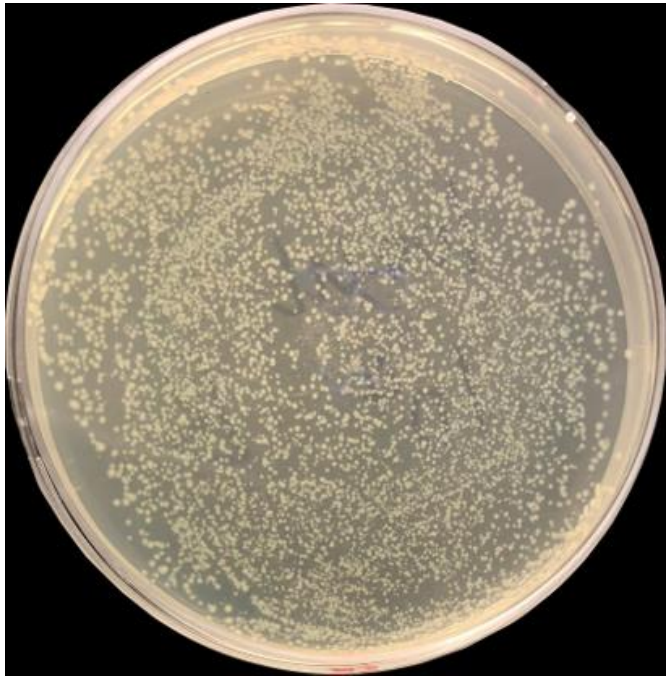
Nanostructures as viricide to block, deform and kill the attached virus



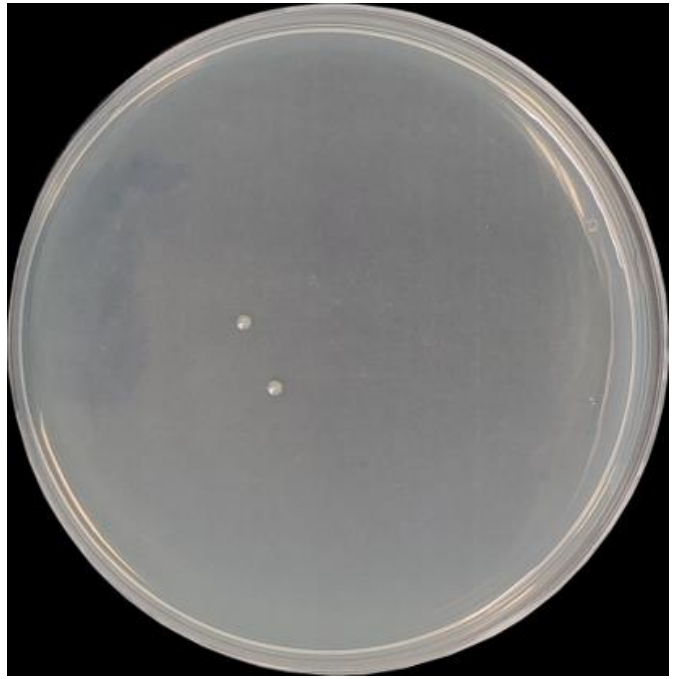
Cagno *et al.* 2018

Anti-bacterial/virus stainless steel
Professor Mingxin Huang (ME) and Professor Leo Poon (SPH)

Stainless steel is widely used in daily life



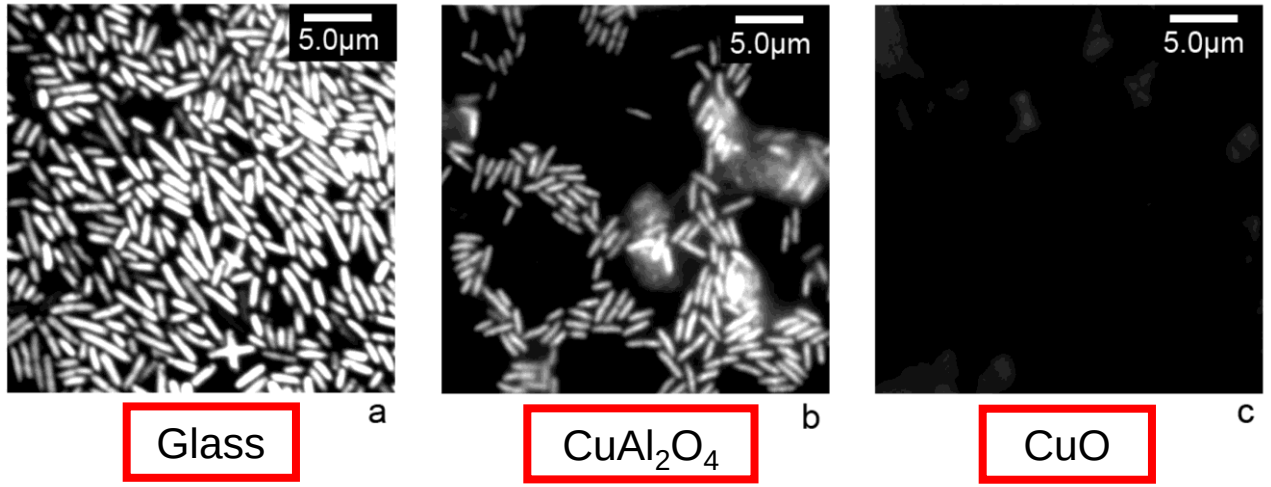
Conventional stainless
No anti-bacterial property



HKU anti-bacterial stainless steel
Excellent Anti-bacterial (E. coli) rate > 99%
Patent pending

New Anti-Virus/Bacteria Copper Spinel Material (Professor Kaimin Shih, CIV)

- Copper Oxide (CuO) is proven to kill bacteria and viruses, but is highly leachable to result in the environmental toxicity.
- We successfully developed the low-leachable Copper Spinel materials with anti-bacteria adhesion capability. The anti-virus property, such as for COVID-19, is also expected.
- The applications can be on the surfaces of door handles, elevator buttons, bus/MTR handrails, mask surface/filter, etc. to reduce virus spreading.



E. Coli **bacteria adhesion was substantially inhibited with the new copper aluminum spinel ($CuAl_2O_4$) coated surface. Although copper oxide (CuO) showed the same capability, its copper leachability was found to be 3000mg/L after 12-hour of acid leaching, significantly higher than that (40 mg/L) of copper aluminum spinel** (*Tang & Shih, Chemosphere 2010; Shih & Tang, J. Environ. Monitor. 2010*)**.**

A portable clean air delivery and contaminated air extraction system for elderly in elderly homes and baby strollers (Professor Dennis Y.C. Leung, ME)

Corornavirus has the highest death rate for the elderly than all other age groups. Therefore protecting seniors as they are most vulnerable, say experts

Explained: A possible reason why COVID-19 has killed more elderly patients

What makes the elderly especially vulnerable to the virus? James Diaz, a professor at Louisiana State University's School of Public Health, has hypothesised that the reason could lie in the victims' medications.

By: Explained Desk | New Delhi | Updated: March 25, 2020 11:19:37 am

MORE EXPLAINED

Explained: Can unborn baby be infected with coronavirus?

Coronavirus positive cases among tests: trends, and an outlier

An Expert Explains: Cyber frauds trying new ways, it's important to secure data, accounts

Explained: Can gargling with salt water prevent COVID-19 infection?

Battery driven clean air delivery or contaminated air extraction system for elderly and baby strollers

Portable and battery driven module

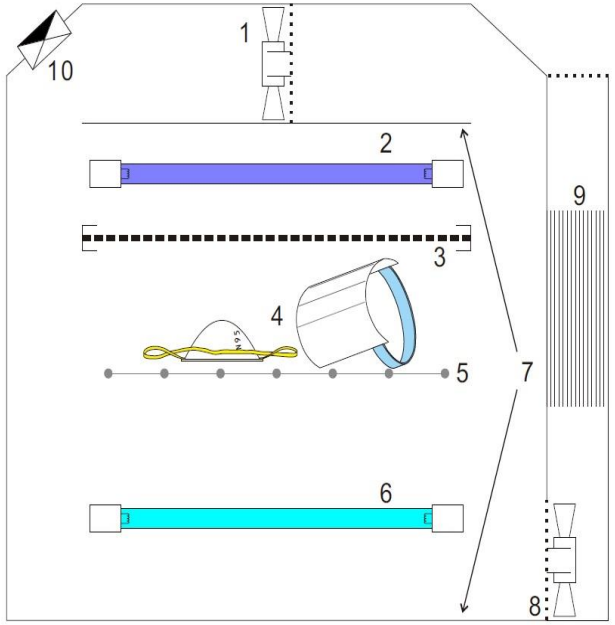
Clean air delivery

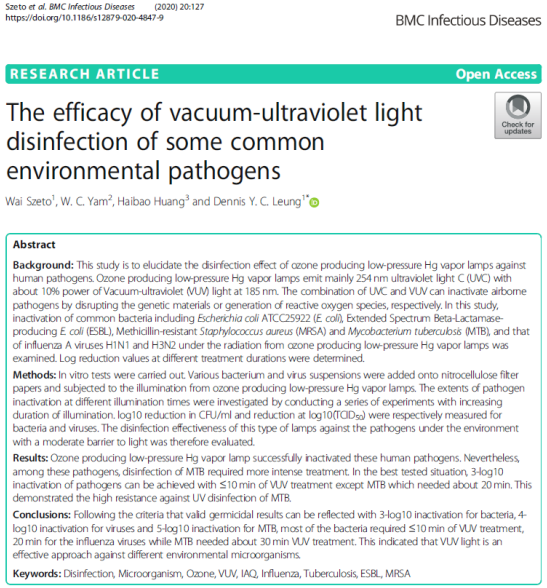
Contaminated air extraction

Baby stroller

Novel VUV disinfection chamber for efficient sterilizing fabric materials, medical and surgical products (Professor Dennis Y.C. Leung, ME)

Proven: can kill/inactivate 99.9% of common pathogens like E. coli, Methicillin-resistant Staphylococcus aureus (MRSA) and Mycobacterium tuberculosis (MTB), and that of influenza A viruses H1N1 and H3N2 in less than 15 minutes





Szeto et al. BMC Infectious Diseases (2020) 20:127
https://doi.org/10.1186/s12879-020-4847-9

BMC Infectious Diseases

RESEARCH ARTICLE Open Access

The efficacy of vacuum-ultraviolet light disinfection of some common environmental pathogens

Wai Szeto[1], W. C. Yam[2], Haibao Huang[3] and Dennis Y. C. Leung[1*]

Abstract

Background: This study is to elucidate the disinfection effect of ozone producing low-pressure Hg vapor lamps against human pathogens. Ozone producing low-pressure Hg vapor lamps emit mainly 254 nm ultraviolet light C (UVC) with about 10% power of Vacuum-ultraviolet (VUV) light at 185 nm. The combination of UVC and VUV can inactivate airborne pathogens by disrupting the genetic materials or generation of reactive oxygen species, respectively. In this study, inactivation of common bacteria including *Escherichia coli* ATCC25922 (*E. coli*), Extended Spectrum Beta-Lactamase-producing *E. coli* (ESBL), Methicillin-resistant *Staphylococcus aureus* (MRSA) and *Mycobacterium tuberculosis* (MTB), and that of influenza A viruses H1N1 and H3N2 under the radiation from ozone producing low-pressure Hg vapor lamps was examined. Log reduction values at different treatment durations were determined.

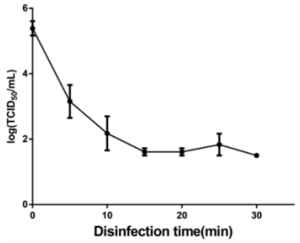
Methods: In vitro tests were carried out. Various bacterium and virus suspensions were added onto nitrocellulose filter papers and subjected to the illumination from ozone producing low-pressure Hg vapor lamps. The extents of pathogen inactivation at different illumination times were investigated by conducting a series of experiments with increasing duration of illumination. log10 reduction in CFU/ml and reduction at log10($TCID_{50}$) were respectively measured for bacteria and viruses. The disinfection effectiveness of this type of lamps against the pathogens under the environment with a moderate barrier to light was therefore evaluated.

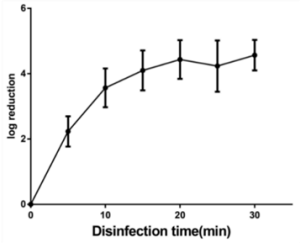
Results: Ozone producing low-pressure Hg vapor lamp successfully inactivated these human pathogens. Nevertheless, among these pathogens, disinfection of MTB required more intense treatment. In the best tested situation, 3-log10 inactivation of pathogens can be achieved with ≤10 min of VUV treatment except MTB which needed about 20 min. This demonstrated the high resistance against UV disinfection of MTB.

Conclusions: Following the criteria that valid germicidal results can be reflected with 3-log10 inactivation for bacteria, 4-log10 inactivation for viruses and 5-log10 inactivation for MTB, most of the bacteria required ≤10 min of VUV treatment, 20 min for the influenza viruses while MTB needed about 30 min VUV treatment. This indicated that VUV light is an effective approach against different environmental microorganisms.

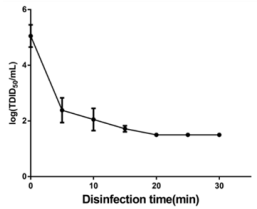
Keywords: Disinfection, Microorganism, Ozone, VUV, IAQ, Influenza, Tuberculosis, ESBL, MRSA

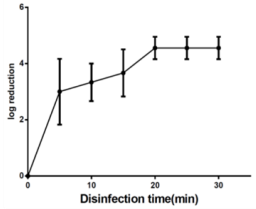
H1N1



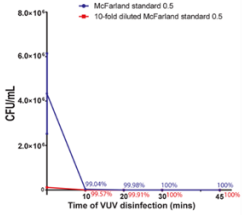


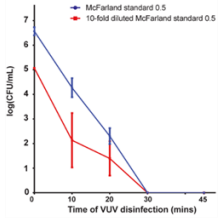
H3N1

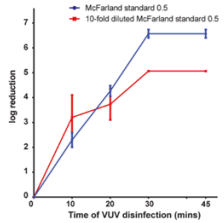




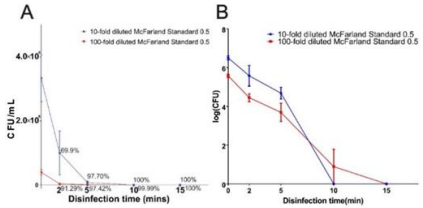
Mycobacterium tuberculosis

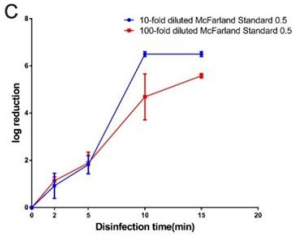






Methicillin-resistant Staphylococcus aureus





Coronavirus: To be tested and confirmed

1. Recirculation fan;
2. VUV lamp (185nm);
3. Ti doped quartz;
4. Mask/medical device;
5. Supporting grid with mesoporous CeO_2 based photocatalyst;
6. Far UVC lamp;
7. Reflector;
8. Exhaust fan;
9. MnO_2 based catalyst;
10. Non-return valve.

Improved filtration test for face mask in a more realistic setting

Professor Christopher Chao (ME), Professor Yuguo Li (ME) and Dr. S.C. Fu (ME)

- Standard test
  - Tested the face mask material in a well-sealed apparatus
  - Not tested the actual personal exposure/ aerosol release
- Actual scenario
  - Considerable amount of air leak through the gaps between face and mask
- Fit test
  - Only apply to respirator, not mask
  - Not quantitative tested bio-aerosol
- Improved test
  - Test with a person/manikin wearing the mask
  - Use bacteriophage for virus survival test
  - Collect air sample under breathing action
  - Include effects of humid exhaust
  - …and more

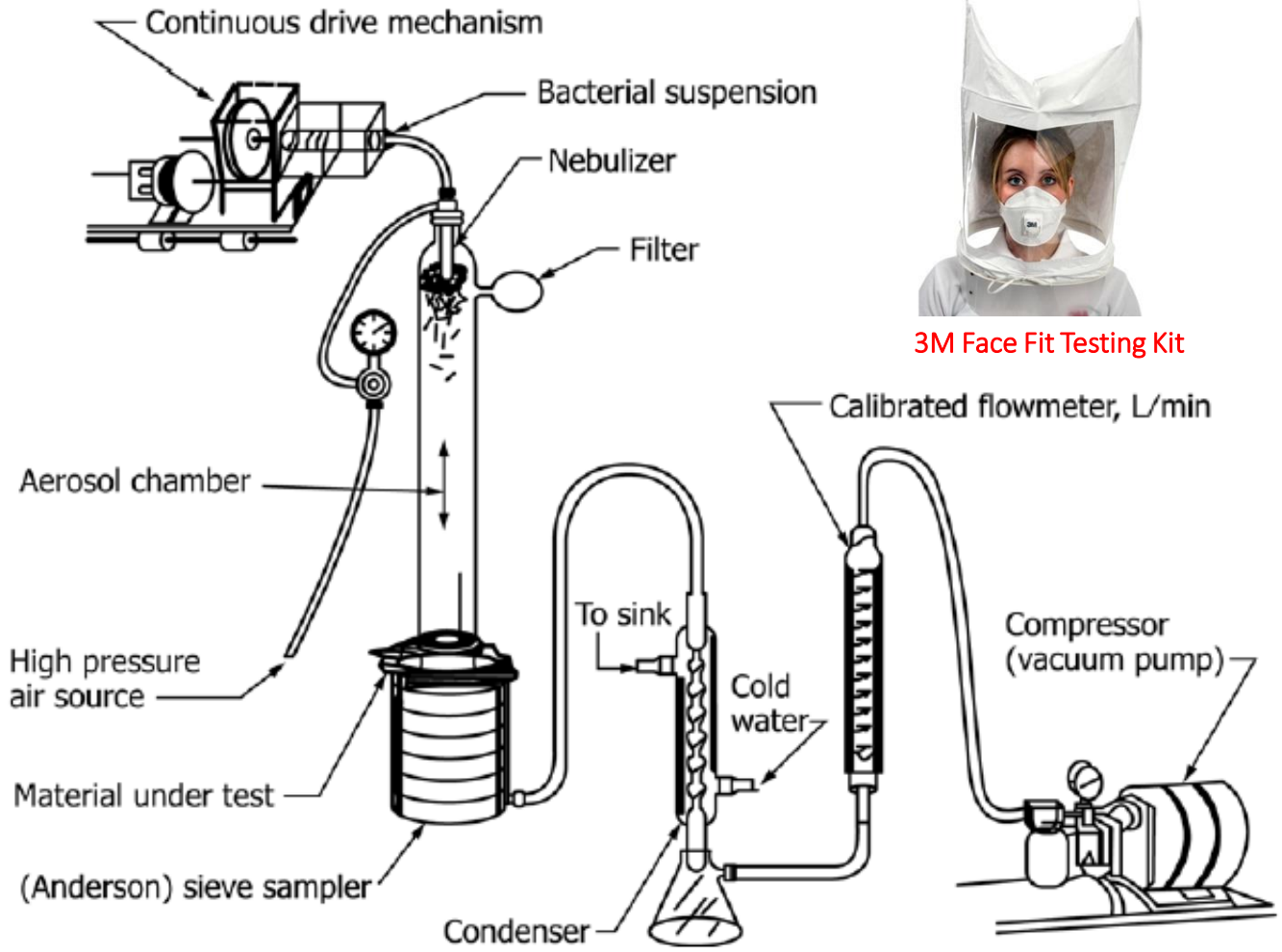


FIG. 1 Bacterial Filtration Efficiency Test Apparatus

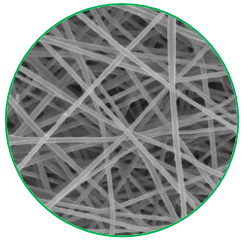
BFE Test Apparatus (ASTM F2101)

3M Face Fit Testing Kit

Porous nanofibrous filter for reusable face masks (Professor C.Y. Tang, CIV)

Conventional mask

- Function loss after wetting
- Disposable usage
- Bacterial adhesion



Nanofibrous filter

- Durable function
- Reusable
- Antibacterial

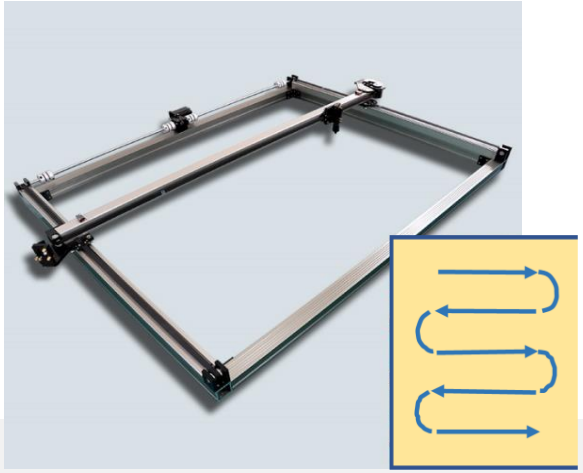
Property	Conventional face mask	Nanofibrous face mask
Removal Efficiency	★★★	★★★★
Function	★	★★★
Reusability		★★★★
Sustainability	★	★★★★

Extension from previous works on nanofibrous water filter: two US patents, one Chinese patent; Gold Medal at 2019 Exhibition of Inventions Geneva; Innovators under 35 for the Asia Pacific Region by MIT Technology Review (Dr. Gao Hao); Technology licensed

UVGI disinfection system on movable platform
Professor Christopher Chao (ME) and Dr. S.C. Fu (ME)

- COVID-19 viruses can be inactivated by ultraviolet germicidal irradiation (UVGI) exposure
- Cleaner air filter → Cleaner air it can provide
- Moving platform (like a scanner)
- Less UV lamps
- Prevent any dead zone
- Flexible to install sensors, like camera for fast and easy visual inspection
- Protect technicians
- Extend filter service time
- Suitable for places like isolation wards equipped with expensive HEPA filters

UVGI exposure is not uniform even with multiple UV lamps



Commercial 2D moving platform

Quarantine and Contact Tracing

Professor George Huang

Photo credit: https://www.worldpropertyjournal.com/real-estate-news/hong-kong/hong-kong-real-estate-news-jll-residential-market-monitor-report-march-2020-coronavirus-impact-on-hong-kong-property-industry-hong-kong-covid-19-property-report-11892.php

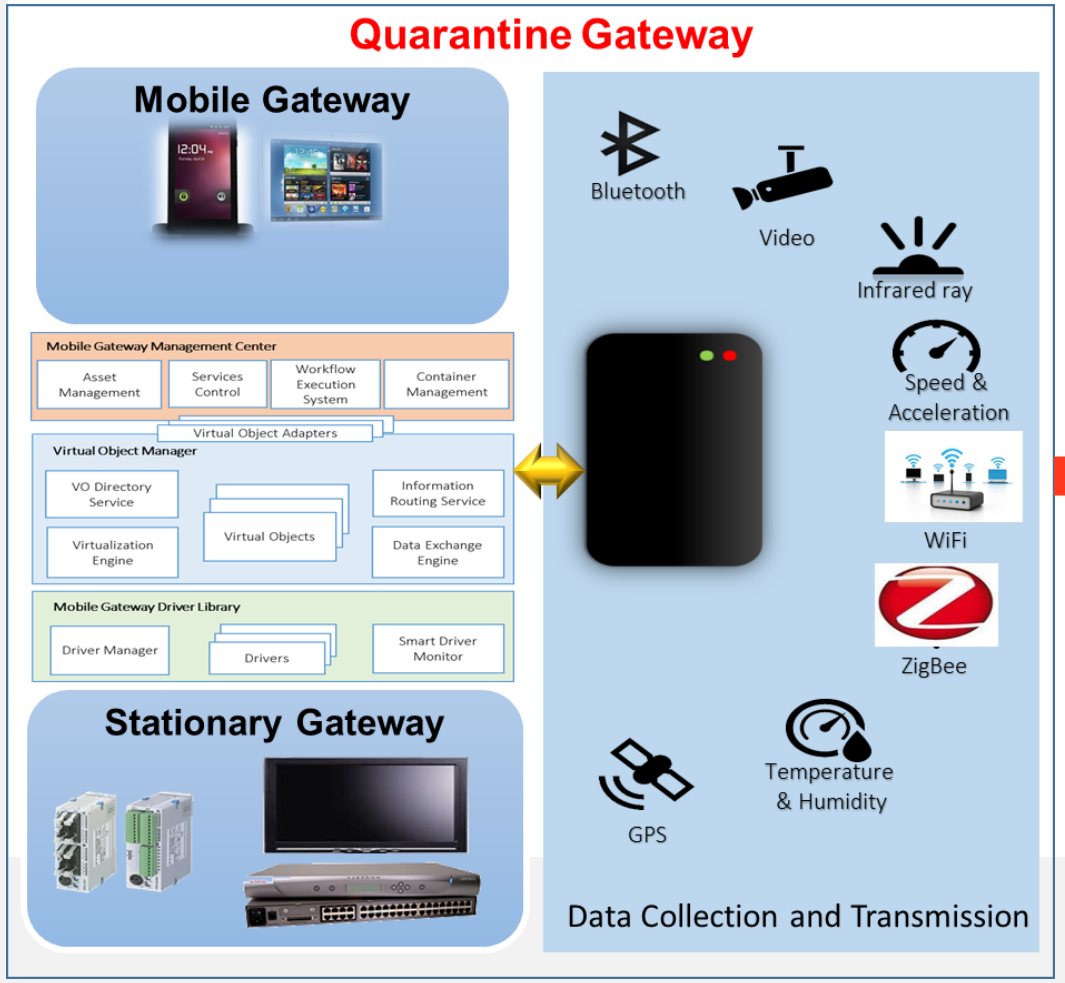
Quarantine Gateway (Professor George Huang, IMSE)

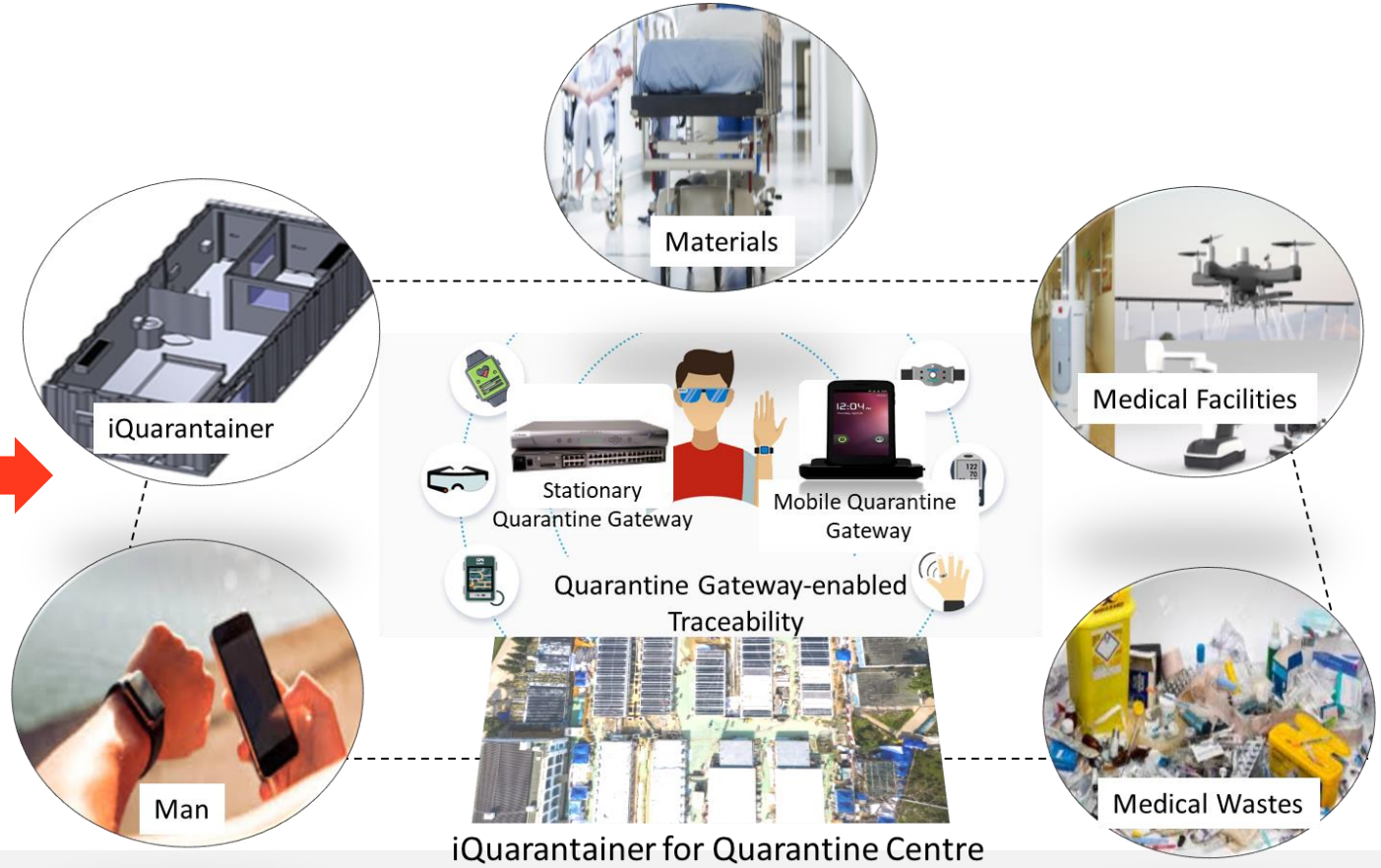
Challenges

- Inefficiency of tracking people, facilities, and wastes in the quarantine centre
- Traceability using limited data sources

Innovations

- Collaborative locating with multi-sources and heterogeneous channels based on smart quarantine gateway
- A reactive and proactive approach using self-learning Genetic Positioning model





iGather (Professor George Huang, IMSE)

Challenges

- Difficulty for tacking the spread of COVID-19 in various communities such as bars, public libraries, theaters, etc
- Lack of historical trajectory data for public health protection in CHP

Innovations

- Use short-range Bluetooth communications to establish a voluntary contact-tracing network in close proximity with each other for public health authorities
- An intelligent reporting and alerting service for potential infected people from the authority parties for efficient protection

Public Health Authorities

- Centre for Health Protection
- Department of Health
- Hospital Authority

iGather

Venues

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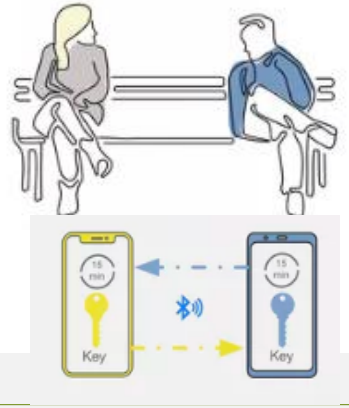
Buses

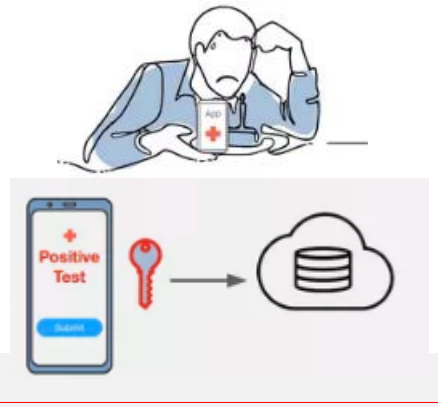
Restaurants

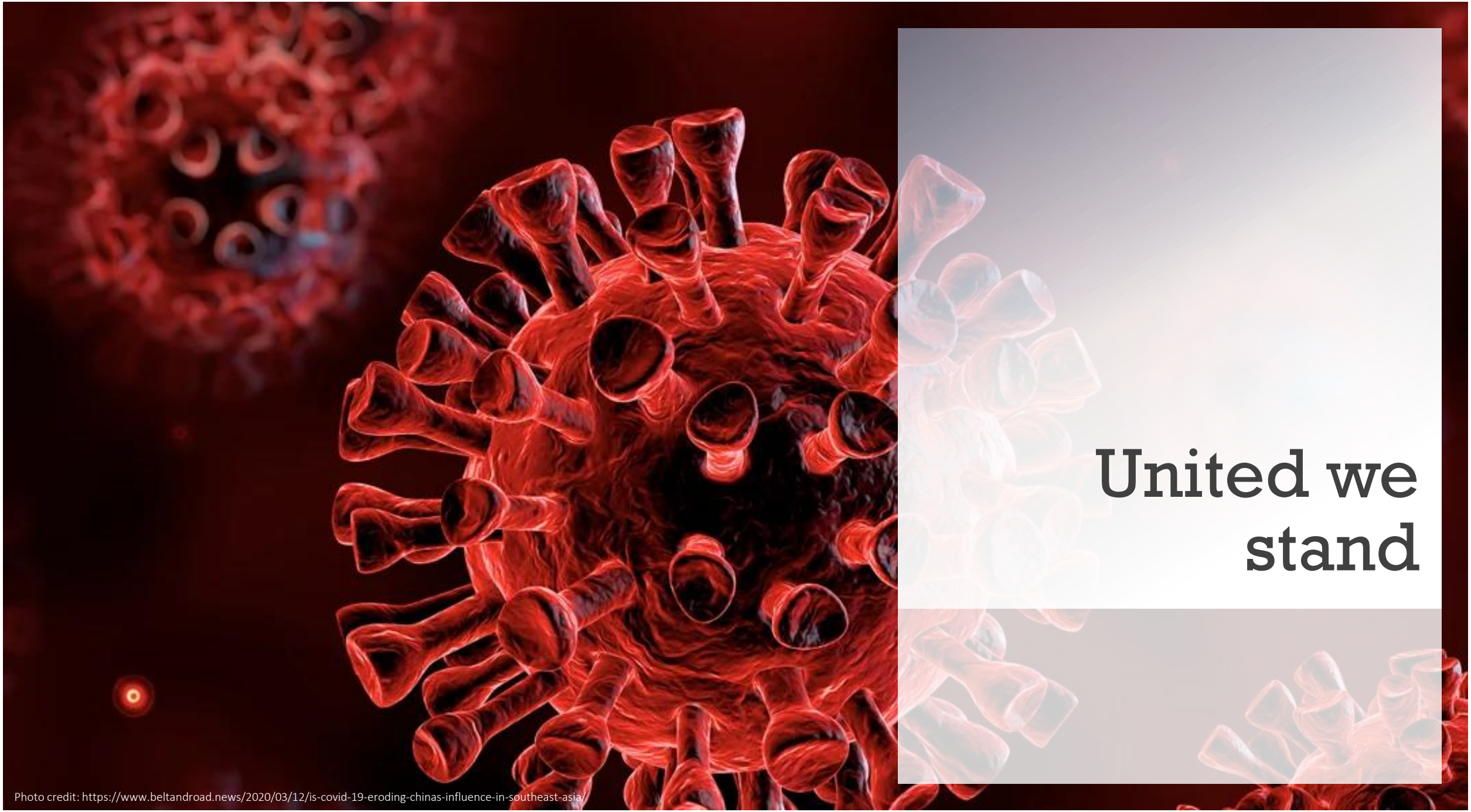
Registration and Scanning

Contact Tracing



Digital Surveillance





United we stand

Photo credit: https://www.beltandroad.news/2020/03/12/is-covid-19-eroding-chinas-influence-in-southeast-asia/