

IoT-enabled Environment Science and Deep Citizen Science



Stefan Poslad, Raphael Kim, Guangyuan Zhang, Rana Massoud,
Francesca Palermo

<http://iot.eecs.qmul.ac.uk>

Email Stefan.poslad@qmul.ac.uk

Outline

The aim of this guide is to explain what IoT-enabled Environment Science (IoT-ES) and Deep Citizen Science (DCS) are, what these involve & what is the range of technology & design choices to determine these

- ✓ **Part A: On overview of what IoT-ES and DCS involves**
- Part B: some previous & current results from IoT2US Lab concerning IoT-ES and DCS

Problem: The World Needs More Scientists



- World's population is increasing (7.7 billion as of 2018-10)
- How can we make the world a sustainable, a better place as it changes?
- We need more scientists for a better understanding of the world!
- So how many scientists are there?
- How do we define a scientist? ... by education qualification or ... ?
- Assume workforce is on average $\geq 60\%$ of a country's population ...
- E.g., for Pakistan, 0.03% of the population are scientists
- Can 0.03% of the population change the behavior of its citizens?
- We need more scientists!

Problem: It's not just about too few scientists, 2



It's also about too few science allocated resources ...

- Training professional scientists takes time, to become experienced ...
- Although earlier scientists made measurements using human observations (Humans as sensors) or using simple scientific instruments
- Today's professional scientists' equipment tends to be ↑ sophisticated / complex, to learn to operate, & to maintain
- Equipment is ↑ expensive, far ↓ affordable - especially in less well off world regions
- Scientists tend to often perform & validate their work in controlled labs
- Whereas to change the world, science needs to be performed in the wild ...

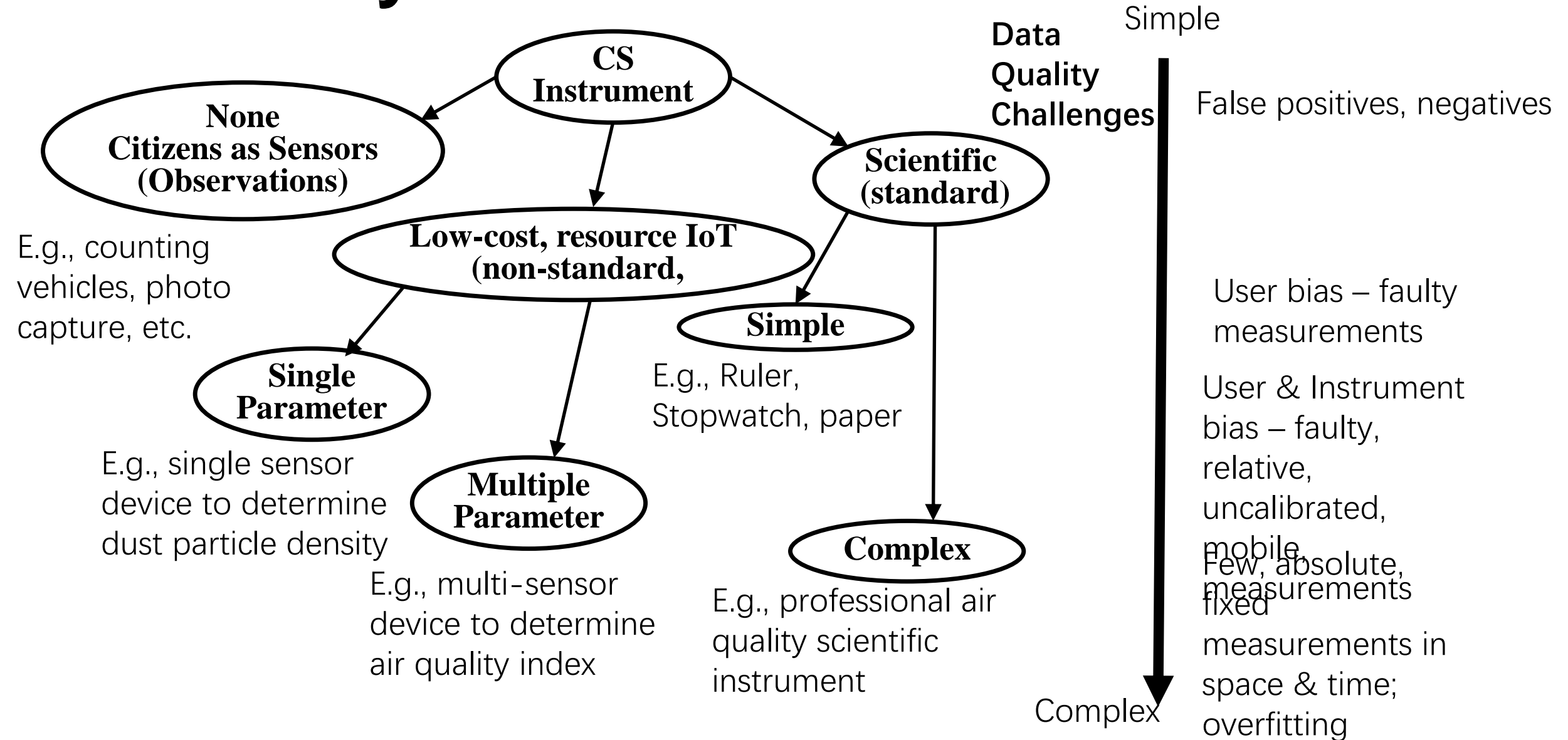
Drivers for Citizen Science (CS)

- To aid scientists through **citizens providing wider, more temporal-spatial measurements** of the physical and natural world than scientists' conventional approaches, e.g., using mobile air quality monitoring rather than that based upon networks of static, sparse, measurement stations;
- **Environment monitoring equipment may be prohibitively expensive** to be used to capture temporal-spatial heterogeneity and identify environment hotspots that is required for the development of robust real-time strategies for exposure control – hence the need for low-cost equipment such as IoT based approaches;
- There are **a lack of scientists and specialized resources** to monitor the physical and natural world, especially in developing countries;
- To serve education and outreach goals, **to widen, make more inclusive, the participation in science by citizens** .

Taxonomy of CS Instruments

- Different types of CS instrument can introduce different challenges, including those for data quality, and concerning the outcomes and decisions that can be drawn from that data.
- Projects employing IoT systems of sensors for monitoring the environment require a quantitative analysis of uncertainties for data quality estimate.
- While analysing the data quality of projects on environmental monitoring, environmental factors or operating conditions also need to be considered as they impact the performance and efficiency of the sensors.
- Our focus of this survey is on low-cost IoT-CS systems and deployment issues therefrom, e.g., data quality.

Taxonomy of CS Instruments



IoT- CS Challenges

- *Calibration and reliability of sensors*
- *Sensor sensitivity versus selectivity*
- *Sensor stability and response time*
- *Variable operating conditions*
- *Slow changes in environment state*
- *Robustness*
- *Equipment costs*
- *Maintenance & operational costs*
- *Longevity of components before replacement*
- *Trust by the scientific community and decision makers*
- *Ownership and dissemination of the monitored data*

Outline

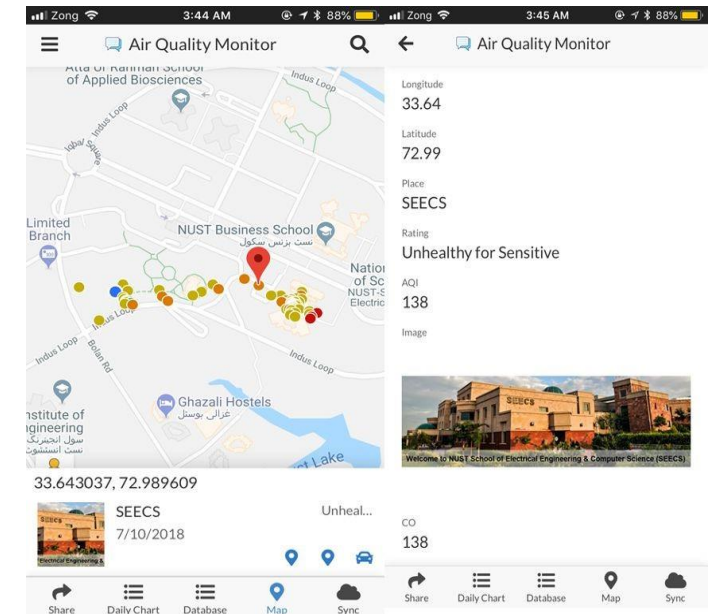
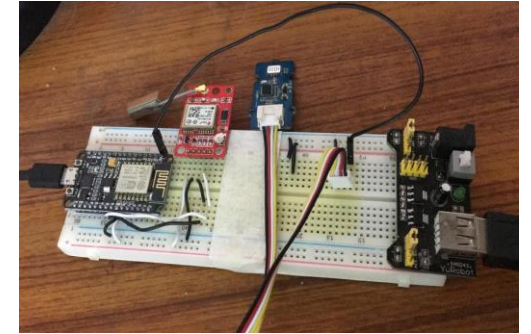
- Part A: On overview of what IoT-ES and DCS involves
- ✓ **Part B: some previous & current results from IoT2US Lab concerning IoT-ES and DCS**

Recent Studies (2016-2020)

- A Low cost AQ IoT system: a Study in Pakistan
- A Public Transport Bus as a Flexible Mobile Smart Environment Sensing Platform for IoT in Beijing
- Gamify road vehicle driving to promote more eco-friendly driving behaviour
- Estimating Large-scale More Finely-grained Temporal Spatial Human Population Density Distributions
- Estimating Global Horizontal Irradiance (GHI) to assess the potential for solar energy
- How air quality affects people's mobility
- Sensing physical environment structural changes
- Internet of Bio-Nano Things (IoBNT)

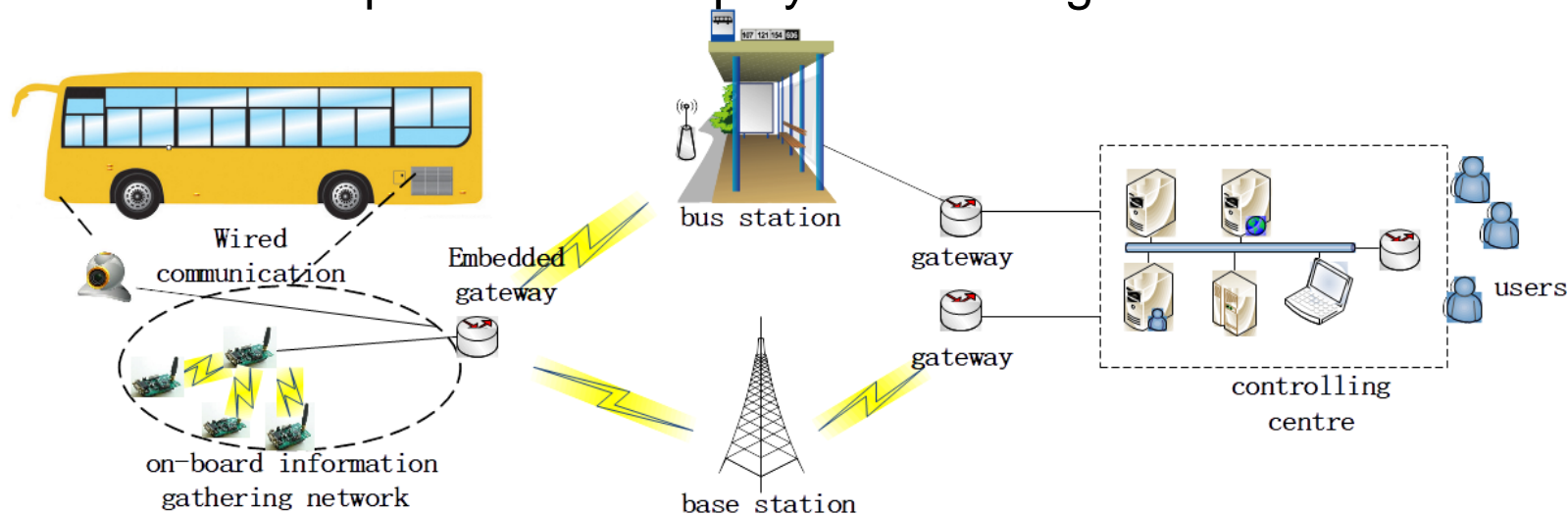
A Low-cost Air Quality IoT System Study (in Islamabad)

- **Objectives:** To realise a cost effective IoT AQ system
- **Method:** Used NodeMCU system on chip which is a low cost, low energy, open, wireless LAN platform connected to sensors
- **Results and Conclusions:** 25000 samples that were collected for the month of August 2018 for a road segment of Rawalpindi leading to Islamabad. Upon analysis, it is observed that humidity and temperature are negatively correlated against NO_2 and inherently affect the NO_2 balance in the air. This mainly happens as NO_2 is a water-soluble gas, the concentration of this gas declines during high humidity as well as during rain. We demonstrated air quality monitoring by collecting data using temperature, humidity, carbon monoxide and nitrogen dioxide sensors & performed data analysis to infer the relationship of pollutant gases with weather parameters influencing air quality.



A Public Transport Bus as a Flexible Mobile Smart Environment Sensing Platform for IoT in Beijing

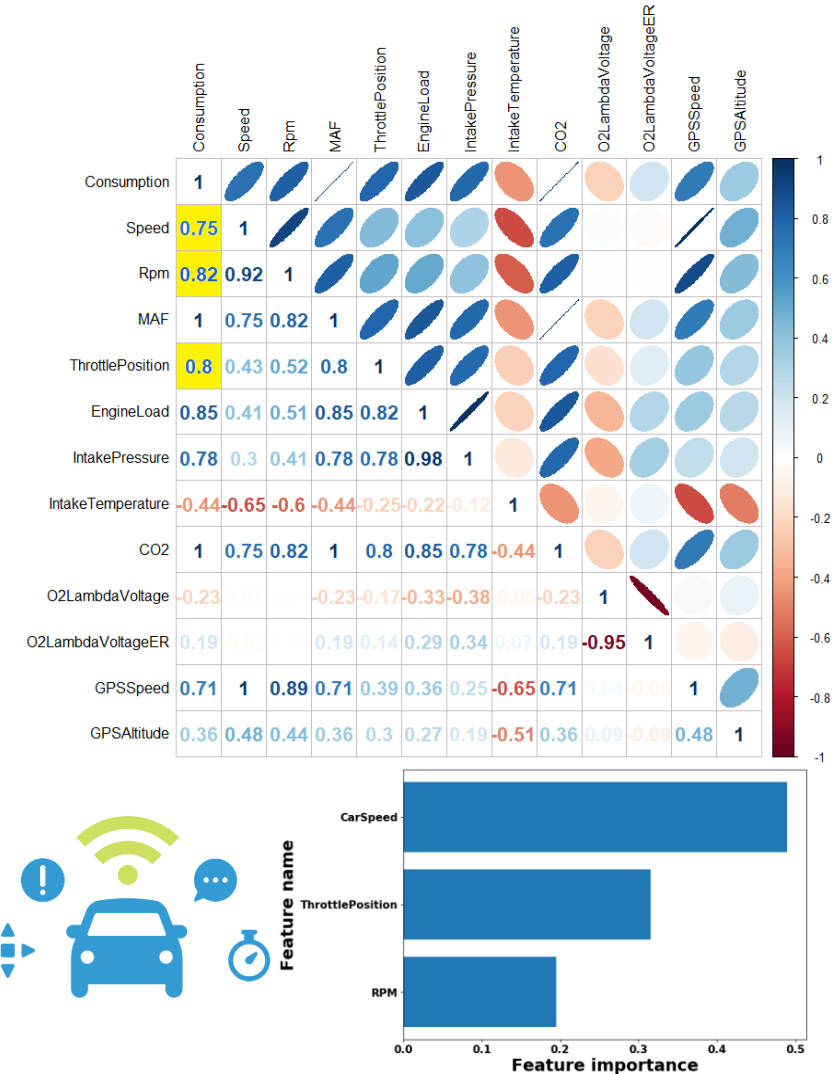
- **Objectives:** requirements, design and pre-deployment testing of a transportation bus as a Mobile Enterprise Sensor Bus (M-ESB) service in China 2 supports 2 main requirements: monitor urban physical environment, & to monitor road conditions. Integrating both environment & road monitoring & using a data exchange interface to feed a data cloud computing system is novel.
- **Method:** onboard information-gathering network (comprising sensors, sensor local area network and sensor access node including memory to store data and CPU), embedded gateways to upload on-board sensor data to access a IP backbone network & remote data-centre.
- **Results and Conclusions:** proposed a new management model for a bus company to act as a Virtual Mobile Service Operator. Pre-deployment testing was undertaken to validate our system



Car-driving Gamification 1

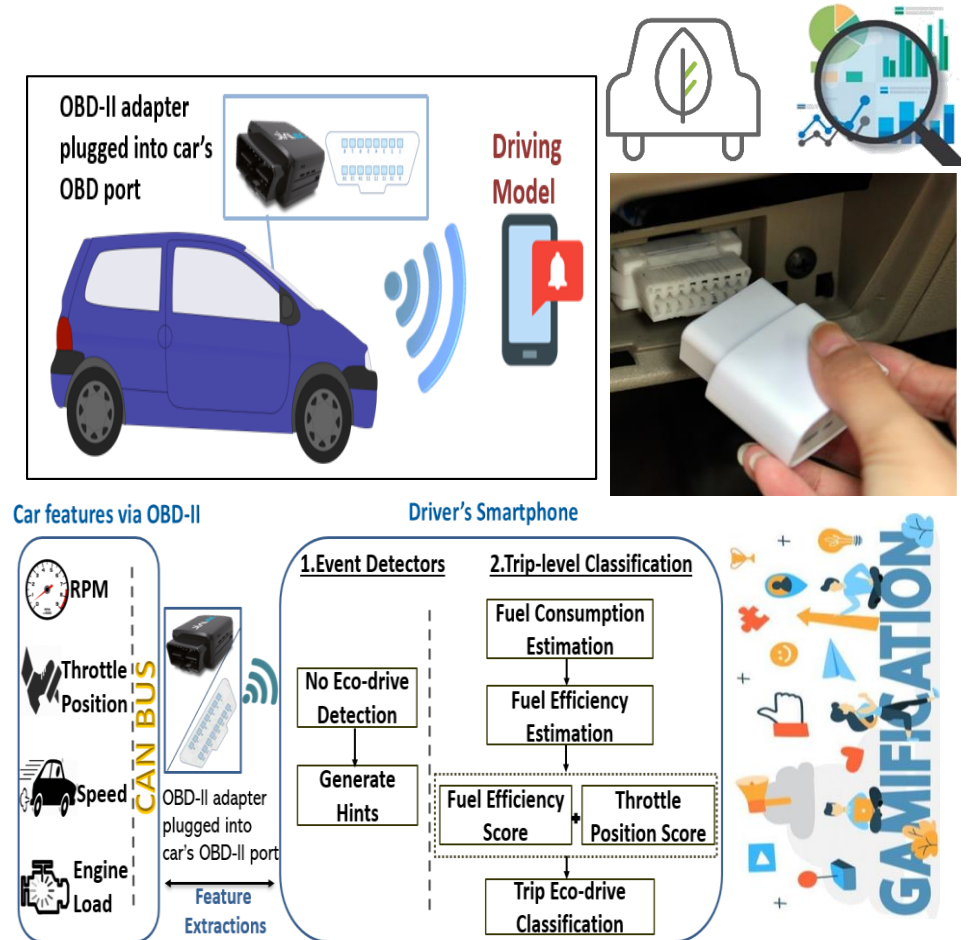
- **Focus and interest:**

- Access vehicular data via the Controller Area Network (**CAN**) bus, that can be queried through the automobile sensing and communication protocols, On-Board Diagnostics (**OBD**).
- Relying on **gamification** motivation to assist automotive drivers in promoting more fuel-efficient driving as vehicles become ever more powerful **IoT** platform.
- Need for **serious games** (**SGs**) in transportation: SGs' motivation towards behavior improvement (training and learning while having fun with virtual rewards mechanism).
- Naturalistic driving data analysis.
- Application of Artificial Intelligence (**AI**) and Machine learning (**ML**) towards sensing drivers' performance.



Car-driving Gamification 2

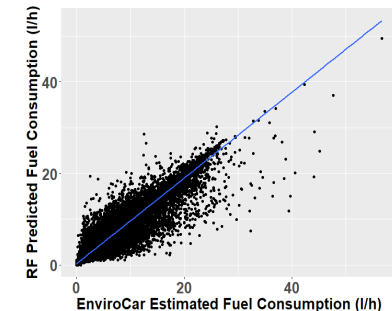
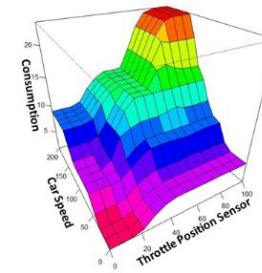
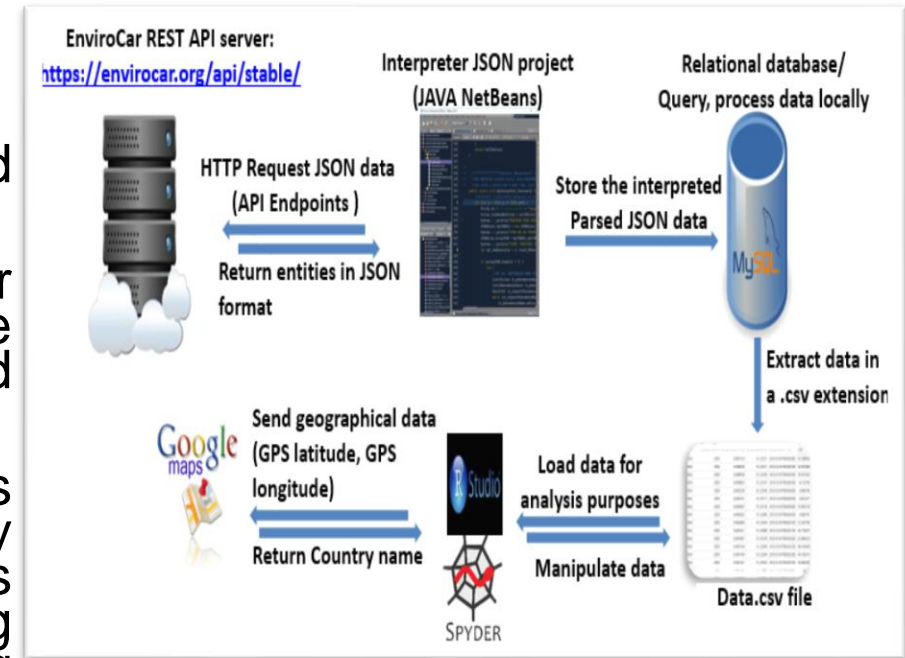
- **Objectives:** Process vehicular data in real-time (specifically on driving efficiency), used to assist automotive drivers in promoting more fuel-efficient driving.
- **Method:** Use Fuzzy Logic for real-time feedback while driving and use Random Forest for instant fuel consumption estimation (& quantitative value as a gaming mechanism, i.e., an updated score) relying on 3 On-Board Diagnostic-II signals throttle position, RPM and car speed. Categorise driving style after each trip based upon fuel efficiency and throttle position.
- **Results:** Those inputs are controllable by drivers & fuzzy rules can provide real-time advice for driver. Those inputs + engine load are able to predict fuel consumption.
- **Conclusions:** Combining fuel efficiency with throttle position values for a eco-driving classification allows considering how dynamic driving behaviour is sometimes affected by other factors. Gamification motivation can lead to positive eco-driving improvement.



Car-driving Gamification 3

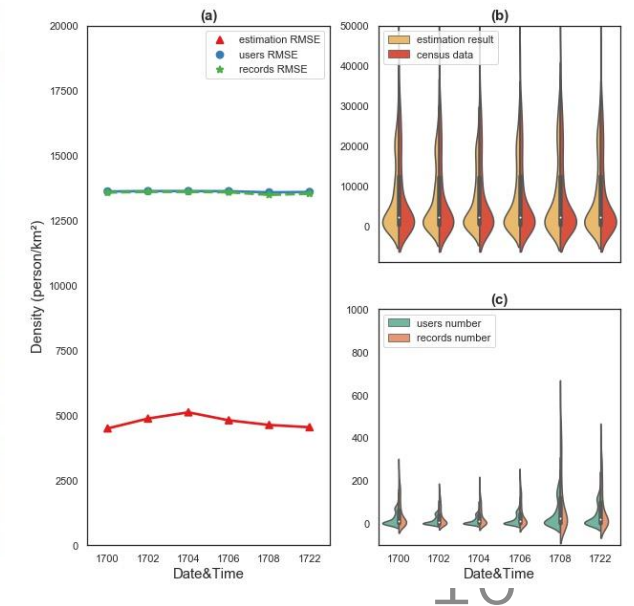
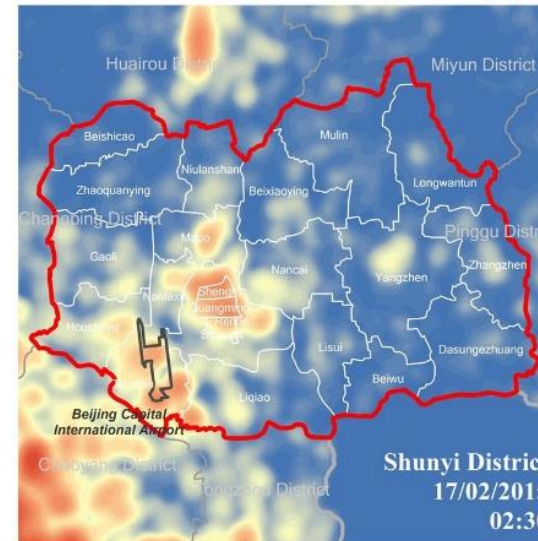
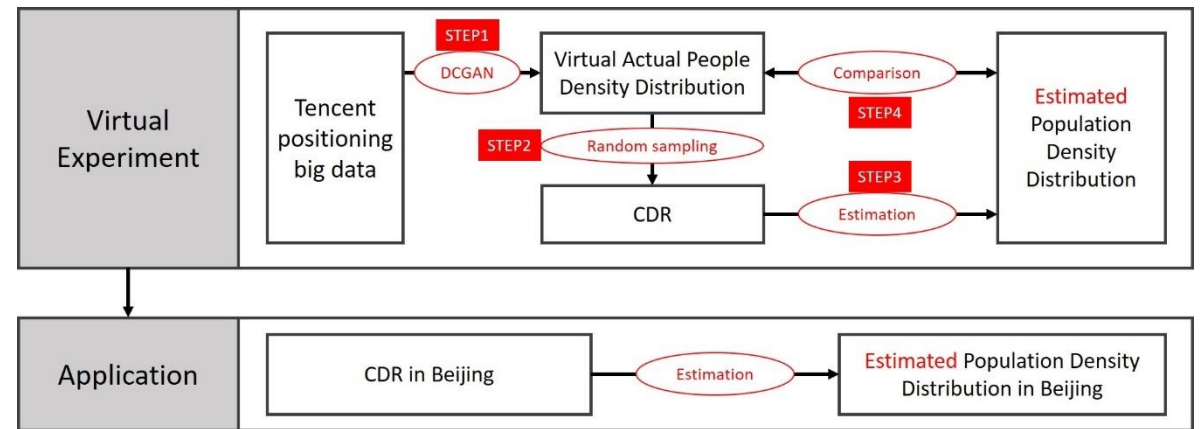
Key Outcomes (in more detail):

- Selected sensors that are affected by driving styles and affect strongly fuel consumption level.
- Provided real-time easy to understand feedback for common drivers in general, in case inefficient driving style attitude is detectable (avoiding driving distraction and irritation).
- Estimated fuel consumption with machine learning: this quantitative value is needing in estimation fuel efficiency for eco-driving categorization after each drive. Also, this quantitative evaluation is important as an ongoing updated score, to facilitate reaching a higher gaming level, or as a player's energy, etc.
- Improved fuel consumption models with more inputs and different tuned machine learning techniques.



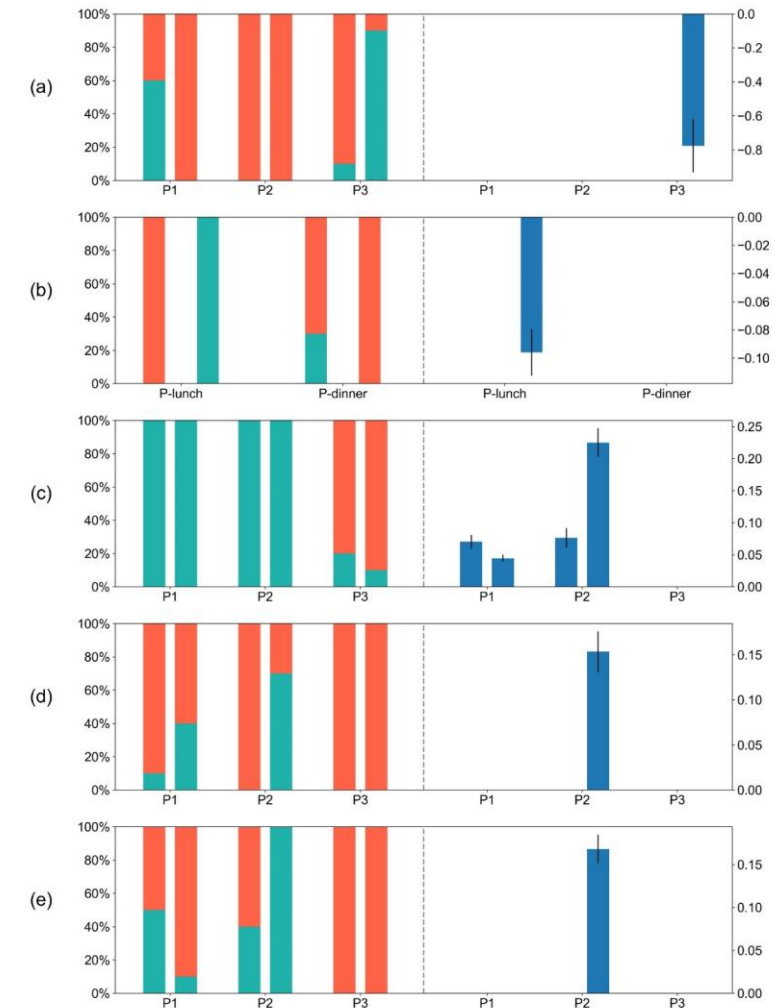
Estimating Large-scale More Finely-grained Temporal Spatial Human Population Density Distributions

- **Objectives:** raising a method to estimate more finely-grained temporal spatial population density distributions based upon mobile phone data.
- **Method:** deep convolutional generative adversarial networks (DCGAN), kernel density estimation (KDE), cosine comparison.
- **Results and Conclusions:** single-users-used number and single-records-used number with location have be compared with our method based on the census data in nighttime. Results also show the accuracy, authenticity and memory saving by our estimation method, where the RMSE is about 5000 while the other two distributions are over 13500. Process saves memory and comput. time to extract and analyze CDRs data but plays a detailed and effective performance, which is the reason why we regard our method as an fast and accurate approach.



How Air Pollution affects People's Activities during Daily Life, ADLs (in Beijing)

- **Objectives:** detect how air pollution affects people's daily routine activity in Beijing.
- **Method:** Using people's density, air quality and other control data to input fixed effect model to estimate the correlation coefficient which can reflect the relationship between the people's activity and air pollution.
- **Results and Conclusions:** air pollution puts negative impact on people's entertainment options in afternoon (2 -6 PM), while it put positive impact on people's house-stay options in morning (6 -10 AM) and hours in the middle of a day (10 PM- 2 PM).
- Air pollutions lower people's desire to go to restaurant for lunch but put little significant influence on the choice to have dinner in restaurant.
- When $PM_{2.5}$ increase $50 \mu g/m^3$, revenue of the restaurant would decrease 0.1 million RMB of whole Beijing.
- Transportation options are also affected: people tend to decrease walking & bike-riding itinerary but select bus or subway to avoid absorbing excessive polluted air.

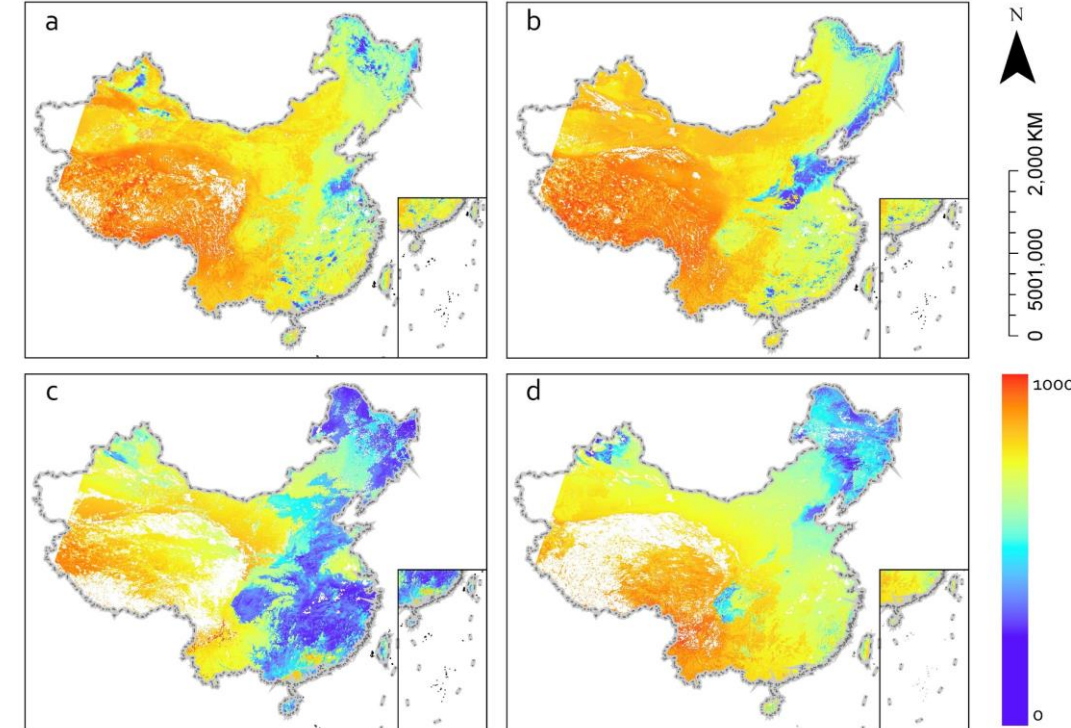
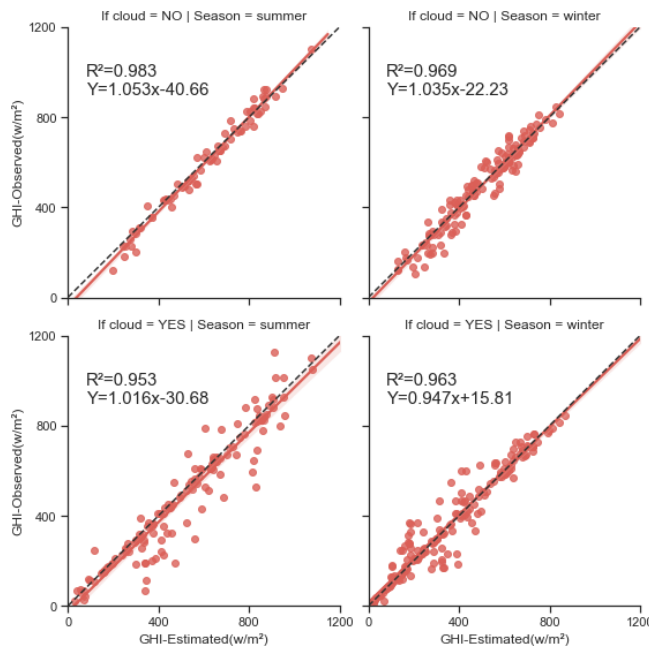


Estimating Global Horizontal Irradiance (GHI) to assess potential for solar energy

- **Objectives:** to estimate real-time GHI using a deep belief network (DBN) from satellite Images
- **Method:** we propose a DBN to estimate GHI under all-sky conditions derived from Himawari-8 satellite images with a high accuracy and high efficiency, and a high spatial and time resolution for a large geographical area.

Results and Conclusions:

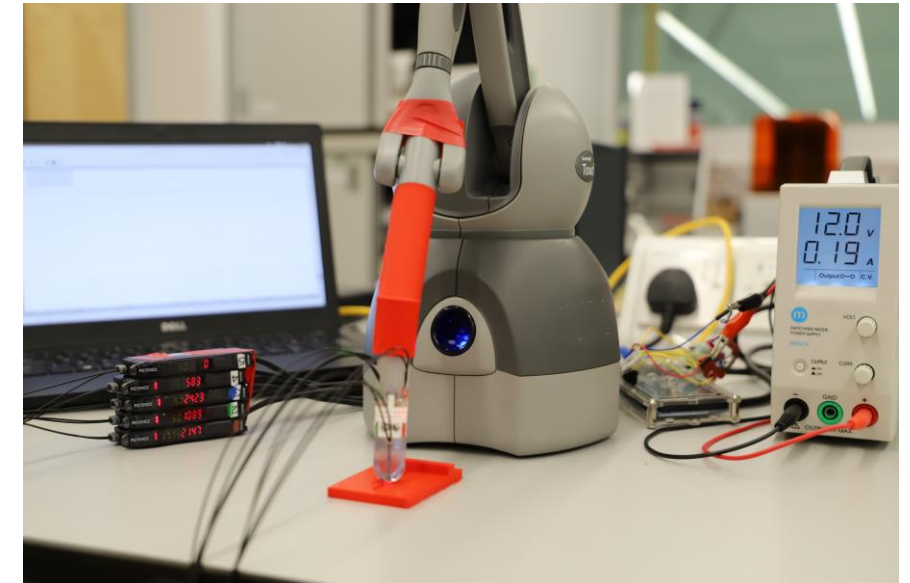
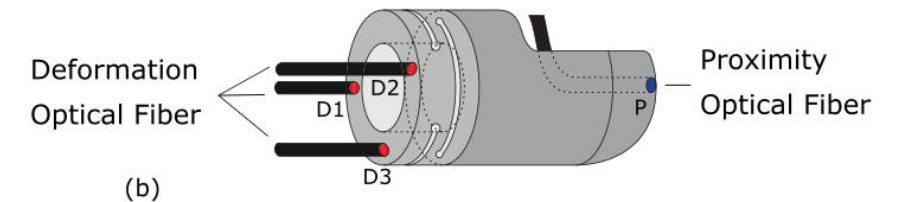
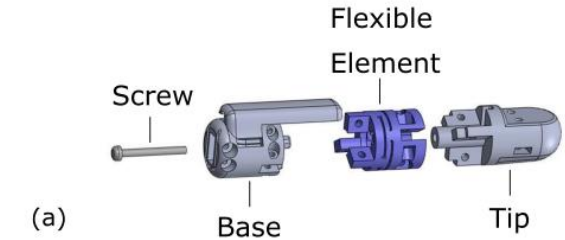
The results showed that our method could effectively estimate instantaneous GHI with correlation coefficients of larger than 0.95, and an overall RMSE between 30w/m^2 to 80 w/m^2 .



Our proposed a new method holds good promise for accurately estimating instantaneous GHI and conducting research on solar energy potential on flat areas.

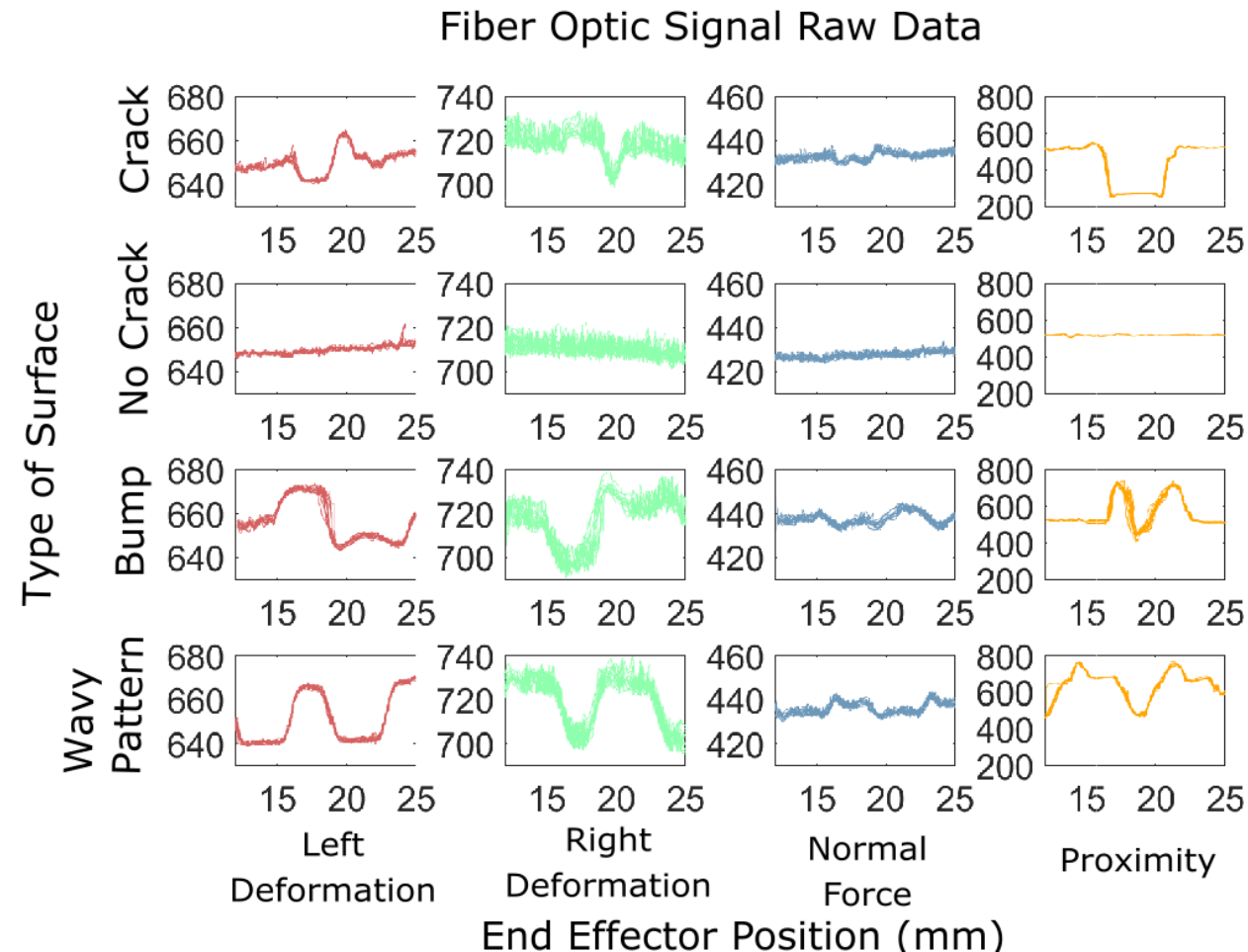
Sensing physical environment structural changes

- **Objectives:** Tactile and proximity sensing to perform automatic crack detection
- **Method:** Custom-designed integrated tactile and proximity sensor used to slide across different surfaces.
Data used to detect and classify cracks through the implementation of a Random Forest Classifier



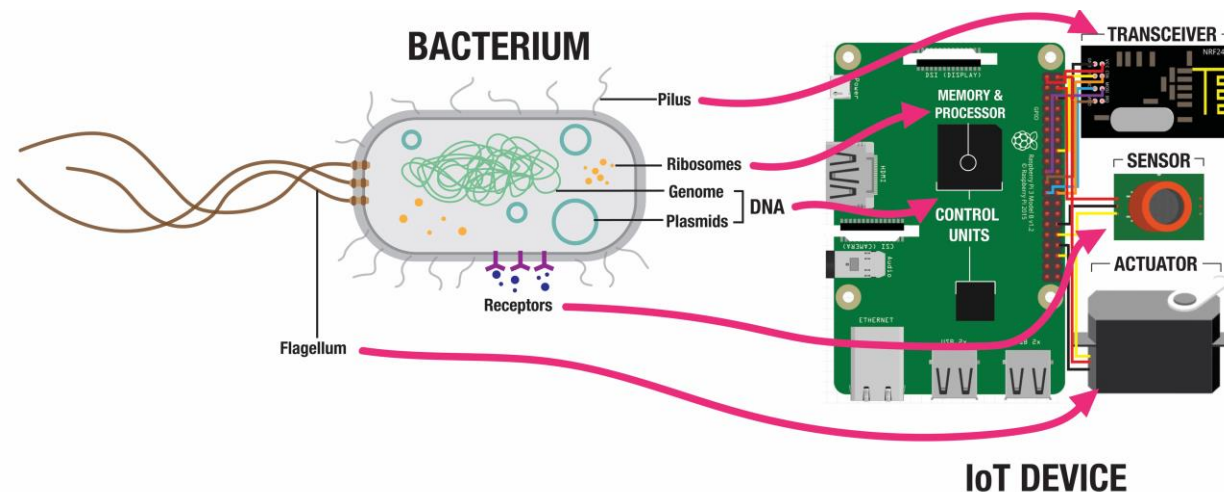
Sensing physical environment structural changes 2

- **Results:** Average crack detection accuracy of 86.46%. Kruskal-Wallis ($p < 0.001$) indicates statistically significant differences among results obtained with only force data, only proximity data and both force and proximity data
- **Conclusions:** In contrast to previous techniques, which rely on visual modality, the proposed approach is suitable for operation in extreme environments where nuclear radiation damages electronic components of video cameras



Internet of Bio-Nano Things (IoBNT)

- **Objectives:** Highlighting opportunities and challenges of integrating Bacteria in IoT
- **Method:** We compare and contrast features of bacterial cells with those of modern IoT devices.
- **Results and Conclusions:** Bacteria share features that serve common functions with electronic IoT devices
- Bacteria provide space efficiency, autonomous capabilities, replicability and ability to operate in remote and hazardous environments
- Scalability and stability of bacterial devices are current challenges
- Simple models and prototypes can be explored through DIY Biology communities and collaboration with professional biologists



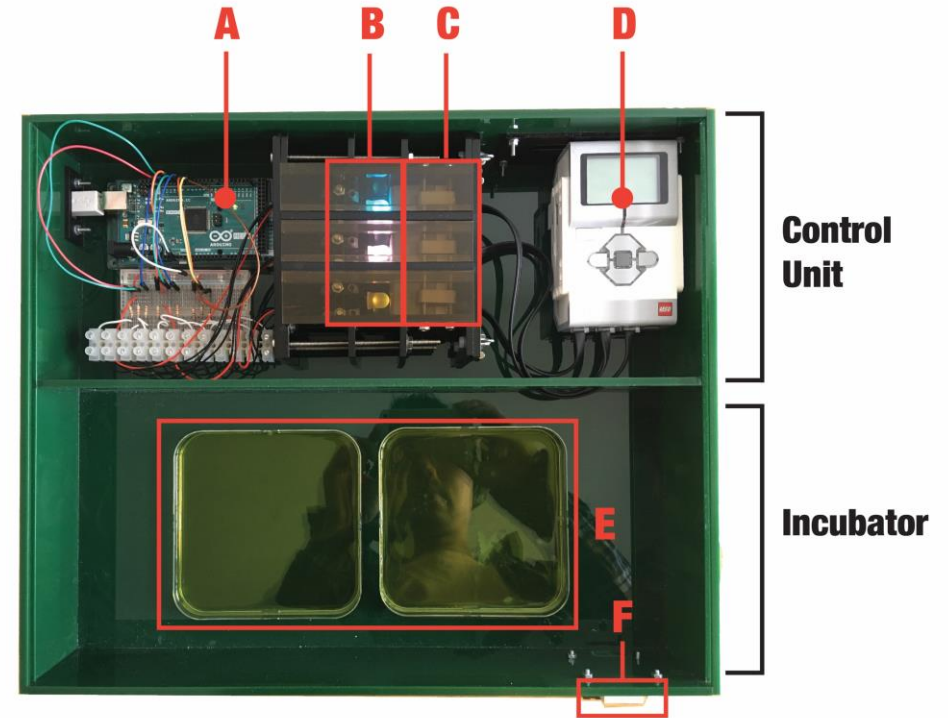
Player Experiences in Biotic Gaming

- **Objectives:** Measuring player experience (PX) dimensions in Biotic Game called Mould Rush
- **Method:** We compared PX measurements of a biologically integrated and non-biologically integrated game amongst 40 participants, through GEQ and participant interviews.
- **Results and Conclusions:** Biologically integrated game offered a significantly more positive playing experience, achieving higher GEQ scores in Flow, Immersion, and Positive Affect.
- Participant interviews suggest the reasons for positive PX in biotic games are novelty, aesthetics, and slowness of gameplay
- The results help in revisions of the game design heuristics to consider biological implications in gaming



Edutainment for Ubiquitous Bacterial Computing

- **Objectives:** Highlighting edutainment potential for ubiquitous bacterial computing and introduction of new biotic game console, MouldCraft
- **Method:** We presented arguments for the opportunities for edutainment in ubiquitous bacterial computing
- **Results and Conclusions:** MouldCraft is a biotic game console that allows playful interactions between humans and micro-organisms through a smartphone
- MouldCraft allows exchangeable DNA components that can change mechanics of biotic gameplay
- Set of game ideas with micro-organisms were presented
- MouldCraft is controlled by remote users through smartphone



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See the IoT lab publications for more details about our studies

If you have a IoT-ES, DCS challenge, we invite you to consult with us at the IoT2US Lab.

Appendix: Past (before 2015) Env. Sci. Studies

- Collaborative, Complex and Critical Decision-Support in Evolving Crisis (TRIDEC, 2011-2013)
- Environmental Data Exchange Network for Inland Water (2002-4)

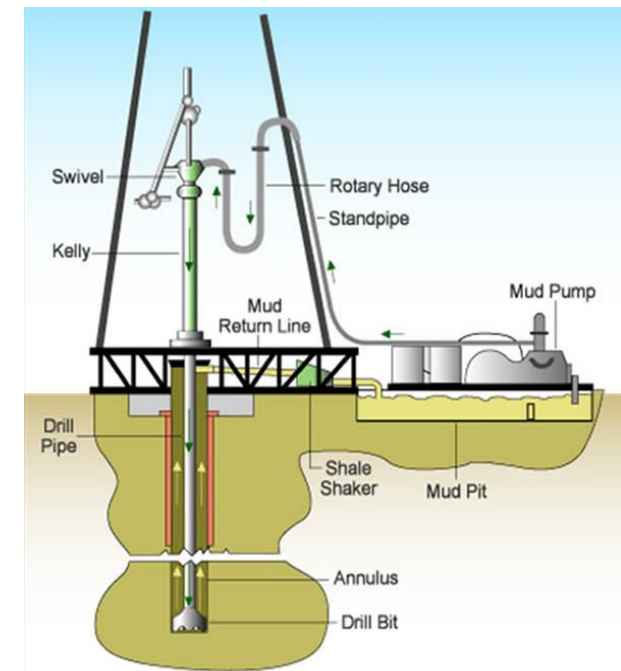
Collaborative, Complex and Critical Decision-Support in Evolving Crisis (TRIDEC, 2011-2013)

- **Objectives:** Adaptive framework for collaborative information management adding innovative functions for the support of complex decision support processes
- **Method:** AQMP (Advanced Message Queuing Protocol) distributed message broker platform was used to support resilient, scalable info. sharing between many sensor data publishers and many data subscribers to process & present the data combine with use of a semantic registry
- **Results and Conclusions:** TRIDEC demonstrator at the Meteorological, Climatological and Geophysical Agency (BMKG) in Jakarta, Indonesia, 2013 . This was accompanied with the installation of hardware and the deployment of software components, which were configured and adapted to the local conditions. After the integration of the existing sensor network and extensive subsequent system tests, the demonstrator was handed-over to the BMKG staff for use.

Offshore Buoys (Tsunami warning)



Subsurface Drilling Rigs



Environmental Data Exchange Network for Inland Water (2002-4)

- **Objectives:** To realise an early Web-accessible service for inland water monitoring data
- **Method:** Mult-agent based system was used for the information exchange system core.
- **Results and Conclusions:** Start-up services agents were registered, Users entered query at UI (multi-lingual, EGV terms). Query propagates through the agents sniffer, terminal o/p). User sees the result at UI

Inland Water Quality

