
ICRI
2012
2015

INTEL COLLABORATIVE RESEARCH INSTITUTE FOR SUSTAINABLE CONNECTED CITIES

OCT 2012- OCT 2015

Prepared December 2015

Imperial College London

UCL

VISION

ICRI CITIES WILL DELIVER RESEARCH THAT EXPLORES HOW TECHNOLOGY CAN ENHANCE QUALITY OF LIFE FOR CITIZENS, CREATE NEW ECONOMIC OPPORTUNITIES AND IMPROVE THE ENVIRONMENTAL WELL BEING OF CITIES.

THIS REPORT

ACHIEVEMENTS

ICRI Cities delivers outstanding research recognised by industry and academia. The achievements sections highlights our proudest moments over our first three years.

ICRI CITIES

An overview of the Intel Collaborative Research Institute is provided as context for our research focus and the background to the Intel ICRI / ISTC programme.

RESEARCH + LIVING LABS

Our work focuses on the role technology plays in creating resilient urban environments, economies and communities. This section provides an overview of all our projects.

PUBLICATIONS+ ENGAGEMENT

We publish our research in journals, conferences and workshops, and document our work through film and social media. Our 104 papers and collection of videos are highlighted here.

ICRI PEOPLE

At the heart of the ICRI are a group of fantastic researchers from various disciplines. Here we provide an overview of the key ingredient that made the ICRI a success.

FUTURE AGENDA

As we transition into years four and five of the ICRI our work becomes more focused and moves into new parts of the city. Our planned activities are described here.

CONTENT

FOREWORD

PROF. MARTIN CURLEY

VICE PRESIDENT, SENIOR PRINCIPAL ENGINEER,
DIRECTOR, INTEL LABS EUROPE

I am very pleased to see the publication of the 2012-2015 report summarizing the discovery phase of the Intel Collaborative Research Institute for Sustainable Connected Cities based in London. We live in an era of transformation where the collision of mega trends such as Moore's law, Mass Collaboration and Sustainability are creating the conditions for disruptive change and the ICRI is perfectly situated to capitalize on this opportunity. Using London as a test bed, Intel and our partners UCL and Imperial College are researching and advancing the state of the art of deploying Urban IOT for transformation, aligned with the Smart London Plan.

The ICRI exemplifies the principles of Open Innovation 2.0 with a shared vision of urban transformation focused on the triple bottom line of economic, social and environmental value as well as involving actors from across all parts of London society and beyond. As an example the research of the ICRI has materially impacted the development of the Intel® IOT platform as well as demonstrating how cities and city life could be improved in the future.

Following three years of successful operation, discovery and outcomes from the ICRI we are now entering a capstone phase, where in partnership with the London Legacy Development Corporation we will blanket the Queen Elizabeth Olympic Park in IOT devices with a goal of transforming the park operation, user experience and sustainability. A new core ICRI partner on the capstone phase is the Innovate UK's Future Cities Catapult and this will further strengthen the ICRI. A perfect storm of disruptive technologies such as the Internet of Things, Cloud Computing, Big Data is creating unparalleled opportunities to put high precision, high frequency 'closed loop' controls circuits in place for societal systems where previously only 'open loop' control was possible – the capstone investment gives us the perfect test-bed to test and demonstrate this in action.

I would like to thank all our ICRI researchers, collaborators and members of the associated ecosystem for their engagement and efforts. Together we are pathfinding the way to a future of sustainable intelligent living.

CHARLES SHERIDAN

DIRECTOR, INTERNET OF THINGS SYSTEMS RESEARCH LAB, INTEL LABS EUROPE

THE WORLD IS EXPERIENCING 2 MEGA TRENDS THAT SHALL HAVE A PROFOUND EFFECT ON THE SHAPE OF SOCIETY AND CITIES IN THE FUTURE.

1 We are experiencing the largest demographic population shift in history, driven by the mass movement of people from rural to urban centres.

2 The rise of the Internet of Things (IoT) driven by the explosion in growth of connected things – projected to reach 50 billion+ devices by 2020.

Both these mega trends converge in our cities and through the Intel ICRI Cities in partnership with UCL, Imperial College, Future Cities Catapult and many London stakeholders we have been driving a focused research agenda and Living Labs methodology to enable a Smart and Connected Society. Documented in this report are the many projects conducted over the first three years of the Institute. The breadth of projects covering the socio economic and political challenges of deploying technology in the urban environment is testament to the diversity of the researchers who define the ICRI.

Intel Labs Europe is proud to have been founding member of this world leading institute with our research partners.

ANTHONY FINKELSTEIN

CHIEF SCIENTIFIC ADVISER TO HM GOVERNMENT
PROFESSOR OF SOFTWARE SYSTEMS ENGINEERING,
UNIVERSITY COLLEGE LONDON

The disruptive potential of IoT technologies is now well understood but we have much less understanding of how the interplay between changing technology, changing cities and changing human behaviours will shape that disruption. ICRI cities eschews the simplistic 'build it and they will come' approach of too much research in this area. Instead it drives innovation by looking at real deployments and real users. It takes account of the way technology is coopted by users to their own goals. This sort of work is only possible through collaboration between Intel and world-leading university institutions in a global city.

ACHIEVEMENTS

ICRI CITIES DELIVERS OUTSTANDING RESEARCH RECOGNIZED BY INDUSTRY AND ACADEMIA. WE BRING TOGETHER RESEARCHERS FROM INDUSTRY AND ACADEMIA IN AN OPEN IP ENVIRONMENT TO RESEARCH, COLLABORATE AND BUILD SYSTEMS FOR DEPLOYMENT IN THE FIELD. WE ENHANCE THE VISIBILITY OF INTEL WITHIN FUTURE CITIES RESEARCH, WE PROVIDE CREATIVE APPROACHES TO THE USE OF TECHNOLOGY IN AN URBAN CONTEXT AND CONTINUE TO INNOVATE THE IOT TECHNOLOGIES REQUIRED TO DELIVER SUSTAINABLE CONNECTED CITIES.

IMPACT TO INDUSTRY

ICRI Cities contributed to the early stage development and delivery of Intel's first end to end IoT reference platform in 2014.

Technology insights and innovations learned from Living Labs deployments influenced an IoT Gateway design for Plug n Play sensors that led to an Intel Labs Europe technology transfer to the Intel Internet of Things Group and planned product launch in Q1 2016.

Data validation and field testing of 131 Galileo (Gen 1) IoT gateways at scale provided technology insights and recommendations for future product enhancements to Internet of Things Group and New Devices Group.

Living Labs stakeholder engagement research and use cases feature in Intel Labs UX cross lab working group and Intel Developer Forum demos.

The ICRI helps drive Intel's position as thought leader in Smart Cities activity through continued engagement as advisors (e.g. Smart London Board) and as through industry recognition such as the 2014 Frost & Sullivan Global Smart City Infrastructure Emerging Market Innovation Award.

IMPACT TO RESEARCH COMMUNITY

104 published papers; 6 in top tier journals with impact factors of 2 and above, with a further 7 in peer-reviewed conference papers, 3 honourable mentions at CHI, 2 in top ranked computing magazines and 2 best demo awards.

Produced the first mobile phone-based opportunistic networking scheme that not only achieves proven optimal routing in terms of throughput and data rates but also rewards the phone-user via a virtual market. Our work does not need to record past performance to predict future relay opportunities and provides a reward to the phone user that compensates for any costs incurred, all in a decentralised scalable way. This scheme outperformed pure backpressure and pure social-aware schemes with perfect future knowledge.

Produced the first fully distributed solar powered WSNs power management system that maximises rate allocation continuously, outperforming state-of-the-art approaches by factor 10. That is, the state of the art approaches achieve 2 days under the same conditions and we ran our experiment for 14 days without disruption.

Opportunistic work extended with Mechanism Design principles to discourage phones to mis-report their capabilities. Experiments with Android phones and trace-driven simulations verify our theoretical analysis and demonstrated that our approach improves performance significantly (around 100%) while confirming that our system achieves incentive compatibility, individual rationality, and server profitability.

Produced a validated sensor data trust framework that was validated using real datasets and was shown to help achieve robust in-network processing, decreasing the deviation from the 'true' averages by 87% and at the same time continuing to detect sensor failures.

Produced the first fully distributed and optimal wireless cross-layer cooperative network system, demonstrating an 88% performance improvement over state-of-the-art approaches.

Study of Smart Citizen showed 70% of the sensors bought via crowd funding were not reporting any data. 72% of survey respondents said they hadn't used their sensors due to technical difficulties, lack of time to set them up, or that they never intended to use them as they crowd funded the project due to sympathy with the instigators or the projects values. Crowdsourcing provides cost effective ways to obtain and communicate urban data but we need to understand how to motivate citizens to engage in such socio-technical schemes.

Through our deployments of several 'physical questionnaire systems' in different settings (Voxbox, Small Talk, Sense-us, Mill Road) we have learned that we can design and use novel interactive technologies that encourage citizens to give their views and opinions, in contrast to traditional survey methods that have been less successful or automated sensor-based systems that would fail to capture detailed, qualitative and nuanced responses.

Crowd-sourced data (both passive – e.g., via sensors that people carry with them, and active – e.g., via user explicit data input) is relied upon extensively to accomplish a variety of tasks cheaply and at scale (for example, to monitor noise pollution, or citizens' happiness). We have shown quantitatively that such data suffers from a number of biases, due to the fact that self-selected volunteers are producing it. We have developed metrics to quantify different bias forms (e.g., cultural, geographic, economic, social) in such geographic datasets.

SCALING OUR INVESTMENT

A key measure of the success of the ICRI Cities in creating a London based research ecosystem has been the leveraging of the $3m investment by Intel during first 3 years to over $11.5m in funded research activity at the institute (funding bodies included: EU FP7, EU H2020, Innovate UK, EPSRC, EU EiT).

In addition our Living Labs activity led to Intel being identified as a key partner to deliver IoT test beds for EU H2020 research, leverage a co-investment made by Future Cities Catapult to scale across multiple stakeholders in London and is promoted by the Smart London Board as an exemplar smart city project.

TECHNICAL INNOVATION:

London Living Labs projects in Hyde Park and Enfield provided the proving ground for the deployment of the air quality sensor platform that informs the design of Intel's new IoT platform. The London team supported deployment testing, data validation and API requirements and testing.

Participated in Ofcom trial on TV White Space in London which is among the first of its kind in Europe.

Developed proofs of concept using our lightweight Sensing Uncertainty Metric that indicates sensor accuracy and trust levels.

Creation and evaluation of VoxBox, an IoT system for gathering crowd opinions at public events. VoxBox was realised using open-source hardware and software and was designed to be modular and adaptable. VoxBox was evaluated in the wild at four events and was used by members of the public over 200 times

Produced an optimal assignment algorithm for the SDN controllers in wireless city environments to enable them to match the best available access points to IoT devices using Crowdsourcing.

Designed and implemented the Android support for low-power, secure, and always-on device-to-device communication, based on Bluetooth Low Energy (BLE) and WiFi direct.

DISTANCE deployed connected devices into over 10 schools across the UK. The gateways used an early version of Palmerfield and the Wind River build on Galileo. Devices included weather stations and air quality monitors.

Co-authored the first open-source toolkit for energy disaggregation: NILMTK.

Developed a mobile network Crowdsensing system that maintains data integrity using Mechanism Design Theories to discourage participant cheating behavior while optimizing opportunistic wireless resources.

Developed a fully distributed algorithm for real-time anomaly detection in sensing data streams, and successfully applied this approach to the detection of false data injection attacks in smart grid systems.

HuddleLamp enables citizens to join their mobile devices and by this create new forms of fun and social data exploration in semi-public spaces (e.g. libraries, museums, schools). Mobile devices are temporarily turned into spatially-aware displays as parts of a multi-device system without any prior installation or configuration by users. This is achieved using off-the-shelf Intel hardware and free and open source software.

Designed a novel programming approach to designing scalable systems for the City Internet of Things that automatically determines the minimal set of and will produce image code for the nodes that compose the network, cloud to edge, ensuring type soundness.

Mood Squeezer was one of the first studies to explore moods and the role of play in work environments with tangible IoT. It involved a 5 week, in the wild deployment of multiple connected technologies within a commercial premises in the Canary Wharf area of London.

AWARDS

WON BEST DEMO AT BUILDSYS 2014 FOR NILMTK ENERGY TOOLKIT

TWO HONORABLE MENTION AWARDS, ACM CHI'14 (TOP 5% OF PAPERS)

"SMART DUST" VOTED TOP VIDEO IN THE IMPERIAL TECH FORESIGHT FUTURE VISION COMPETITION AND WAS PRESENTED LIVE IN THE 2034: TECH FORESIGHT EVENT

2014 FROST & SULLIVAN GLOBAL SMART CITY INFRASTRUCTURE EMERGING MARKET INNOVATION AWARD

BEST DEMO AWARD, ACM INTERACTIVE TABLETOPS AND SURFACES'14, DRESDEN, GERMANY - HUDDLELAMP: SPATIALLY-AWARE MOBILE DISPLAYS FOR AD-HOC AROUND-THE-TABLE COLLABORATION

ICRI CITIES

PROGRAMME

WHAT IS AN ICRI?

In the spirit of Intel's U.S.-based Intel Science and Technology Centers (ISTCs), Intel Collaborative Research Institutes (ICRIs) are collaborative research initiatives among Intel (the founding sponsor), other sponsors (including either companies or governments), and leading universities in specific countries or regions worldwide.

Each Institute focuses on a specific technology area or discipline, bringing together a community of top researchers from across academia. Each Institute is funded by Intel and potentially other sponsors for up to five years. With a significant investment going directly to the participating universities, the Institute's academic participants play a leading role in setting and driving institute research agendas.

WHY DID INTEL DEVELOP AND ADOPT THE COLLABORATIVE RESEARCH INSTITUTE MODEL?

Intel derived the ICRI model to engage a broad set of universities and leading academics in a way that would be responsive both to new sponsor imperatives and to research advances realized within academia. Further, Intel wanted to significantly expand and strengthen collaboration between leading academics, companies, governments, and Intel's internal research community. The features of the ICRI model are designed with these goals in mind.

Maximizing the breadth and depth of intellectual exchange requires that sponsor researchers spend significant time at the ICRI's participating universities and, in turn, that academic researchers, including post-docs and interns, spend significant time at Intel. Although each sponsor may use a different internal approach, at Intel, to ensure direct communication and intellectual engagement, the ICRI will report into the Intel Labs research division that is best aligned with the research objectives of the institute.

ABOUT

EACH YEAR INTEL LABS INVESTS IN SEVERAL INDUSTRY / ACADEMIC RESEARCH CENTRES GLOBALLY. THE AIM OF THAT INVESTMENT IS TO DEVELOP THE RESEARCH ECOSYSTEM THAT WILL BE SIGNIFICANT FOR THE FUTURE BUSINESS OF INTEL.

The investment in the Sustainable Connected Cities Institute reflects an increasing market desire to deliver systems at a city scale. This trend is enabled through our increased ability to sense and understand our environment. Technology is enabling the use of data as a new material to support connectivity and the shaping of our urban environment.

The Technology Strategy Board estimate that by 2030 the global market for integrated city systems will be £200 billion. The research output from ICRI Cities provide first probes into our understanding of how we can deliver the anticipated systems.

WHY LONDON

THE MOTIVATION FOR LOCATING IN LONDON HAS BEEN DRIVEN BY 3 KEY FACTORS:

The position of London as a diverse, cosmopolitan and complex city provides the perfect environment for exploring many of the issues facing western cities

The external investments being made in developing London as a centre for research on “future cities” (e.g. UK government’s Technology Strategy Board / InnovateUK)

The presence of two world class academic institutions (UCL and Imperial) and the established creative, design and financial sectors.

London is on of the largest cities in the world; it has the largest GDP in Europe and with over 300 languages and 200 ethnic communities. Its diversity offers an exciting test bed to create and define sustainable cities. The institute engages with local communities to understand how they want to live in their cities and involves them in co-designing technological innovations.

London forms the initial focus of activity, but it is our vision that the ICRI will develop into the hub at the centre of an ecosystem of partnerships with other institutes, companies and cities around the world focused on Sustainable Cities.

3 GUIDING PRINCIPLES

ICRI CITIES IS FOUNDED ON THREE GUIDING PRINCIPLES:

DESIGN FOR HUMANS

– AS PART OF THE SOLUTION

BUILD FOR THE LONG TERM

– DESIGN ROBUSTLY FOR THE IMPERFECTIONS OF THE REAL WORLD

DELIVER THE TRIPLE BOTTOM LINE

- SOCIAL, ECONOMIC AND ENVIRONMENTAL VALUE

Compute technology in the urban environment will develop as a mix of centrally controlled ubiquitous systems and organically developed distributed platforms. Designing for a blended interaction where creases in the system present opportunities rather than silo'd disfunction is our goal. Future platforms require a more adaptive highly distributed environment that intelligently directs data from a variety of fixed, mobile and participatory sources, in the format required by each of the interested parties (e.g. utility managers, local community groups, emergency services, road network maintenance etc).

We strive for a better understanding of how cyber-physical systems behave in urban environments across time, competing human stakeholders and disruptive events. The key differentiator in our approach is - rather than mitigating unreliability we will embrace it. The city platforms of the future need to accept that data may be inaccurate due to lack of precision, or loss of calibration, and build systems that understand this and either overcome this problem or at least recognizes it exists and acts accordingly. It will need to do so with a metric that indicates its trustworthiness so that the destination services know how to treat the data.

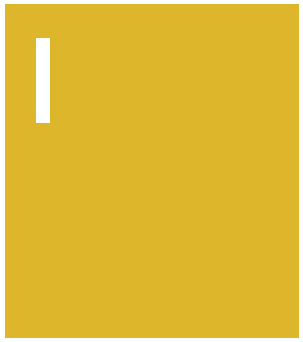
From the outset we have endeavoured to bring together collaborators from industry, academia, government and citizens. Our projects thrive on having multiple stakeholders engaged so that we can understand the long term sustainability of the projects in terms of social, technological, economic, environmental and political factors. We sustain this approach through recruiting and collaborating with staff with broad multidisciplinary backgrounds.

RESEARCH + LIVING LABS

RESEARCH + LIVING LABS

WE ARE INTERESTED IN THE ROLE TECHNOLOGY PLAYS IN CREATING RESILIENT URBAN ENVIRONMENTS, ECONOMIES AND COMMUNITIES. OUR GOAL IS TO DEPLOY TECHNOLOGY IN A WAY THAT ENSURES CITIZENS CAN TRUST DECISION-MAKING SYSTEMS AND PARTICIPATE IN THE CREATION OF THE VALUE NETWORKS THAT ARE REQUIRED FOR THE DEVELOPMENT AND ACCEPTANCE OF FUTURE CITIES INFRASTRUCTURE.

WE SELECTED THREE PRIMARY RESEARCH THEMES TO FOCUS OUR EFFORT:



CITY AS A PLATFORM:

What techniques and schemes can be used to make the notion of an elastic City Platform that offers scalable, safe, reliable and cost-effective ways of monitoring, supporting and enhancing urban infrastructures and ecosystems?

HARNESSING THE INVISIBLE CITY:

How can technology help recognize, leverage, visualise and support the out-of-sight, hidden or forgotten resources and data flows of urban environments for optimisation and informed decision making by city managers, businesses and citizens?

ENABLING CONNECTED COMMUNITIES:

How can technology help us innovate with emerging ideas of community, work, leisure, place and identity yet protect privacy in a city of a billion sensors? How can novel human-environment interfaces encourage sustainable behaviours in the long term after the subsidies run out?

THE ICRI HAS A BROAD PORTFOLIO OF PROJECTS WITHIN THESE THEMES FROM A DIVERSE GROUP OF RESEARCHERS. WE DESCRIBE THREE TYPES OF PROJECT:

FELLOW TRAVELLER COLLABORATIVE PROJECTS

The ICRI has attracted interest from different researchers in the UK and more broadly across Europe. We have several projects that are funded by national and European funding councils. These projects have allowed us to bring in more staff into the ICRI and have provided the foundation for our collaborative work.

CROSS INSTITUTE LONDON LIVING LAB (L3)

Our work on L3 has provided the cornerstone for many of our cross ICRI discussion and has provided the focus to test the research developing in the institute. We have explored energy saving routing protocols, observing community engagement and data visualization.

FOCUSED RESEARCH PROJECTS

Our eight funded PhD researchers provide a depth of research that comes from undertaking a PhD. Their research questions are directed by the PI's and all build on the themes developed in the institute.

PROJECTS

CROSS INSTITUTE

PHD RESEARCH

CROSS INSTITUTE

LONDON LIVING LAB

"WHAT THE [INTEL] SENSORS GIVE US AN OPPORTUNITY TO DO IS TO LOOK AT THE WHOLE PICTURE. SO WE MOVE BEYOND JUST LOOKING AT THE TRAFFIC ISSUE, AND START TO GET A BROADER PICTURE OF WHAT'S GOING ON, AND EXPLORE OTHER AREAS OF AIR POLLUTION THAT TODAY HAVEN'T REALLY BEEN THOUGHT ABOUT," SAYS NED JOHNSON, PRINCIPAL ENVIRONMENTAL HEALTH OFFICER AT ENFIELD COUNCIL, GREATER LONDON.

The London Living Labs is a city scale environment that is instrumented to enable experiments to be carried out in situ. It has been established by Intel, the Future Cities Catapult, researchers at ICRI Cities and a collective of local stakeholders in the city.

The environments include schools, parks and city neighbourhoods, which are instrumented using an Intel Galileo-based end-to-end Internet of Things infrastructure and informed through an ethnographic research process. Our multi-layered, people-centric approach helps us to better understand and design for a range of scenarios and use cases with communities, city officials and stakeholders to help design for the connectedness and sustainability of future cities. The current installation base is 120 gateways servicing about 600 sensor end points. Locations include Hyde Park, Enfield, Brixton, Elephant and Castle and Tower Bridge. Further deployments are in progress in Manchester, Peterborough, Dublin and San Jose.

The low cost Intel gateways developed to connect a broad array of sensors are providing a steady stream of data which is contributing to a quantified community. Building an end-to-end solution that supports the addition of heterogenous sensors and the hooks to allow developers to build tools and services via the Mashery-based API allows us to quickly prototype applications and support interventions in the community.

FORWARD RESEARCH QUESTION

How can we instrument the city without the constraints and cost of a fixed infrastructure? See page 62

How can we help different stakeholders make sense of all these data? See page 52

TOWER BRIDGE

WHAT IS THE IMPACT OF VEHICULAR IDLING WHEN TOWER BRIDGE IS RAISED AND CAN WE NUDGE DRIVER BEHAVIOUR THROUGH ROAD SIDE SIGNAGE?

Partners: Southwark Council, Aecom, Future Cities Catapult

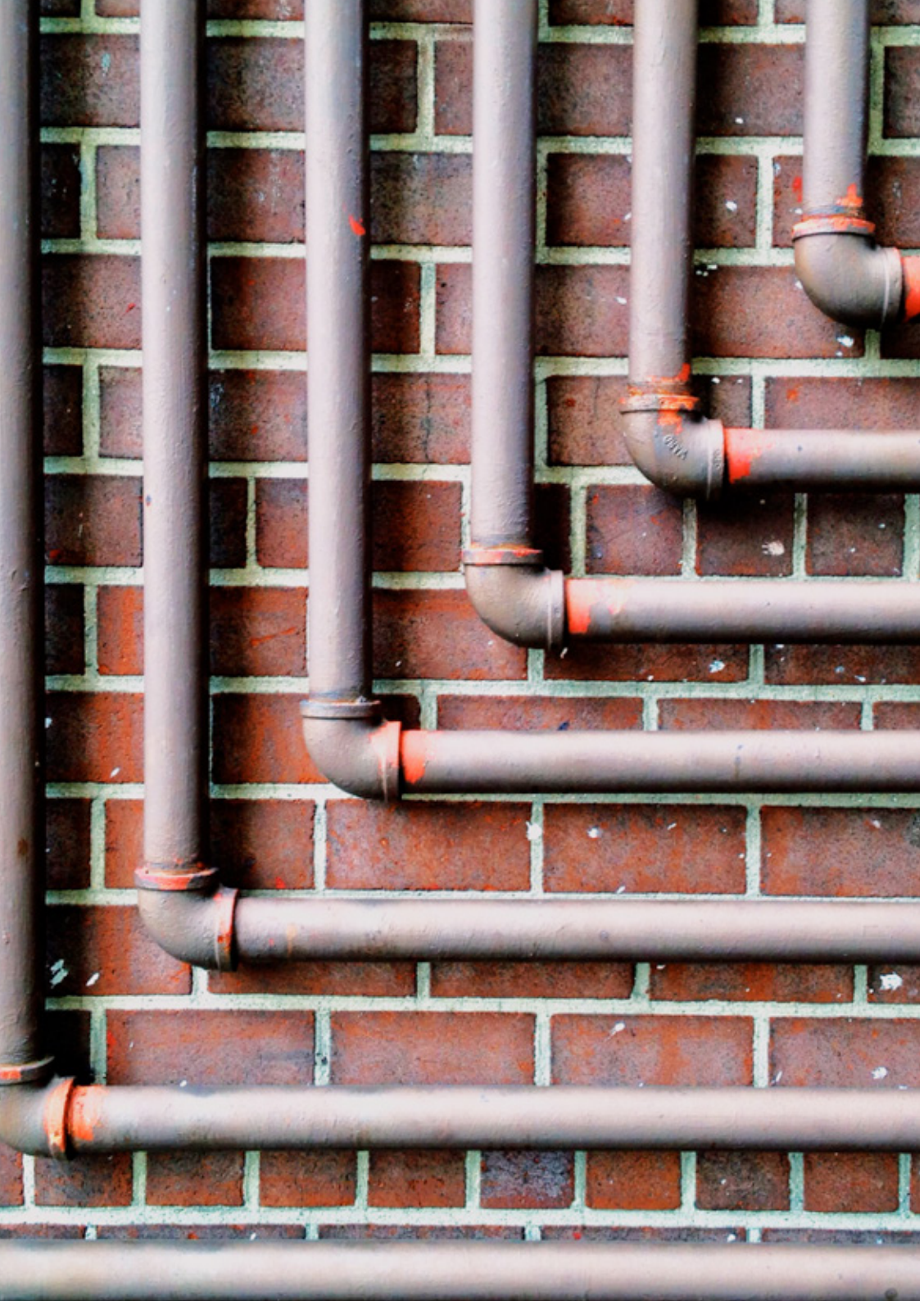
What is the impact of vehicular idling when Tower Bridge is raised and can we nudge driver behaviour through road side signage?

Working with Southwark council we are installing sensors on Tower Bridge road to measure the air quality when the bridge is raised and the potential for behavioural interventions using targeted, real-time public signage.

Six Intel gateway devices have been installed along the southern access road at increasing distance from the Bridge. The data from the sensors plus information from the bridge management system (open / close periods) and traffic data will be used to monitor the impact of vehicles on localised pollution levels. We are currently working with engineers and environment experts on data validation of the baseline readings. Intelligent signage will be deployed in early 2016 to test the behavioural impact of messaging.

FORWARD RESEARCH QUESTION

How can we present sensed data back to citizens, so to help them reflect upon it and possibly change their behaviours? See page 94



WISDOM

Water analytics and Intelligent Sensing for Demand Optimised Management

HOW CAN ICT OPTIMISE WATER DISTRIBUTION NETWORKS AND ENCOURAGE CUSTOMER BEHAVIOUR CHANGE?

CSTB, Advantic, Cardiff Council, Provincia della Spezia

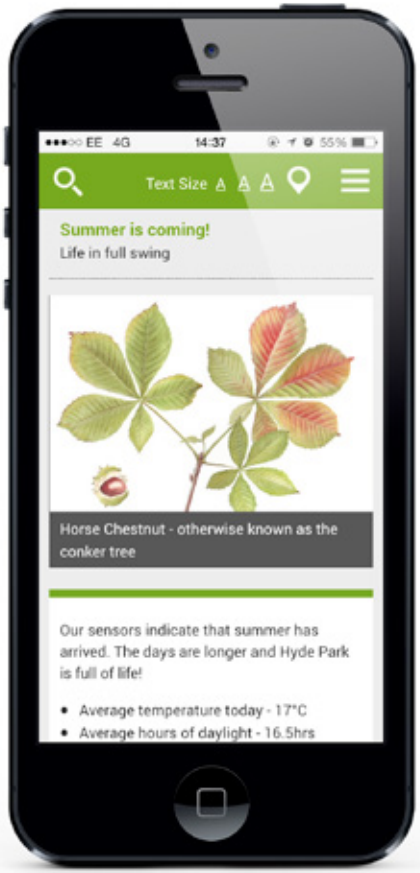
New business and technology platforms are required to manage urban water resources. FP7 funded WISDOM aims to achieve a step change in water and energy savings via the integration of innovative ICT frameworks to optimise water distribution networks while inducing change in consumer behaviour through innovative demand management and adaptive pricing schemes.

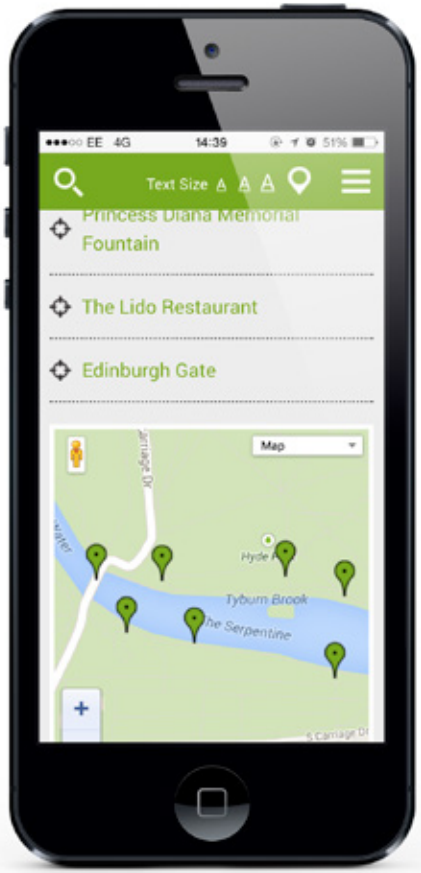
Fundamental to this framework are the needs of users and stakeholders and this requires the interoperability of a number of demand and operational models, fed with data from diverse sources such as sensor networks and crowdsourced information.

- Adaptive and intelligent analytics will be used to produce decision support systems that will drive the ability to increase the variability of both supply and consumption.
- The WISDOM framework will be modelled and simulated with initial testing at an experimental facility in France (AQUASIM), then installed and evaluated in Cardiff (UK) and La Spezia (Italy).
- Considering TV White Spaces for a potential spectrum for Machine-to-Machine and Wireless Sensor Network communications in near future.

FORWARD RESEARCH QUESTION

How can we visualise these vast amounts of data back to utility companies, so to facilitate understanding and action? See page 52





CITY-INSIGHTS
THE POWER OF HERE

HYDE PARK

CAN SENSOR DATA HELP US RUN A CITY PARK MORE EFFICIENTLY BALANCING ECOLOGY WITH ACTIVITIES TO GENERATE REVENUE AND ENGAGEMENT?

The Royal Parks, EE, City-Insights

FORWARD RESEARCH QUESTION

How can we instrument the city without the constraints and cost of a fixed infrastructure? See page 82

Nature, in the form of urban green spaces, is central to making cities liveable. From air pollution mitigation and the high biodiversity they support, to the vast social and public benefits, the value of green spaces and urban parks is rarely disputed and cities around the world are prioritising 'urban greening' on their agendas. Yet at the same time, the need to develop cities further, and with limited land available to do so, is putting increasing pressure on existing urban green spaces.

ICRI Cities are partnering with the Future Cities Catapult and The Royal Parks to implement an Environmental Monitoring project focusing on one of the world's great municipal green spaces: London's Hyde Park. Designed to prototype and test an innovative network of wireless sensors, including soil, air, water and more, the project collects unprecedented near real-time data on the park's eco-system and social fabric, and explores how technology can help us manage and experience urban parks in imaginative new ways.

Technically we are focusing on the practicalities of deploying heterogeneous sensor platforms where access to power is constrained, monitoring the reliability of the data being captured and exploring different communication strategies such as muling and mesh networking.

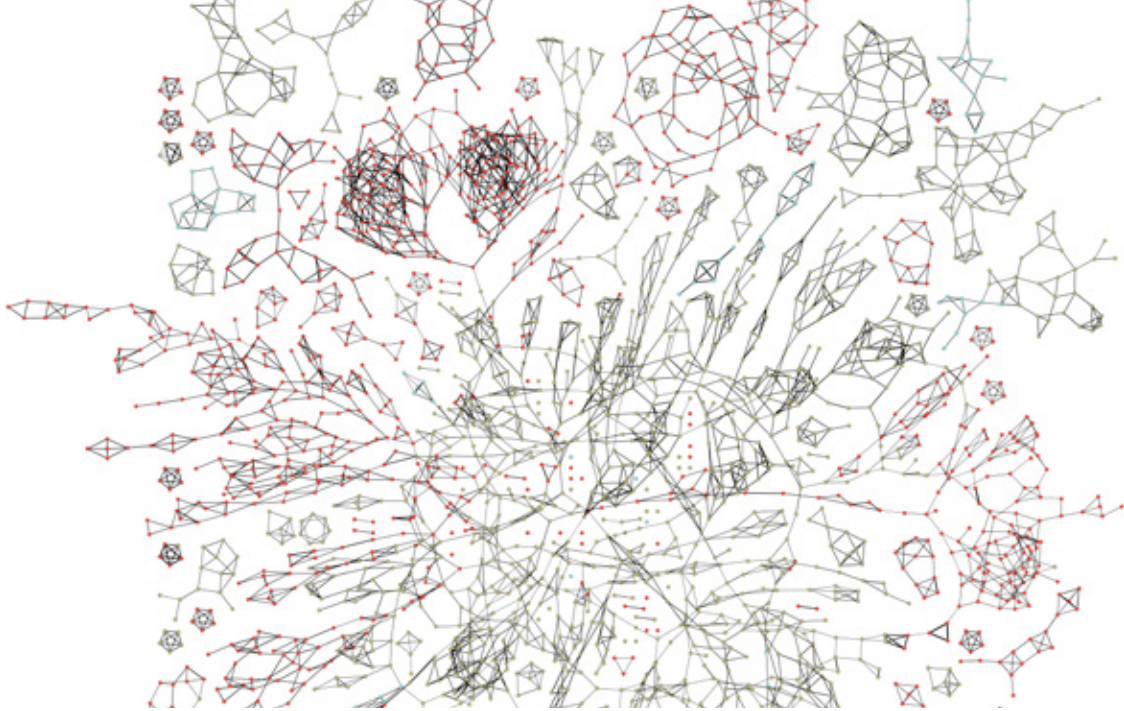
Key outcomes:

- We have deployed different sensor platforms on existing Intel Galileo based gateway architecture (weather, light, air quality and agri sensors).
- We used live sensor data to drive responsive story telling in the park via a City-Insights app.
- We used anonymised and aggregated mobile phone data to track the flow of people through the park.

MOBILCITY:

Advanced Networking for Mobile Internet of Things

HOW CAN WE CREATE MOBILE SDNS THAT PERFORM LOCAL LOAD BALANCING AND INTERFERENCE MANAGEMENT AND YET THROUGHPUT, UTILITY, ETC., GLOBALLY? CAN WE CROWDSOURCE ACCESS POINTS AND THEIR CURRENT PERFORMANCE AND USE THIS FOR MOBILE APPS?



University of California, Irvine

FORWARD RESEARCH QUESTION

How can we incorporate this technology in the wild and make it part of international testbeds? See page 144

Open Wi-Fi access points (APs) are demonstrating that they can provide opportunistic data services to moving vehicles. We present CrowdWiFi, a novel vehicular middleware to identify and localise roadside WiFi APs that are located outside or inside buildings. CrowdWiFi consists of two components: online compressive sensing and offline crowdsourcing. On- line compressive sensing (CS) presents an efficient framework for the coarse-grained estimation of nearby APs along the driving route, where received signal strength (RSS) values are recorded at runtime, and the number and locations of APs are recovered immediately based on limited RSS readings.

Offline crowdsourcing assigns the online CS tasks to crowd-vehicles and aggregates answers on a bipartite graphical model. Crowd-server runs offline crowdsourcing and iteratively infers the reliability of each crowd-vehicle from the aggregated sensing results. It then refines the estimation of APs using weighted centroid processing. Extensive simulation results and real testbed experiments confirm that CrowdWiFi can successfully reduce the number of measurements needed for AP recovery, while maintaining satisfactory counting and localisation accuracy. In addition, the impact of CrowdWiFi middleware on Wi-Fi handoff and data transmission is examined.

UbiFlow is the first software-defined IoT system for combined ubiquitous flow control and mobility management in urban heterogeneous networks. It adopts multiple controllers to divide urban-scale SDN into different geographic partitions and achieve distributed control of IoT flows. A distributed hashing-based overlay structure is deployed to maintain network scalability and consistency. Based on this UbiFlow overlay structure, the relevant issues pertaining to mobility management such as scalable control, fault tolerance, and load balancing have been examined and studied.

The UbiFlow controller differentiates flow scheduling based on per-device requirements and whole-partition capabilities. Therefore, it can present a network status view and optimised selection of access points in multi-networks to satisfy IoT flow requests, while guaranteeing network performance for each partition. Simulation and realistic testbed experiments confirm that UbiFlow can successfully achieve scalable mobility management and robust flow scheduling in IoT multi-networks; e.g. 67.21% improvement of throughput, 72.99% improvement of delay, and 69.59% improvement of jitter, in comparison with other OpenFlow protocols.

HUDDLELAMP

HOW CAN WE ENABLE USERS TO TEMPORARILY SHARE THEIR PERSONAL DEVICES FOR CREATING A JOINT CROSS-DEVICE SYSTEM FOR A SOCIAL AND FUN DATA EXPLORATION?

UCL ,University of Konstanz

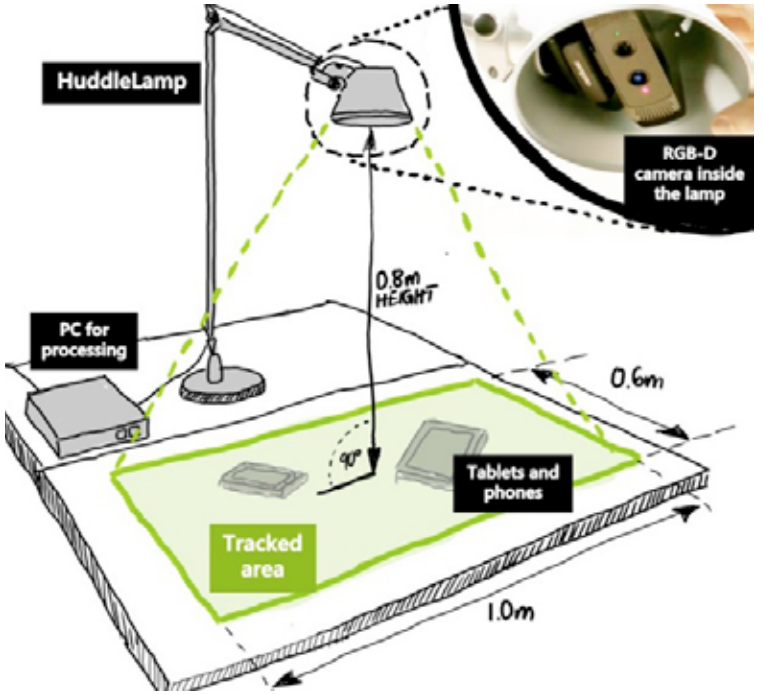
FORWARD RESEARCH QUESTION

How can this technology support sense-making and understanding of environmental datas? See page 42

HuddleLamp is a low-cost technology that turns the exploration of maps or visualisations of urban data in a social and fun experience. It uses a desk lamp with an integrated depth camera to track mobile devices and hands on a table. This enables a new breed of spatially-aware multi-user and multi-device applications for collaboration without expensive interactive tabletops or large displays.

HuddleLamp is our first step towards a "sharing economy" for excess display and interaction resources in a city: Instead of letting their devices idling away in pockets or bags, citizens can temporarily add them to a shared multi-user and multi-device system at any time without installing software or attaching markers. There is no need for setup or pairing. Instead this happens implicitly as a by-product of natural use in space, for example, by bringing multiple devices to the same room, placing them side-by-side on a table or desk, and moving them around as needed.

HuddleLamp got great attention in social media and was featured in international tech blogs such as Gizmodo or Hackaday and has over 50,000 views on YouTube. After having created our free and open source base technology (see www.huddlelamp.org), we are now looking at creating and studying examples for the visual exploration of urban data. Our goal is to enable citizens to create their own bottom up urban observatories for community engagement and activism in spaces such as schools, public libraries, community centres, or museums.



ENFIELD

HOW CAN SENSOR DATA EMPOWER COUNCILS AND CITIZENS TO ADDRESS AIR POLLUTION?

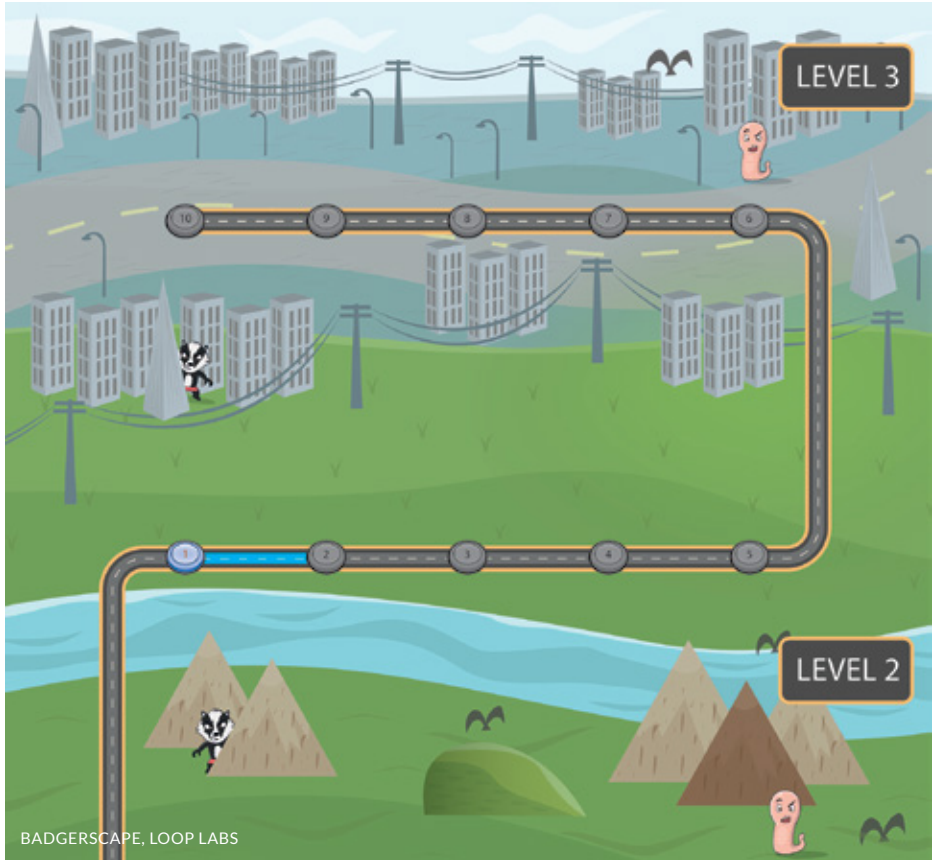
London Borough of Enfield, Future Cities Catapult, Local Schools

Enfield borough was declared an Air Quality Management Area specifically for the two pollutants Nitrogen Dioxide (NO2) and Particulate Matter (PM10). Both these limits, which are set by the European Union and adopted by the UK government, were breached in parts of Enfield borough. As part of its Air Quality Management Action (AQMA) plan, the council are keen to work with ICRI-Cities to explore how a lower cost, highly distributed sensor network can be used to raise public awareness of air quality issues.

Focus research areas include:

- Road traffic as source of pollution - building an evidence base in both high volume routes (M25, A10, North Circular) and residential areas.
- Perception vs reality - measuring air quality in places generally perceived to have or produce bad air, such as the sewage works or a demolition company.
- Human exposure - understanding human exposure over time to air pollution in sites that were frequented by citizens, such as schools, transport hubs such as bus stations, etc.

In 2014 we focused on deploying the test bed to validate the technical architecture, in 2015 focuses on community and stakeholder engagement to explore the use of the data being generated. A total of 80 air quality sensors were deployed



BADGERSCAPE, LOOP LABS

BRIXTON "WALK THE TALK"

HOW CAN AQ DATA ENCOURAGE MORE CONNECTED, HEALTHIER COMMUNITIES?

Loop Labs, Local Primary schools and Community Organisations, Ogilvy Change, Lambeth Council (Public Health, Sustainable Travel)

We worked with citizens to design interventions that can encourage new attitudes towards air quality and air pollution. The Brixton Listening Lab fused participatory design, data, and play to codesign urban services that approach sustainability from a different angle through behaviour change, community sensing, data visualisation and ambient technology.

The six month feasibility study funded by Innovate UK prototyped a data-driven urban behaviour change model to focus on nudging walking behaviours in the urban environment as a way of improving air quality, providing individual and public health tools, and building community connectedness. The intervention focused on decreasing driving behaviour for walkable journeys. Around 50% of all car journeys in London are under 3km.

Collaborating with local partners Transport for London, Lambeth Council, schools and other community leaders we co-created "Badgerscape", a game allowing children to gain virtual game lives via parental / adult tracked walking activity.

In the prototype, children gather points collected from adult team members to rise through game levels. Points are generated by adults on a smart phone tracking app, which can track walking behaviour such as steps, distance, calories, and map routes. Data generated by kids and their adult teams are currently aggregated and visualized in player leaderboards. By designing with the children, Walk the Talk was able to design for the narrative styles and characters that allowed information, incentive and motivation to come alive through the eyes of children, their parents and the connected community.

FORWARD RESEARCH QUESTION

How can the design of urban data and IoT become more inclusive and accessible to support community engagement strategies for participatory regeneration?

See page 56

ELEPHANT AND CASTLE

DEPLOYMENT OF AQ SENSORS TO SUPPORT TESTING OF INNOVATIVE NOX REDUCTION TECHNOLOGIES

Lend Lease, Southwark Council, King's College

Working with property developer Lend Lease and Southwark council, we are deploying a number of NOx specific, real-time sensing nodes that will enable testing of innovative NOx reduction technologies.

A design of experiment has been developed that will test the use of a novel photocatalytic paint which scrubs NOx pollutants from the surrounding air when exposed to the air. The first 6 months of the trial consists of the sensors measuring the environment to establish a baseline. This was followed in 2015 by the introduction of the paint, the test will then continue for a further 6 months. AQ sensors will be used to validate the effectiveness of the new photocatalytic paint and includes a comparative trial with the London Air Quality Array within Elephant and Castle. Trials with the photocatalytic paint are being outlined within the scope of this project with the potential for a transparent coating being included on all surfaces in order to maximise the coverage of this innovative substance.

FORWARD RESEARCH QUESTION

How can we automate data annotation processes?

See page 80

INTERNET OF SCHOOL THINGS (DISTANCE)

HOW CAN THE INTERNET OF THINGS SUPPORT OPEN EDUCATION BY ENCOURAGING EDUCATORS, STUDENTS AND BUSINESS TO SHARE CERTAIN TYPES OF DATA OPENLY FOR THE FIRST TIME?

Xively, Science Scope, Explorer HQ, Stakeholder Design, University of Birmingham's Urban Climate Laboratory, UCL Centre for Advanced Spatial Analysis, and The Open University.

DISTANCE (Demonstrating the Internet of School Things – a National Collaborative Experience) was a project working with eight UK schools representing geographical, socio-economic, and domain-diversity across UK, inclusive of primary, middle and secondary levels. We developed hardware, software and web services that teachers used in the classroom to enrich their lessons with sensors and sensor data. Our goal was to design new ways to support the next generation not only as consumers of the future digital data economy, but also its creators.

The project's design process placed dynamic collaboration with teachers and students at its core – collaborating with students and teachers on key project deliverables, from the initial visioning workshops, to developing technologies suited to teachers' and student's interest in bringing the real world into their classrooms, to the in-situ fieldwork and feedback allowing rapid iteration of session plans, data visualisations and interactive platforms.

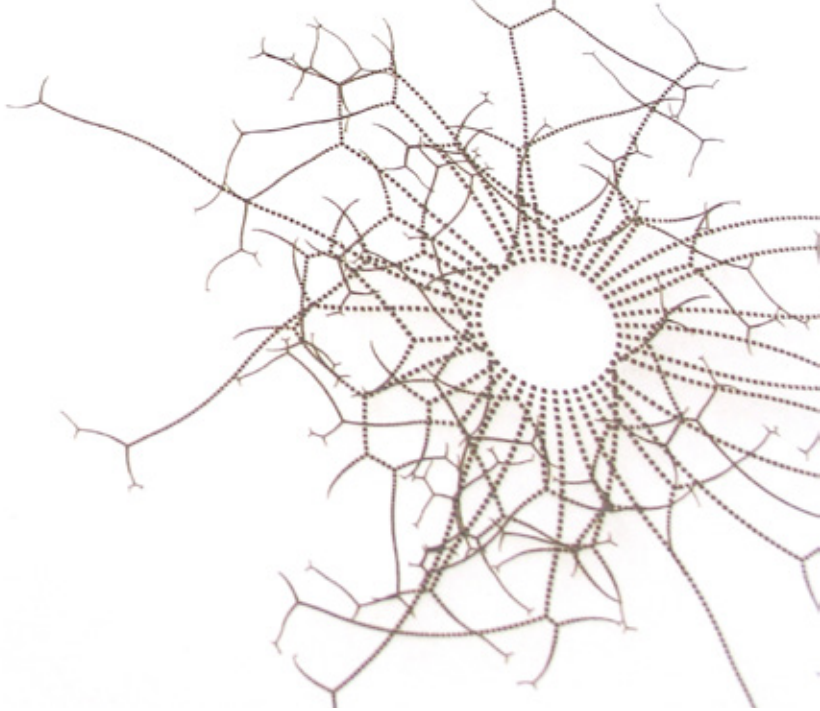
Key outcomes:

- We developed and deployed an end to end technical and social solution (30+ Intel Galileo based IoT devices).
- Delivery of a dozen participatory design workshops with students and teachers, crossing diverse domains such as weather, mobility, performance, robotics, energy and health.
- Development of OFSTED-read curriculum and technology prototypes supporting over 10 use cases.
- Design of three web-based user interfaces for data visualisation.

FORWARD RESEARCH QUESTION

How can we scale up the adoption of these IoT data-loggers? See page 62

COMPUTE CONTINUUM BEYOND THE EDGE



HOW CAN HIGHLY-DECENTRALISED, LIGHTWEIGHT PROTOCOLS AND ALGORITHMS UTILISE THE MIX OF HETEROGENEOUS COMPUTATIONAL DEVICES DISPERSED THROUGHOUT FUTURE CITIES?

FORWARD RESEARCH QUESTION

How can we provision this technology at city scale? See page 42

The Smart City vision is to have widespread sensing of city conditions to guide infrastructure, policies and services. However, we must be careful in how we instrument the city and not lose track of long-term consequences. When sensing truly becomes ubiquitous, bringing with it an explosion of devices communicating data, then existing network infrastructures will become saturated. This motivates IoT and sensor nodes running multiple applications that might belong to different stakeholders. This leads to a continuum where data is processed from source devices via edge devices to the cloud. The question is where do we carry out processing: with what nodes and how? Specifically, maximizing the use of these systems is important but also brings many challenges in terms of scheduling processes and programming systems without knowing where they run.

We view this as city as a programmable device. The traditional approach to programming over many devices is to place a runtime on all nodes to abstract away the underlying hardware. We take a different approach. Given that code deployment can be initiated remotely and at any time, it makes sense to instead adapt compiler based approaches where optimisation is done when the application is compiled/ initially deployed. We believe that in order to cope with the large heterogeneity present in our target networks we should aim to have controlled variation, rather than arbitrary homogeneity. This ensures that hard to foresee complex interactions involving the placement of computation and communications can be ironed out in advance.

- To this end we have developed a framework for developing smart city applications, which we name Scaffold. The main component of this framework consists of a compiler, which takes a program annotated with source data, commands and requirements in our Scale language and automatically determines the minimal set of actual programs that will need to be running in the nodes that compose the network, cloud to edge. Depending on the requirements this compiler can also inject the programs with runtimes, allowing for dynamic behaviour, whilst retaining as much intelligibility as possible.

- We have also developed Scanner, a registry and automatic deployment system for sensors, actuators and processor nodes in smart city scenarios. This system allows us to take the output of the Scale compiler and query the current state of the network in order to determine appropriate target nodes in which to install the various images produced by the Scale compiler.

VOX BOX

HOW CAN WE BEST ENGAGE A CROWD TO GIVE THEIR OPINIONS AND FEEDBACK IN-SITU?

Tour de France,
Electro Magnetic Field

FORWARD RESEARCH QUESTION

How can we deploy this technology in other city settings? See page 144

Gauging public opinion and gathering feedback can help organisations for example to improve the experience provided at public events, improve products or customer services, or target audiences for engagement in political or local issues. However, it can be difficult to get people to give their feedback. Handing out questionnaires at events can provide in-situ feedback but requires interrupting people in their activities and may result in low response levels. Emails or web surveys after the event can reach a large audience but response rates are typically low and feedback is taken out of context.

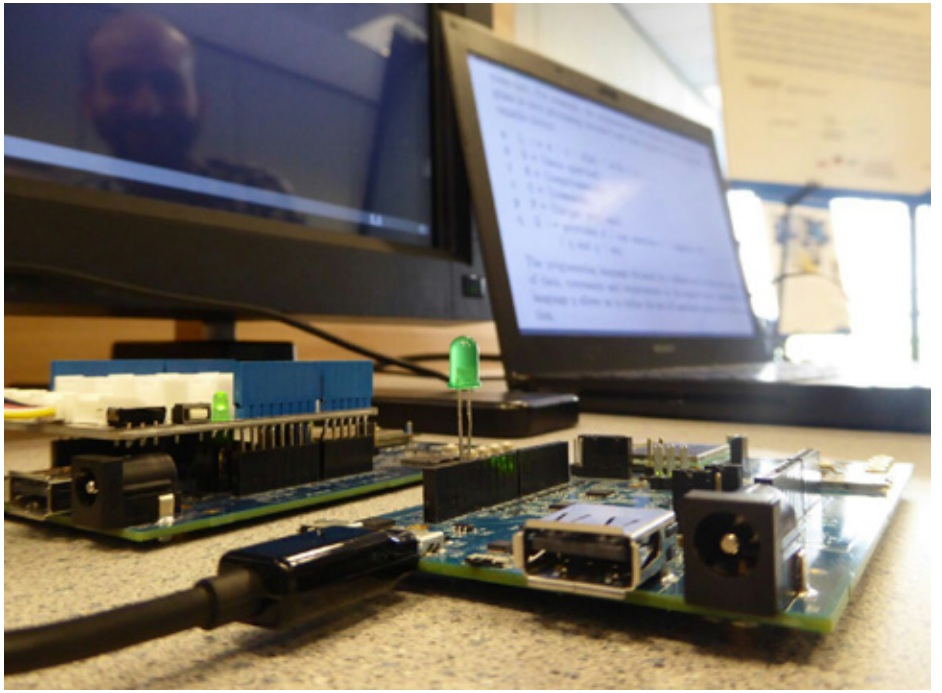
VoxBox aims to turn the task of filling out a questionnaire individually at an event into a pleasurable and engaging experience of giving feedback that can be done by individuals as well as groups together. VoxBox is a tangible questionnaire machine that allows event attendees to share their views using a range of physical sliders, dials and buttons. They can then see how their views compare to those of others at the event by looking at real-time data visualisations presented on the other side of the device.

VoxBox was designed by considering traditional questionnaire structure and limitations, and employs deliberate strategies to encourage participation and completion, show progress throughout the survey, group similar questions, gather answers to open and closed questions, and connect answering and seeing results more closely. The system is modular and consists of five question modules, which relate to demographics, current mood, crowd information, event feedback and an interactive telephone question asking open-ended questions. The system was developed with Arduino boards and it uses I2C as a communication strategy, allowing all question modules to communicate with a main control point. A WiFi shield enables connection with a backend server where all data is uploaded and processed before being visualised in real-time on the back of the VoxBox.

VoxBox was deployed in the wild at two London fan parks for the Tour De France, a one-day Digital Democracy event in Cardiff, and a hacker festival in Milton Keynes during the summer of 2014. Over 200 people used the VoxBox at these four events, from whom feedback on the events was collected through the VoxBox, and data was gathered on the use of VoxBox through user observations.

Following these events the research team have been overwhelmed with requests for the VoxBox to be used in different venues and events, for example to gather feedback on student open days, to evaluate an interactive play for children, and to gather census data.

SCAFFOLD: NETWORK-WIDE PROGRAMMING AT CITY SCALE



HOW CAN WE SIMPLY PROGRAMME IOT IN THE CITY?

FORWARD RESEARCH QUESTION

How can we reason about such distributed and dynamic progresses in the City See page 144

The worldwide proliferation of mobile connected sensing, processing and physical actuation devices has brought about a revolution in the way we live, and will inevitably guide the way in which we design applications for these networks. With the Scaffold project we intend to show how the scalable development of applications for highly distributed, heterogeneous large networks requires a shift from the current device-centric programming model to a network-centric semantic model, whereby individual devices are abstracted away and identified by the semantic descriptions of the services they provide. This requires the development of programming primitives that have network-wide semantics.

Moreover, with the very large amounts of data that is predicted to be produced, processed and manipulated, the current cloud-centric architectures for such systems will become inviable. That is because we will be producing more data at the edge that must be processed with precision in a timely manner, and which we do not necessarily want to store at the high frequency that it is produced. The emphasis should be shifted from manipulating individual points of data to manipulating streams of data to enable real-time processing and reasoning. This requires that the programming models not only take into account semantic descriptions of the streams rather than individual devices and data points, but also the various modalities of computing that are possible in this scenario; a computing continuum from in-network processing to cloud computing spanning a range of devices from cloud to edge.

The programming model we developed (Scaffold) allows us to do just that by abstracting away the requirements of the application and then selecting one of the computing modalities available in the computing continuum.

By harnessing semantic descriptions of sensor stream data, processing capabilities and physical capabilities we have augmented programming languages in order to provide support for network-wide programming of cyber-physical systems targeting large heterogeneous distributed networks. This is in contrast with current approaches to urban IoT application development, where one would have to independently design and deploy individual applications for all the participating devices. With Scaffold, the application developer can define a single piece of network-wide code for the application, which will then be automatically divided into the necessary images, compiled and deployed to the appropriate devices, enabling the development of larger scale applications than with traditional techniques. In the Queen Elizabeth Olympic Park deployment, we will be testing the Scaffold approach to application development with a real world scenario, and examining questions of multi-tenancy and constrained network dynamic behaviour in practice.

DEEPOPP: FACILITATING MOBILE ACCESS TO SOCIAL MEDIA CONTENT ON URBAN UNDERGROUND METRO SYSTEMS

HOW DO WE BUILD ALTERNATIVE NETWORKS FROM PHONES WHERE THERE ARE NO TRADITIONAL NETWORKS AVAILABLE?

FORWARD RESEARCH QUESTION

How can we make such systems secure? See page 144

London Underground carries millions of workers, tourists and students every day, and Londoners spend an average of 45 minutes a day on it. Its trains complete over two billion journeys each year, travelling through tunnels deep below ground as well as tunnels on or near the surface that navigate under roads, parks, and even rivers. These conditions make access to social media while relying on existing mobile networking infrastructures extremely difficult. On sub-surface lines with intermittent signal coverage, passengers have trouble knowing when they can use their phones; they may repeatedly attempt to access content and will often give up trying whereas on deep-level lines passengers assume they have no access to content at all. Besides the Underground, other metropolitan rapid transit systems such as the Paris Metro, the New York City Subway and in some areas the subways in China face similar issues. Therefore, efficient solutions are needed for mobile access to social media in underground environments.

Opportunistic mobile data prefetching has been proposed as a potential solution for providing access to content when no connectivity is available while also helping to reduce energy consumption by only accessing data at times of high signal strength. Most of the existing content prefetching solutions base their operations on network conditions. However, prefetching social media content to mobile clients has unique features, e.g. 1) mobile users have strong personal preferences about social media content; 2) a user typically only sees a subset of social media he subscribes to; and 3) freshness of social media is critical due to its time-sensitive nature. Therefore the challenge

of when, what and how to prefetch/access social media data are all tightly coupled. The goal is to exploit signal coverage, and fetch, cache, and make content available to a client application.

To facilitate mobile connectivity for travellers using underground mass transit systems, DeepOpp system is designed. DeepOpp is a context-aware system that enables offline access to social media content. A mobile client running DeepOpp employs opportunistic content prefetching based on intermittent availability of connectivity opportunities (such as urban 3G or station WiFi), to enable offline access to online social media. To achieve efficient prefetching of content on the resource-restricted mobile client, DeepOpp detects connectivity opportunities by learning from previous signal traces, and optimally chooses which social media items to cache based on the context of network condition, user preference and phone's status.

DeepOpp can measure signal characteristics (strength, bandwidth and latency), and based on current and historical information make signal coverage predictions in order to activate data prefetching of social media content. An Android-based implementation of DeepOpp has enabled real testing on the London underground and demonstration of its benefits, which promote it as a viable solution for cities with similar metro systems. The prototype of the DeepOpp client application to support prefetching, caching and displaying of social media contents from Facebook, as a proof-of-concept, under intermittent signal availability on the Underground is implemented. The DeepOpp app also provides some controls that mobile user of the phone can manage. In the general settings, the user can opt to enable optimiser, download over 3G (need data plan support), and choose content to download (e.g. text, image and video). Once the optimiser is selected, the user can control specific optimiser thresholds for power, storage and data plan.

In the future, the system will be extended to operate for Instagram and Twitter social streams as well. Another future plan is the definition and implementation of optimisation techniques. Thus, the mobile prefetching and caching operations will consider network conditions and user preferences to reduce smartphone resource consumption such as power and storage, as well as data plan usage.

CROWDWIFI: EFFICIENT CROWDSENSING OF ROADSIDE WIFI NETWORKS

HOW CAN WE REDUCE THE NEED FOR FIXED COMMUNICATIONS INFRASTRUCTURES FOR VEHICULAR SYSTEMS

University of California, Irvine

FORWARD RESEARCH QUESTION

How can real-time tasks be scheduled in opportunistic vehicular WiFi networks.See page 144

Roadside WiFi networks are increasingly being tapped into by end users with WiFi interfaces in vehicular networks opportunistically for a broad range of applications including ad hoc data dissemination and low-cost Internet access. These networks use fixed access points (APs) that provide improved higher bandwidth connectivity due to better signal propagation characteristics and their ability to exploit spare spectrum. This is especially the case in locations with limited cellular coverage or in environments vulnerable to the obstruction of satellite signals by buildings and is typical in both urban environments (with significant built infrastructure) and in rural areas (where cellular connectivity may be sparse). To support smooth continuous Internet operation in the presence of dynamics caused by vehicle mobility, the design of a middleware that supports accurate real-time identification of roadside APs presents unique opportunities and challenges. To address the above challenges, CrowdWiFi, a crowdsensing middleware specifically designed for vehicular networks, has been proposed. It consists of two major components to enable efficient lookup on roadside WiFi networks: an online compressive sensing component and an offline crowdsourcing component. The online compressive sensing component running at the vehicle end coarsely counts and localizes nearby APs in real-time while driving, using sparse signal collection capabilities. The offline crowdsourcing component running at the server end assigns online compressive sensing tasks to some mobile vehicles, then aggregates the online sensing results uploaded by these vehicles, and produces a fine-grained estimation of AP distribution. We exploit the use of compressive sensing (CS) techniques to reduce complexity for in-network localization algorithms which require a large number of RSS (Received Signal Strength) readings. The AP lookup tasks are assigned to crowd-vehicles using geographical participation to gain information from aggregated answers. The aggregation problem is then transformed into an iterative inference problem on the graphical model to obtain the reliability of each crowdvehicle. As the first mobile middleware using the concept of crowdsensing to localize roadside APs in vehicular networks, CrowdWiFi provides multiple benefits in roadside WiFi networks. For example, in conditions where a popular AP is congested, the mobile vehicle can switch to other candidate APs in its communication range. It also helps understand the topologies and network characteristics of large scale WiFi networks, e.g. network density, connectivity, interference properties, etc, in urban areas. Furthermore, the lookup of APs may reveal interesting social aspects of vehicular networks so that mobile vehicles can be involved in location based services and mobile cloud support.

SENS-US

HOW CAN WE SCALE UP TANGIBLE SURVEYS TO NATIONAL LEVEL AND RETHINK HOW THE UK CENSUS IS CARRIED OUT?

Somerset House as part of the Civic Bureau
Southbank Centre as part of the Web We Want festival

FORWARD RESEARCH QUESTION

How can we use such technologies to rethink civic engagement as a more distributed, in-situ activity that fits into the daily lives of busy people?
See page 144

Census data is collected in the UK every ten years through a laborious process of sending out surveys and organising follow-up interviews. Census data is then used by central and local government as a way of deciding how and where to allocate their budgets and to help plan future housing, education, health and transport services. However, as the population grows and changes, the census becomes harder to carry out. Furthermore, there appears to be little public awareness of what happens with collected census data and how sharing information actually manifests positive change in local areas. In collaboration with the Civic Workshop we designed and developed the Sens-Us system to explore how collecting census data (and other data at scale) could be more dynamic and localised through the use of interactive technologies in-situ as opposed to paper or digital questionnaires. Sens-Us is a set of physical data collection and visualisation devices consisting of five interactive questionnaire stations that address different themes (demographics, health, belonging, place & city life, and trust), plus a visualisation station that shows collected data in real time. Participants use a smart card to "log in" at each station, so that their answers can be linked across the different themes and so that relevant and personalised data is shown to them at the visualisation station. For each theme we explored what data people were willing to disclose, with whom, and for what reasons. We also aimed to give people insight into how sharing their data can be beneficial for the common good, and explore how this changes their views on data sharing. More generally, Sens-Us also raises questions such as, how scaled up data collection activities (such as a census) can be more integrated into our everyday lives, more citizen-led and locally relevant, and how this can change the relationship between citizens and the state. Sens-Us was deployed for 8 weeks at Somerset House, a prestigious arts venue in central London. During this time over 800 visitors interacted with the Sens-Us system, answering the census-based questions and viewing collected data. Our results showed that physical systems like Sens-Us provide benefits over paper and digital methods, such as serendipitous discovery, contextual validity, and low barriers to participation. Sens-Us also gave participants more control over how they contributed, by allowing users the flexibility to answer questions in their desired order and to skip certain themes that they did not want to answer. We also explored the privacy aspects of physical systems like Sens-Us where people are providing answers in public, in a physical manner. We compared the answers to sensitive and potentially provocative questions captured through Sens-Us with answers to the same questions captured through an online survey that people answered in their own homes or more private spaces. We found that there was very little difference between the two, suggesting that privacy concerns were not heightened by the act of entering data into a physical device in a public space.

SMALLTALK

HOW CAN WE ENGAGE WITH YOUNG CHILDREN TO UNDERSTAND THEIR VIEWS AND OPINIONS?

The Young Vic Theatre

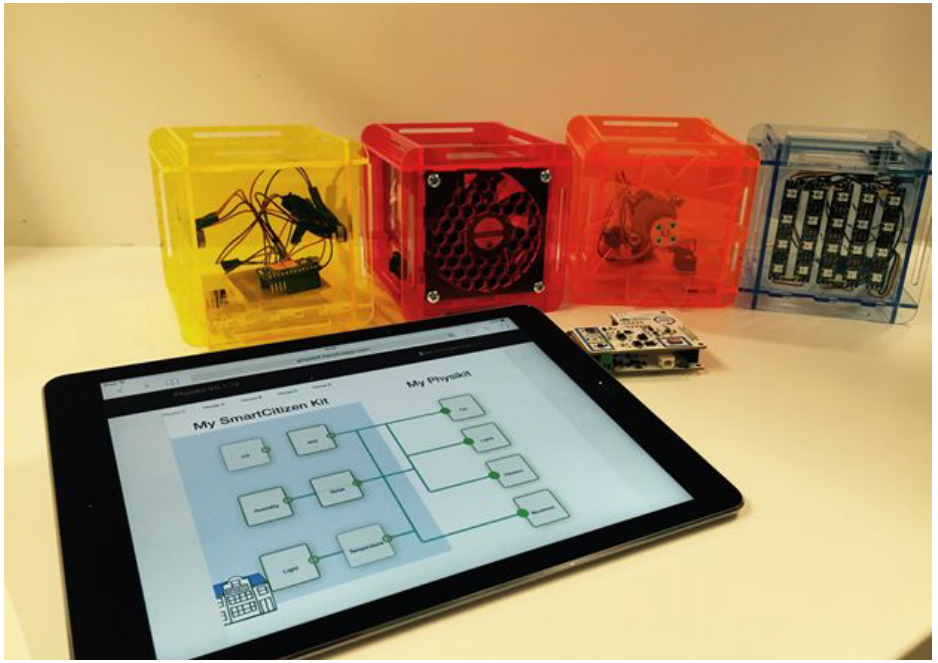
FORWARD RESEARCH QUESTION

How can such technologies be scaled to a variety of urban environments to understand the views of young city dwellers? See page 42

Many approaches have been explored to gather thoughts and feedback from young children, such as think-aloud tasks, drawing, or using picture cards. However, it remains a challenging activity. The theatre production company, Fevered Sleep, who are resident at the Young Vic theatre in London, approached us with the challenge of gathering feedback from young children on one of their immersive performances, called Dusk. They had previously experimented with methods such as storytelling and picture cards, which worked well in a classroom setting, with no time constraints, several weeks after the children attended the performance. However, the aims of this project were to design and develop technologies that could gather feedback from children in-situ, immediately after the performance while still in the theatre space. This also meant that time was a key factor as the theatre had a strict schedule of performances throughout the day.

We designed and developed the SmallTalk system to address these challenges. SmallTalk is a physical questionnaire system specifically designed to gather feedback and opinions from young children. In this case it was tailored to the immersive theatre performance, Dusk, and designed to be modular and easily moveable in the theatre space. The system consists of five interactive question boxes. Each box asks a question or questions that the children can answer by pushing buttons, moving rollers and turning dials. Audio was included for all question and answer text to support children who could not yet read and was recorded by the main character in Dusk to provide a familiar and friendly voice for the children. The final box included a video that featured the main character in Dusk asking the children a number of questions on a screen which they answered by speaking into a large microphone. Questions included demographics, thoughts on the theatre experience, as well as what they liked and remembered most from the performance. SmallTalk was deployed in the theatre space immediately after 7 performances with a mixture of school groups and families. Over 60 children used the system, ranging in age from four to nine years old. Our findings showed that SmallTalk worked very well in the challenging theatre environment and was able to gather interesting insights from the children with minimal adult supervision. The video box worked particularly well and although it required the children to talk out loud, the vast majority provided relevant answers. The answers suggested that the children empathised with the lead character and remembered poignant moments of great happiness and sadness from the performance. From an interaction perspective, it was interesting to see how children aged five and under often struggled to understand the affordances of the different physical inputs and in some cases tried to swipe physical buttons (as a touch screen interaction) before being shown how to push the buttons until they clicked. The children's confidence grew as they moved from box to box, exploring each new interaction, and many requests for 'another turn' suggested that SmallTalk provided a fun, engaging experience.

PHYSIKIT

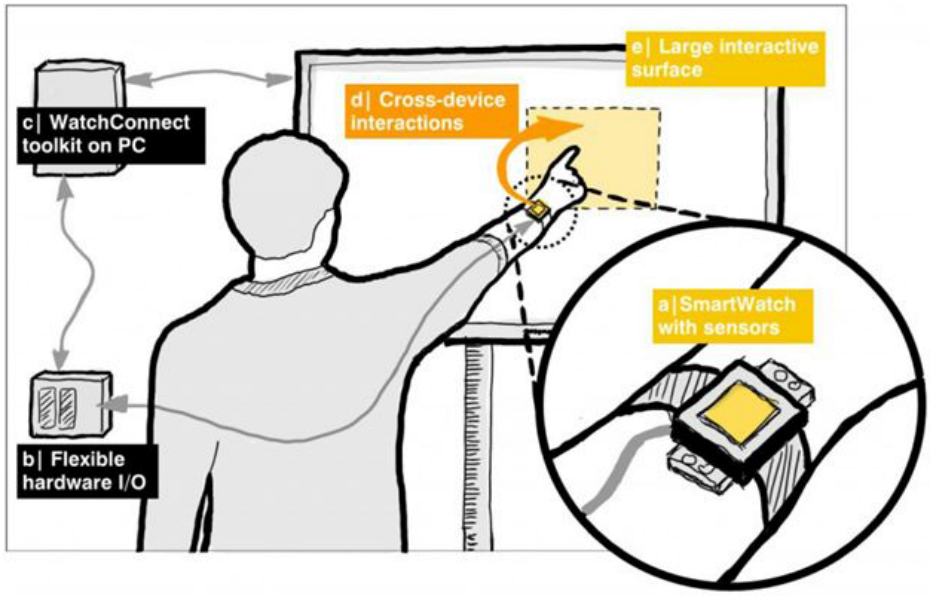


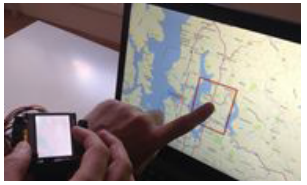
HOW CAN PROGRAMMABLE PHYSICAL VISUALIZATION BE USED BY CITIZEN TO MAKE SENSE OF AND APPROPRIATE URBAN SENSOR DATA?

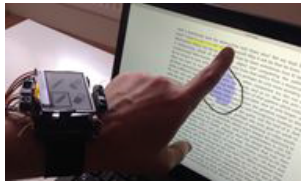
FORWARD RESEARCH QUESTION

How can the concept of end-user programmable physical ambient visualizations be used to empower citizens to visualize Internet-of-things devices and infrastructures in their homes and cities? See page 42

Ubiquitous urban sensors can give us rich information about the world around us, such as current temperature, humidity, air quality, or noise levels. This information can help us make decisions in our everyday lives. We may for example decide to take a different route to work if the air quality on our commute is particularly bad, or we may want to open a window if humidity or CO levels are getting higher inside. On a higher level, such information can make us more aware of our environment and how we contribute to it. While sensor platforms are commercially available and sensors have been placed in our cities and our streets, data from these sensors is usually only available through websites or is stored in large data sheets that are hidden or unengaging to inexperienced users. Furthermore, direct representations of sensor readings do not always make sense to us: what unit are readings presented in, and when are readings out of the ordinary? Physikit aims to make data from sensors more visible in our everyday lives by providing physical and embedded data visualizations in our homes. Such embedded physical devices have shown to be powerful in increasing awareness, and have the ability to become part of the home landscape. Physikit includes four different physical ambient visualizations that can visualize sensor data through light, movement, air and vibration. Through a mobile website, users are provide with an end-user programming interface that can be used to configure or program the different cubes. Users themselves can create connections between different sensor data and the available cubes to explore and engage with data. Physikit provides different visualization modes for showing data continuously, showing relative levels, and alerting when thresholds are reached, Physikit also aims to give people a better feel for how their environment changes over time and what can be considered 'normal'. Physikit was deployed for two weeks in a field study with five households in greater London and the South East UK. During the deployment, participants engaged with the Physikit cubes to explore the data of a Smart Citizen kit. In the two weeks of deployment, participants used the end-user programming interface to create 161 different rules that connected the sensor data to the cubes. Our results showed that participants used the cubes to visualize a variety of different data streams based on their interest and that the end-user programming interface afforded the exploration of different connections. The data showed PhysiCubes were primarily placed in the living room and kitchen and in only few occasion in the bedrooms. The cubes were placed on tables (kitchen counter or table) or on the window sills, and in a few instances the more subtle cubes were placed next to participants' sofas or bedroom tables. Through the Physikit cubes, participants were able to understand changes in the environmental data either directly through the changes produced by the cubes, or the changes would entice users to explore the data via the website .Our field study showed how households successfully and creatively appropriated and used the kit to integrate data into their homes. The cubes probed participants with data changes that resulted in further inspection of the underlying data. The study also showed how people designed their own experiences using the cubes as building blocks. Physikit has shown how it is possible to democratize data to the general public in ways that are meaningful, creative, and aesthetic, while opening the door for end-user programming to be repurposed in the realm of IoT.







WATCHCONNECT

HOW CAN WE EMPOWER PROGRAMMERS TO CREATE NEW CROSS-DEVICE APPLICATIONS AND SYSTEMS AROUND SMARTWATCHES?

Smartwatches give people lightweight and immediate access to messages, notifications, and other digital data while on the go. While already powerful as standalone devices, the capabilities of smartwatches increase significantly when used in tandem with other devices that people carry, such as their phones or tablets, which allows for novel cross-device interaction techniques. However, so far there are only a relatively small number of explorations into watch-centric, cross-device interaction techniques. Building and exploring cross-device interaction techniques and applications is a difficult task, as most existing development kits have only limited support for input gesture recognition, different sensor hardware configurations, rapid interface designs, or cross-device connectivity and transfer of information.

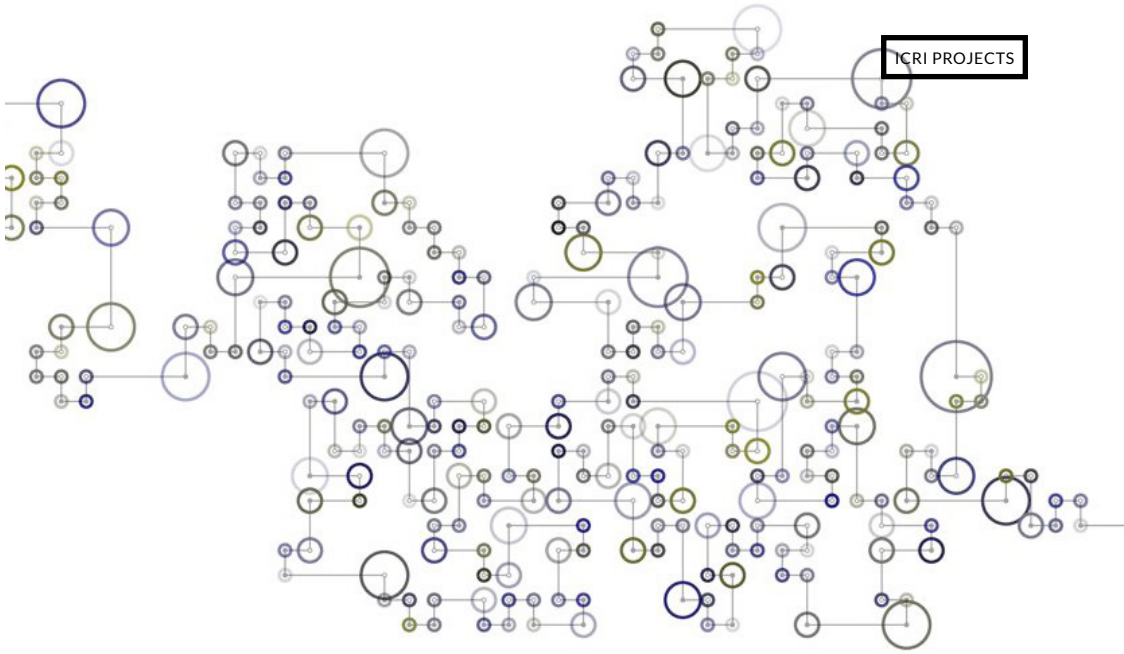
To bridge the gap between concept design and full implementation, we introduce WatchConnect, a rapid prototyping toolkit for watch-centric cross-device interaction techniques and applications. The toolkit provides (i) a modular and extendable hardware platform that emulates a smartwatch and allows for rapid reconfiguration of wearable hardware, (ii) a runtime system and user interface components that support quick prototyping of watch interfaces using an existing UI framework (Visual Studio), and (iii) a rich set of input and output events, machine learning approaches and gestures using a range of built-in sensor mappings and simulators. This work presents a novel approach for rapidly prototyping and designing smart-watch-centric cross-device applications and interaction techniques, using simulated hardware and software building blocks.

The toolkit is released as open source software and can be used to prototype, test and demonstrate novel cross-device applications and interaction techniques with public displays or even Internet-of-Things devices. Example applications include cross-device information transfer using mid-air gestures; interaction with the bevel of the watch to zoom on maps, and add placeholders; or an instrumental e-reader where the watch can be used to reconfigure the finger into different drawing and painting tools.

FORWARD RESEARCH QUESTION

How can we scale up the adoption of these IoT data-loggers? See page 62

MAKING SENSED DATA TRUSTWORTHY



HOW CAN WE BUILD LIGHTWEIGHT DISTRIBUTED ALGORITHMS THAT CAN IDENTIFY FALSE SENSOR DATA INJECTION OR HIGHLIGHT DATA THAT IS UNTRUSTWORTHY?

AESE Imperial

FORWARD RESEARCH QUESTION

How can we deploy these algorithms in practice? See page 42

Critical to many City systems is its ability to understand state from sensors. This could be a transport or water network, smart power grid or simply movement of people. Understanding state leads to making decisions about how to improve services, utilities and systems.This may manifest as changes in city designs or real-time control decisions made to critical utilities. What if that data does not represent the state accurately? What if it is coming from faulty sensors? What if perpetrators are purposefully falsifying data to gain advantage or bring down a city system?

Trustworthiness metrics: Each measurement performed by a sensor has an associated uncertainty in its value, which if not accounted for properly, could potentially derail the decision process. Computing and embedding the associated uncertainties with data are therefore crucial to providing reliable information for sensor-based applications. We developed a novel unified framework for computing uncertainty based on accuracy and trust. We implemented algorithms for computing this and an approach for propagating uncertainties. This was evaluated functionally by applying it to data sets collected from past deployments to demonstrate its benefits for in-network processing as well as fault detection.

False data Injection attack in Smart Grid systems: Reliable real-time sensing plays a vital role in ensuring the reliability and safety of industrial Cyber-Physical Systems such as networked control. Sensor readings may be abnormal or faulty. This could lead to serious system performance degradation or even catastrophic failure. Current anomaly detection approaches are either centralized and complicated, or restricted due to strict assumptions, which are not suitable for practical large-scale Networked Industrial Sensing Systems where sensing devices are connected via digital communications, such as wireless sensor networks or smart grid systems.

We developed a fully distributed general-anomaly detection (GAD) scheme, which uses graph theory and exploits spatiotemporal correlations of physical processes to carry out real-time anomaly detection. We formally proved the scalability of our GAD approach and evaluated the performance for two industrial applications: building structure monitoring and smart grids. Extensive trace-driven simulations validated our theoretical analysis, and demonstrated that our approach can significantly outperform state-of-the-art in terms of detection accuracy and efficiency.

INFRASTRUCTURE FREE CITY

Sensing via Opportunistic Networking

WHAT ARE THE PROTOCOLS AND ALGORITHMS REQUIRED FOR NEXT GENERATION OPPORTUNISTIC WIRELESS NETWORKS?

Imperial AESE, ETH

FORWARD RESEARCH QUESTION

How can we deploy these algorithms at scale? See page 90

Fixed infrastructures have limitations regarding sensor maintenance, placement and connectivity. Employing the ubiquity of mobile phones is one approach to overcoming some of these problems whereby the phone carries the data. This concept, "Data Mules," explores how mobility and social patterns of phone owners can be exploited to optimise data forwarding efficiency.

This is innovative in this research space as prior work in Delay Tolerant Networks (DTNs) typically focus on individual packet routing rather than routing and control for streams of packets. Further no prior work has fully exploited underlying social networks pertaining to human relays, nor have they used opportunistic multi-hop-multi-radio human contacts.

Incentivisation is an important feature of this research in order to stimulate phone owners to serve as data relays. We proposed a scheme which mimics a free market in which those who mule data get rewarded. By combining network science principles and Lyapunov optimisation techniques, we have shown that global social profit across a hybrid sensor and mobile phone network can be maximised. In order to minimise cheating the system we implemented Mechanism Design to weight the pay-back and show that cheating the system never results in reward.

The approach we have taken aligns with our principles to embrace distribution and agility in systems architecture. Therefore our algorithm is fully distributed and makes no probabilistic / stochastic assumptions regarding mobility, topology, and channel conditions, nor does it require prediction.

Phase 1:
Ad hoc experimentation was carried out in order to reason about this work and was compared with theoretical predictions and simulation in Hyde-Park using Mica-Z motes. This work demonstrated that in theory we can outperform other similar approaches using less computational resources.

Phase 2:
Experiments were carried out on Android mobile phones with a study of 15 student users relaying data across Imperial College to test the ability of the algorithms to ensure a profit for all and at the same time efficiently relay data. This highlighted that indeed the profit-based economic model was viable but that connection times using WiFi-Direct for mobile phones was problematic.

SENSING WITH RENEWABLE ENERGY

HOW CAN WE BUILD LIGHTWEIGHT DISTRIBUTED ALGORITHMS THAT CAN OPTIMISE THE USE OF RENEWABLE POWER, FOR NOT JUST SENSOR NODES BUT WHOLE SENSOR NETWORKS ENSURING ENERGY NEUTRAL OPERATION?

Xi'an Jiaotong University, China

FORWARD RESEARCH QUESTION

How can we deploy this technology at scale in urban green spaces? See page 48

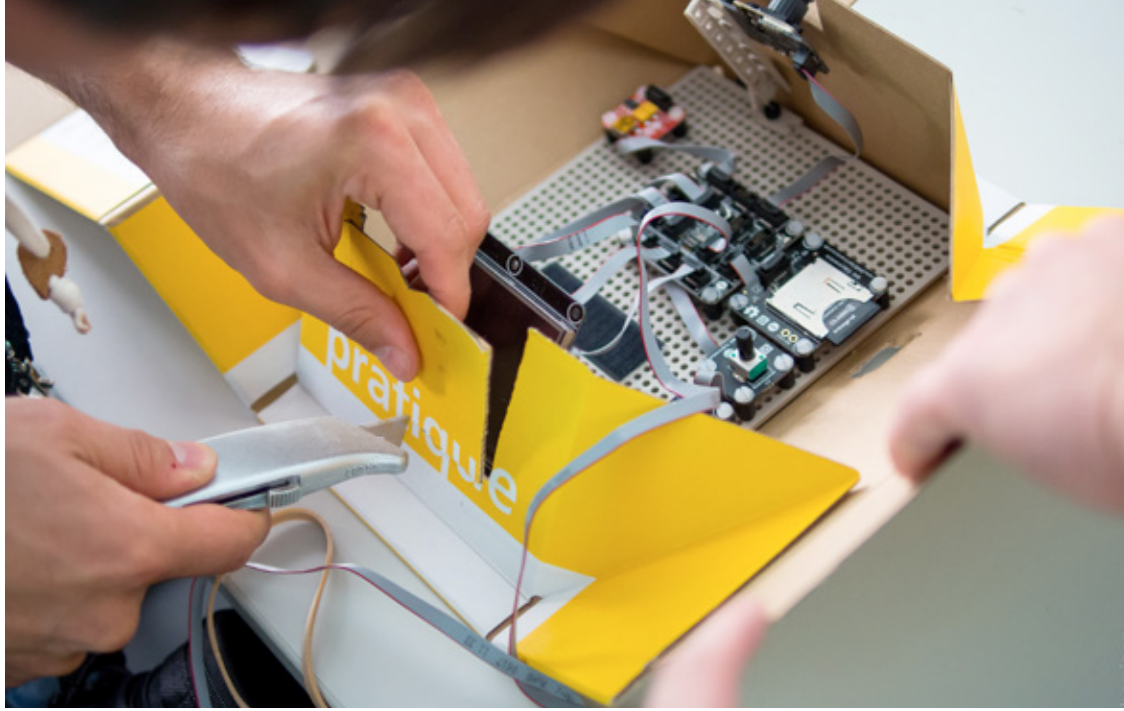
The top two challenges facing wireless sensor networks (WSNs) are that of network-wide longevity and maintenance after deployment. The ability to conserve energy is core to both challenges. Therefore, harvesting energy from the environment brings a step change that ensures the viability of WSN for real-world deployments.

Understanding the optimal usage of fluctuating renewable energy in WSNs is complex. Lexicographic max-min (LM) rate allocation is a good solution but is nontrivial for multihop WSNs, as both fairness and sensing rates have to be optimised through the exploration of all possible forwarding routes in the network. All current optimal approaches to this problem are centralized and offline, suffering from low scalability and large computational complexity—typically solving O(N2) linear programming problems for N-node WSNs. Our work presents the first optimal distributed solution to this problem with much lower complexity. We apply it to solar-powered wireless sensor networks (SP-WSNs) to achieve both LM optimality and sustainable operation. The optimality, convergence, and efficiency of our approaches are formally proven. We also evaluate our algorithms via experiments on both solar-powered MICAz motes and extensive simulations using real solar energy data and practical power parameter settings.

Deployment:

Analysed and simulated then deployed on a network of solar-powered sensor nodes, which consist of following: a MICAz mote, with Emin = 30.4J and Emax = 167.9J, a 9 × 3.8cm2 solar panel, a battery with capacity Bmax = 10.7KJ, efficiency = 74.8%, and a circuit board to power the MICAz mote and control the battery recharge and discharge process.

SENCITY



WHAT SHOULD FUTURE SENSING TECHNOLOGIES LOOK LIKE IN URBAN PUBLIC SPACES?

FORWARD RESEARCH QUESTION

What form should new sensing devices embedded in our cities take? See page 144

The SenCity workshop was hosted at UbiComp 2013 in Zurich, Switzerland. The aim was to explore the uses and form factor of mobile sensing kits and infrastructure sensing in urban environments. This was in response to a growing trend of small sensing kits aimed at citizen hackers with the idea of creating crowd-sensing networks. What we wanted to look at in the workshop was the possible uses of such kits in a real urban environment and what benefits they could bring to the individual citizens who would make up these large crowd-sensing networks. In particular, should sensors be camouflaged or should they be highly visible to citizens? How could their form factor show affordances and provide a flavour of the data being sensed to citizens in the local environment? There is no doubt that such kits could provide huge amounts of data but what could we do with it?

In the workshop, participants were provided with a custom-made "SenCity" sensing kit. Each kit had an LED display, a camera and various knobs, sliders and buttons so users could configure it on the go, without the need for programming. Materials were provided for groups to create casings for their sensor kits, resulting in a range of forms including a variety of anonymous grey boxes, sensing ducks and a hand-shaking alien. In the final part of the workshop, each group then went out into Zurich to try their creations in a real-world environment.

The data and pictures collected from the field testing were visualised using a custom-made visualisation tool that allowed each group to scan through their data, view the pictures, and put together "data stories" describing what they had sensed and why. Several key insights were recorded. Firstly, we observed first hand the significant impact that form factor can have in provoking or alleviating privacy anxieties of the public. Highly visible and curious objects such as the Duck and Alien encouraged a positive response and intrigue rather than an initial negative reaction and privacy concerns. Secondly, many members of the public wanted to interact with the sensing devices and were happy to engage. Some expressed that they would have liked some simple takeaway or reward for their engagement. We conclude that perhaps future sensing should not be such a passive, inaccessible activity in public spaces but rather interesting and informative additions to our urban landscapes.

BRIXTON "DATA WHAT"

HOW CAN THE DESIGN OF URBAN DATA AND IOT BECOME MORE INCLUSIVE AND ACCESSIBLE TO SUPPORT COMMUNITY ENGAGEMENT STRATEGIES FOR PARTICIPATORY REGENERATION?

Partners:
Local Primary schools, Brixton Green Mutual Society, Lambeth Council, UCL Urban Lab

FORWARD RESEARCH QUESTION

How can we encourage communities to reflect upon local issues?

See pages 64, 94, 96

Data What is a project on citizen-led AQ sensemaking in Brixton's Somerleyton Road redevelopment, the largest community led development in the UK. The first workshop explored community-led data literacy using air quality data as a starting point to discussing how to help communities better understand the changes in their neighbourhood as it undergoes new urban developments over time.

The research focus in Brixton Green is to understand the potential of ICT technologies in supporting participatory governance and regeneration, and asks questions such as how the social, economic, and environmental challenges of city life can be addressed with interactive computing technology which engages the public in processes of change.

Key outcomes:

- Air quality monitors and weather stations were installed in the community centre and a local school to monitor changes in air quality at the site over two years.
- Custom tablet-based data visualisation for quick comparisons of hourly NO2 levels across different sites close to Brixton, allowing users to compare their location to others.
- The project supported the emerging importance of the London Living Labs to explore the use of IoT in new models of governance (particularly emergent participatory regulatory cultures).

ORGANICITY
CO-CREATING SMART CITIES OF THE FUTURE

HOW CAN CITIZENS BE EMPOWERED TO CONTRIBUTE TOWARDS SENSING AND COMMUNICATION INFRASTRUCTURES, KNOWLEDGE AND SERVICES FOR SMARTER CITIES?

A key ambition of Horizon 2020 OrganiCity project is to make the creation and design of technologies and services for cities more inclusive for citizens and communities. It aims to tackle the question of how smart cities can be organically grown from citizens and communities instead of being engineered by the visions of large cooperates and city governments alone.

Three clusters – Aarhus (DK), London (UK) and Santander (ES) – recognised for their digital urban initiatives, bring together 15 European stakeholders into a coherent effort to develop an integrated Experimentation-as-a-Service facility across these cities. The resulting facility will be augmented with emerging tools and methodologies for participatory technology design and crowd-sourcing of citizen assets and leveraged for conducting a series co-creation experiments with citizens. The project will examine issues of governance and ownership in a hybrid digital and physical space.

- Bringing opportunistic network protocols and incentivisation algorithms into the wild, initially to better understand the shortcomings of current technological support for such systems and to build algorithms and protocols that will overcome these shortcomings to make opportunistic networking in city systems a viable reality.

- Exploring the use of existing active learning algorithms in a CityPedia like environment to allow citizens and data scientists to label urban data streams for co-creation of urban knowledge; thus contributing to a more scalable creation of knowledge from urban data streams.

- Insights on how business processes and governance models in cities have to evolve to better support co-created smart-city infrastructure.

PHD RESEARCH

URBAN VISUALISATION

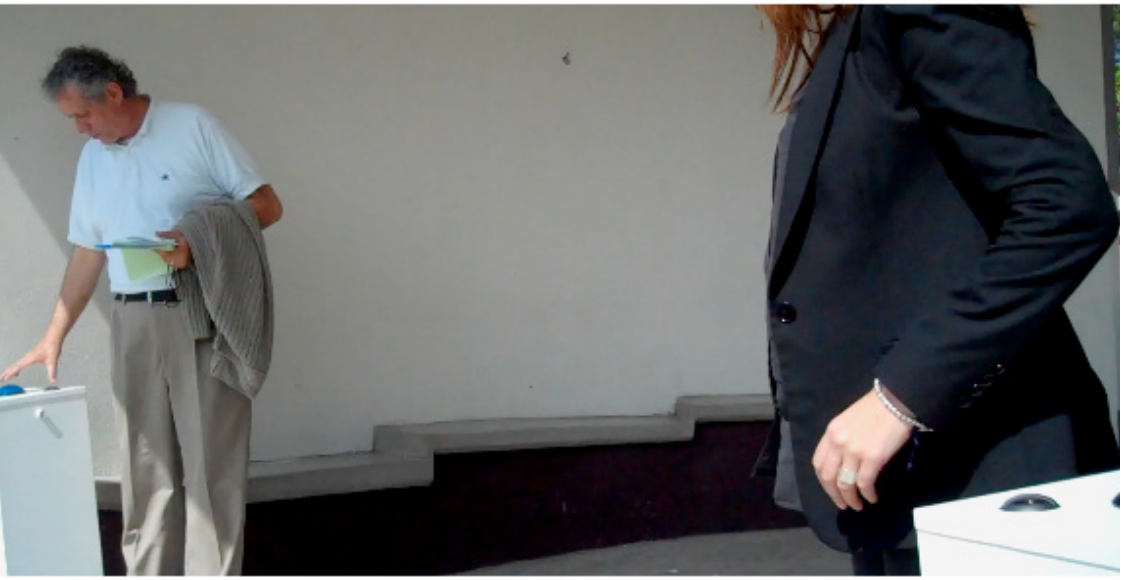
Lisa Koeman

The use of situated technology with the aim of connecting people has increased in recent years, amid widespread concerns that cities are becoming less socially connected. The deployment of public screens has been particularly popular, to display games, photos, or other entertaining content, with the aim of bringing people together. Till date, however, little is known about how publicly collecting and visualising hyper-local data can foster community engagement, by encouraging people to think and talk about their perceptions of the community.

Through a series of in-the-wild studies this PhD investigates how the public collection and visualisation of local data can encourage community engagement. More specifically, the thesis investigates how this process can inform communities, promote reflection, and encourage civic discourse on local topics. The conducted studies explore a number of key questions relating to the design and deployment of situated input technology and visualisations, such as the role of the topics (e.g. who should decide what topics should be addressed?), the role of the input technology design (e.g. where in communities should input technology be positioned? what kind of input method is most effective?), and the role of the visualisation design (e.g. how much information should public visualisations convey? where in communities should they be positioned?).

The contribution of this work is twofold. In addition to the presentation of the design, deployment, and evaluation of four urban visualisation projects, the thesis provides a theoretical framework. This framework describes the design characteristics affecting engagement with urban visualisations, such as the impact of the visualisation's update frequency on sustaining the community's interest in the project, the influence of the input method on contribution quality, and the importance of positioning to ensure participation by a diversity of the community.

LISA KOEMAN IS A PHD CANDIDATE AT UNIVERSITY COLLEGE LONDON. SHE COMPLETED HER MSC IN HUMAN-CENTRED INTERACTIVE TECHNOLOGIES (DISTINCTION) AT THE UNIVERSITY OF YORK, PRIOR TO WHICH SHE GRADUATED CUM LAUDE FROM HER BSC IN INFORMATION SCIENCE AT THE UNIVERSITY OF AMSTERDAM.



DESIGNING NOVEL TECHNOLOGY INTERVENTIONS FOR SUSTAINED COMMUNITY ENGAGEMENT

Mara Balestrini

As HCI moves to the wild, a pressing issue for researchers collaborating with communities to design and develop technologies for positive social impact is how to ensure the sustainability of the resulting interventions and practices. There are very few descriptions of HCI projects that have been appropriated by communities in the long run and have become useful tools to address local issues.

The goal of this PhD is to explore how we can design novel socio-technical systems for sustained community engagement. By carrying out both ethnographic studies of existing community technologies and designing and evaluating novel interventions, this thesis reveals a number of themes underlying sustained community engagement with projects where the participation of users is crucial to their success: ownership, novelty, social interactions, appropriation, and empowerment.

The contribution of this PhD is twofold: on the one hand, it presents a set of themes highlighting key factors that are positively related to sustained community engagement. On the other hand, it presents a novel actionable framework for the design and deployment of sustainable and scalable community technologies. This generative approach ensures that interventions are issue and community-centered, and supports the development of an urban commons.

MARA BALESTRINI IS A PHD CANDIDATE AT UNIVERSITY COLLEGE LONDON. WITH A BACKGROUND AS A "CULTURAL TECHNOLOGIST" SHE IS A STRATEGIC PLANNER AT IDEAS FOR CHANGE WHERE SHE CONSULTS ON SMART CITIES, CITIZEN DRIVEN INNOVATION AND OPEN BUSINESS MODELS AND SINCE 2010, HAS BEEN AN ADVISOR AT CCCB LAB, CENTER OF CONTEMPORARY CULTURE OF BARCELONA, WHERE SHE CONSULTS ON HOW TO ENHANCE EXPOSITIONS AND PARTICIPATION USING NEW TECHNOLOGIES.

COUPLING URBAN SIMULATIONS AND REAL-TIME DATA FEEDS VIA THE USE OF NETWORKED INFRASTRUCTURE

Kostas Cheliotis

Ongoing debates in the past decades have positioned the need for active and engaging public spaces as a central theme in the topic of the transformation of urban space. In addition to theoretic work, researchers have been looking at how these spaces are actually being used, using empirical data to identify the main characteristics of such spaces, in order to shape future well-functioning public spaces.

Following in this vein, this PhD investigates simulation-based approaches to analyzing the workings of public spaces, through direct observation and explanatory modelling of parks in central London. It attempts to codifiy park visitor behaviour, and to further identify how visitor use patterns are affected by the physical as well as social characteristics of the space itself, through agent-based micro-simulations of an actual park.

Park life simulations are further expanded in order to encompass the wealth of real-time urban data feeds currently available, developing into real-time vizualisation and analytics tools. By harnessing a diverse range of real-time data feeds, from social media, to transport, to environmental conditions, these tools can provide informed predictions on current overall park visitor footfall, as well as current activities and crowded/ popular locations within a park. Using these tools and methods then, this research ultimately attempts to develop a always-on, vizualisation and short-term prediction tool of current urban space activity, to help us understand how urban spaces work at the human scale.

KOSTAS CHELIOTIS IS A PHD CANDIDATE AT THE CENTRE FOR ADVANCED SPATIAL ANALYSIS - CASA, UCL, WITH A BACKGROUND IN ARCHITECTURAL ENGINEERING, URBAN ANALYSIS, AND VISUALISATION, LOOKING AT SMALL-SCALE URBAN SIMULATIONS.

EXPLORING THE ROLE OF PEOPLE DYNAMICS IN RELATION TO [FEAR OF] CRIME IN AN URBAN ENVIRONMENT

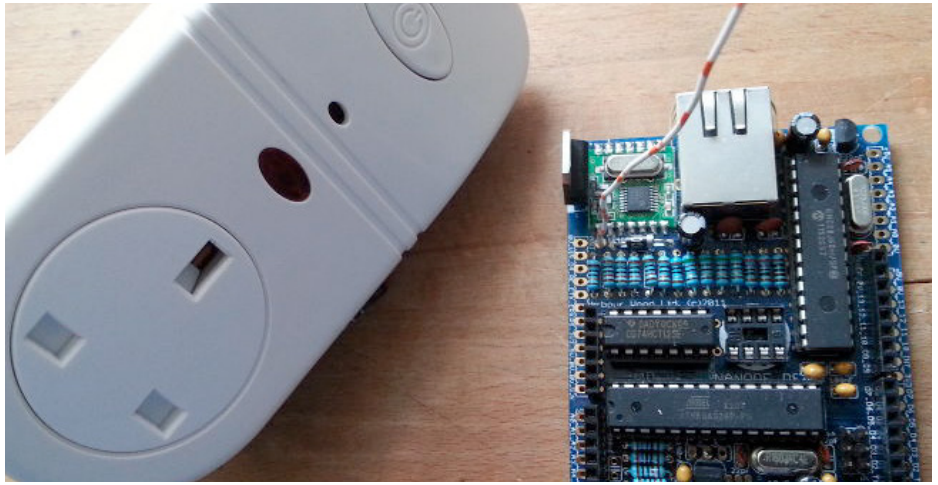
Martin Traunmueller

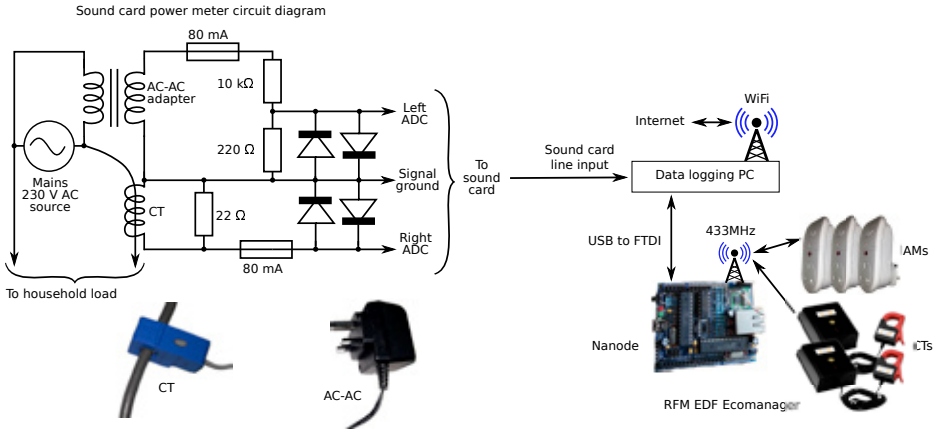
Looking at the situation of urban development nowadays, we observe that besides crime, fear of crime has become an increasing problem for the broad population. In contrast to actual crime activity, fear of crime describes a perception, such as a lack of feeling of safety by the urban population in the environment, that stands in close relation to crime activity but furthermore, supported by modern media, is not restricted to space and time. These circumstances lead to serious problems for a city's inhabitants and its government as fear of crime has great impact on the quality of urban life: As people avoid feared places the city's walkability gets limited and hence leads to increased motor traffic impacting the city's sustainability.

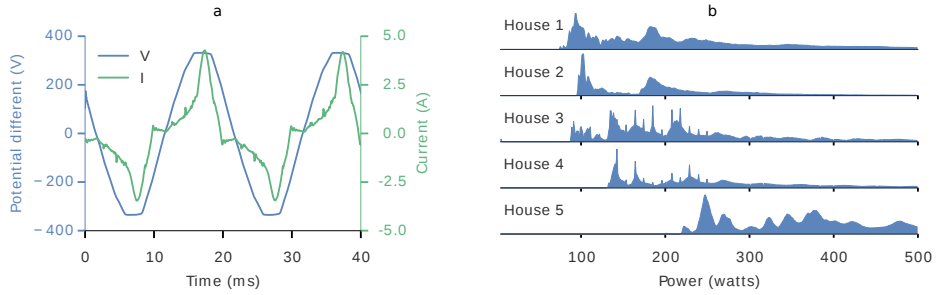
Research that tries to understand complex dynamics behind crime and fear of crime in urban environments suggests that there is a relationship between properties of the city's population (people dynamics) and (fear of) crime. Most conducted work shares the same theories to ground their work in, leading back to Jacobs and Newman who suggest different ways in designing the built environment to take advantage of the resulting social control of (fear of) crime. By including or excluding different demographic population groups through urban design, they describe people dynamics that attract or repel crime activity in an area and impact fear of crime perception at different times.

Each theory has been evaluated, and indeed supported by means of qualitative research methods that enable in-depth and semantically rich investigations into the reasons behind certain phenomena relating to people dynamics and (fear of) crime. However, common methods are very expensive and time-consuming to run so that studies are usually restricted to a rather small number of people (relative to the overall urban population) and constrained to geographic areas (e.g. a neighbourhood); furthermore, they are almost never repeated over time to observe potential changes. To develop an understanding of the relationship between people dynamics and (fear of) crime we propose in this thesis novel ICT based methodologies to complement traditional ones to study the subject at temporal and spatial scale.

MARTIN IS AN ARCHITECT AND DIGITAL URBANIST FROM AUSTRIA. AFTER HIS ARCHITECTURE STUDIES IN VIENNA, MARTIN WORKED AS DESIGN ARCHITECT IN DUBAI AND VIENNA BEFORE HE JOINED THE ADAPTIVE ARCHITECTURE AND COMPUTATION COURSE AT THE BARTLETT/UCL, ESTABLISHING A BRIDGE BETWEEN ARCHITECTURE, URBAN DESIGN AND COMPUTER SCIENCE. HE IS HIGHLY INTERESTED IN INVESTIGATING THE PHYSICAL AND DIGITAL RELATIONSHIPS BETWEEN AN URBAN ENVIRONMENT AND IT'S INHABITANTS, ESPECIALLY IN THE FIELD OF URBAN CRIME AND FEAR PERCEPTION AND THEIR RELATION TO DIGITAL MEDIA. BESIDES HIS RESEARCH AS PHD STUDENT AT THE ICRI, MARTIN IS CURRENTLY GAINING TEACHING EXPERIENCE AS TEACHING ASSISTANT AT THE CENTRE FOR ADVANCED SPATIAL ANALYSIS (CASA).







ESTIMATING AN ITEMISED ELECTRICITY BILL FROM A SINGLE, WHOLE-HOUSE SMART METER

Jack Kelly

You probably want to reduce your electricity bill (who doesn't want to save money?). But which appliances and behaviours should you focus on? Are any of your appliances misbehaving in a way which increases their energy demand? If you have already made changes (e.g. changing light bulbs) then were those changes effective at reducing your energy demand?

By 2020, every house in the UK should have a smart meter installed. Many other countries are also rapidly rolling out smart meters. These meters measure whole-house electricity demand once every ten seconds. But this aggregate data cannot answer the questions posed in the paragraph above. To answer those questions we need itemised (appliance-by-appliance) electricity consumption data. Energy disaggregation is a computational technique for estimating an itemised electricity bill from aggregate meter data. Jack's PhD is on energy disaggregation. The ultimate aim is to help people to save energy.

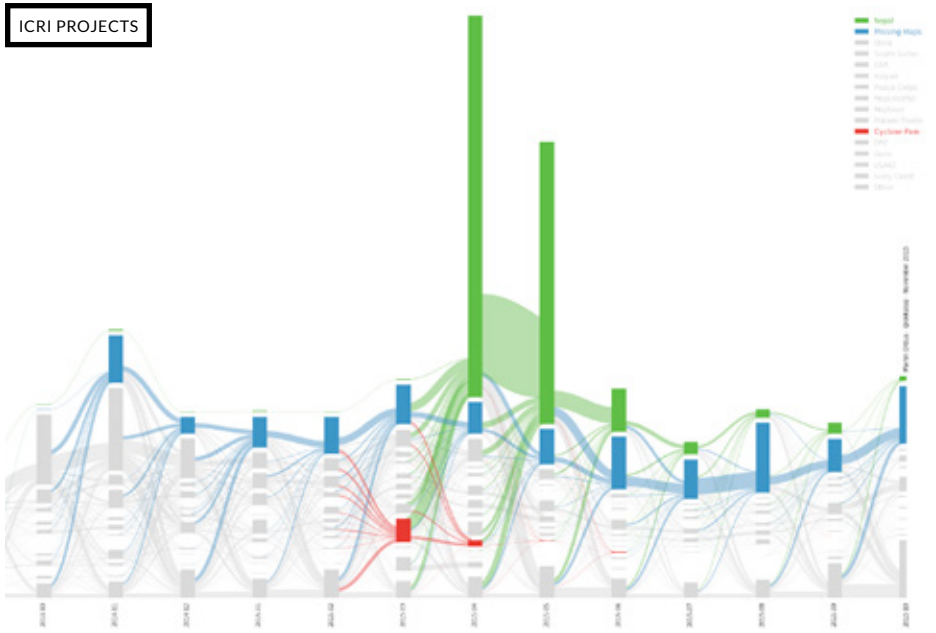
Jack's contributions include: 1) recording and releasing the UK domestic appliance-level electricity (UK-DALE) dataset which is the highest temporal resolution UK dataset of this type available; 2) Jack is one of three lead developers on the first open-source energy disaggregation framework (NILMTK); 3) Jack designed the only metadata schema available for disaggregated energy data - this schema is now used by over 11 datasets; 4) Jack adapted deep neural networks to energy disaggregation and demonstrated that they performed better than two benchmark algorithms.

JACK KELLY WANTS TO USE COMPUTER SCIENCE (ESPECIALLY MACHINE LEARNING) TO HELP MITIGATE CLIMATE CHANGE. HE LIKES TO WORK IN THE MOST OPEN WAYS AVAILABLE. JACK HAS A MASTERS IN COMPUTING FROM IMPERIAL COLLEGE (DISTINCTION) AND A FIRST CLASS UNDERGRADUATE DEGREE IN NEUROSCIENCE FROM UCL

LARGE-SCALE VOLUNTEER ENGAGEMENT IN HUMANITARIAN MAPPING

Martin Dittus

MARTIN DITTUS IS AN ENGD CANDIDATE AT UNIVERSITY COLLEGE LONDON. HE HAS A PROFESSIONAL BACKGROUND IN LARGE-SCALE DATA ANALYSIS AND "BIG DATA" METHODS, AND A DECADE OF EXPERIENCE WITH COMMUNITY ORGANISATIONS. HE WAS AWARDED A MASTER'S DEGREE AT THE CENTRE FOR ADVANCED SPATIAL ANALYSIS AT UCL, AND PREVIOUSLY WORKED AS A SOFTWARE DEVELOPER AND PROJECT MANAGER AT THE INTERNET STARTUP LAST.FM.



The Humanitarian OpenStreetMap Team (HOT) coordinates thousands of online volunteers to trace roads, waterways, huts and houses from satellite data. The resulting maps were used during humanitarian responses to typhoon Haiyan in 2013, the Ebola epidemic in 2014, the 2015 Nepal earthquake, and many other crises. In some cities HOT organises mapathons, social events where new contributors can learn the practice. HOT has an ambition of formidable scale: even after months of work by thousands of volunteers, many regions remain unmapped. How can organisers of such crowdsourcing initiatives best grow their volunteer capacity? The research aims to identify processes that can foster such community growth.

It was developed in close collaboration with HOT organisers, and takes the form of three large-scale quantitative observational studies at the scale of the individual, the group, and the collective. The volume and breadth of HOT activities provides an opportunity to observe a range of contributor engagement aspects within the same crowdsourcing system, involving a large number of projects and participants, with many opportunities to evaluate specific organiser choices and organisational practices. To date we have observed thousands of contributors across a large number of initiatives and contribution settings, involving considerations of task design and task complexity, contributor guidance, peer support, social encounter, and more.

The research contributes new empirical evidence that community-building approaches can have a great impact on sustained crowdsourcing engagement. The highest contributor retention rates were found for initiatives that foster collective experiences, for example through social encounters in offline settings. In particular, initiatives that organise regular mapathons have twice the retention rate of those that follow the same contribution process, but focus on online contributions. Task design and other aspects of the contribution process were found to affect contributor engagement as well, but their impact was comparatively low.

EMPOWERING COMMUNITIES TO CREATE AND BUY PRODUCTS WITH A POSITIVE SOCIAL IMPACT

Jessi Baker

JESSI BAKER IS A DESIGNER & CREATIVE TECHNOLOGIST EXPLORING CONCEPTS FOR THE FUTURE OF THE INTERNET, PARTICULARLY PERVASIVE COMPUTING AND OPEN DATA AND HOW A UNION OF THE TWO CAN INFORM CITIZEN CHOICES. A TRUE BLEND OF ART AND SCIENCE, JESSI HAS A MASTERS IN ENGINEERING FROM CAMBRIDGE UNIVERSITY AND A MASTERS IN DESIGN FROM THE ROYAL COLLEGE OF ART.

Every product has a story: a journey of people, places and raw materials. Yet little information from the supply chain that led to the creation of a product is accessible to the potential consumer. Furthermore, there is paucity of research into how to make the supply chain and product life cycle transparent, supporting the many value sets of the makers of products and the shoppers. The aim of this PhD research is to explore how different technology interventions can be designed and used 'in the wild' with creators and customers of lifestyle products in order to facilitate communication and new forms of connection between the two. It will build upon existing nascent research into product supply chain transparency by examining the process in relation to the rise of local digital fabrication and the use of innovative physical and digital interfaces for shopping.

The main research question to be addressed is: **How can technology empower communities to create and buy products with a positive social impact?** To address this question, social impact measures that will be analysed will include fair wages, skills training and qualitative values such as empathetic connections formed between creators and shoppers within different communities. The PhD will examine the challenges with opening up supply chains looking specifically at small-scale, local production in and around cities and will explore how we can capitalize on existing shopper and creator behaviour to power a sustained dialogue and consumer choices that are more in line to the longstanding personal ethics of the consumer and community.

DETECTING MALICIOUS DATA INJECTIONS IN WIRELESS SENSOR NETWORKS

Vittorio Illiano

Wireless Sensor Networks are widely advocated to monitor environmental parameters, structural integrity of the built environment and use of urban spaces, services and utilities. Yet wireless sensors carry a much higher risk of being compromised. Their deployments are often unattended and physically accessible and the wireless medium is difficult to secure.

Malicious data injections are a particularly threatening type of attack causing sensors to report false information and thereby aiming to produce inappropriate and potentially dangerous responses. They can be particularly difficult to detect if multiple sensors have been compromised as compromised sensors could collude to change the reported measurements whilst making such changes difficult to detect.

Our work, which started in October 2013 aims to design new algorithms for the detection of attacks in such difficult circumstances. A literature survey has revealed a large number of algorithms proposed for anomaly detection in sensor measurements. This survey was published in ACM Computing Surveys on October 2015. Yet many do not consider malicious collusion nor evaluate against realistic threats.

We have designed an initial algorithm, which detects effectively malicious data injections when a single event occurs at a time. This work was published in IEEE Transactions on Network and Service Management on September 2015. Multiple events, however, provide the opportunity for new, more complex attack strategies, such as creating false events near legitimate ones, transforming a severe event into several mild events etc. We have then reviewed and re-developed the initial approach to cope with such complex scenarios and, in addition to detecting malicious data injections, we have developed a methodology to characterise the responsible sensors and to distinguish malicious interference from faulty behaviours.

VITTORIO ILLIANO IS A PHD STUDENT IN THE DEPARTMENT OF COMPUTING AT IMPERIAL COLLEGE LONDON. HIS BACKGROUND IS ON NUMERICAL DATA ANALYSIS, STATISTICAL LEARNING AND MACHINE LEARNING.

INTERNS + CONTRIBUTORS

INTERNS + CONTRIBUTORS

The ICRI has benefited from having a constant flow of "new minds" through the institute via various internships and collaborative projects.

A rotating internship programme has been set-up through Intel Labs Europe to support 2 part time (50 hours / month) interns from London based Design Schools to support project work. The programme has allowed designers from Royal College of Art, Central Saint Martins and London College of Communications to contribute to our projects.

Intel co-funded with the Economic and Social Research Council two PhD interns for six months each. A sociologist from Warwick and an environmental economist from Strathclyde made major contributions to several projects.

The ICRI has benefited twice from the Intel Rotation Engineer Programme supporting Jason Wright and Michael Rosen joining the Intel team for 6 months to support PoC development on Edison and Galileo and support the Living Lab deployments.

HUDDLELAMP: DEVELOPMENT OF JAVASCRIPT APIS TO FACILITATE THE AUTHORING OF HUDDLELAMP APPLICATIONS

Oscar Robinson (UCL Computer Science undergraduate student)
Jonny Manfield (UCL Computer Science undergraduate student)

The HuddleLamp project continuously tracks the presence and positions of devices on a table with sub-centimetre precision. At any time, users can add or remove devices and reconfigure them without the need of installing any apps or attaching markers. This enables users to temporarily share their personal devices for creating a joint cross-device system for a social and fun data exploration. HuddleLamp is intended for the exploration of urban data in semi-public spaces for which conventional interactive tabletops or large screen are much too expensive, e.g., schools, public libraries, community centres.

To enable non-expert developers and communities to write their own HuddleLamp applications, Oscar and Jonny developed JavaScript APIs for HuddleLamp. These libraries build upon the Meteor web framework, are available to to the public. (see huddlelamp.org) and are used in the code samples provided with HuddleLamp.

HUDDLELAMP: ELICITATION OF USER-DEFINED GESTURES AND SPATIAL LAYOUTS FOR MULTI-TABLET INTERACTION

Zhihao Lu (UCL HCIE master student)
Giuseppe Desolda (University of Bari, PhD student)

Lu and Giuseppe contributed to HuddleLamp by planning and conducting user focus groups and user studies that elicited preferred gestures and interaction techniques for multi-tablet HuddleLamp applications from different user groups. The answers were analysed and integrated in a continuously evolving set of design guidelines for HuddleLamp applications. Giuseppe also worked on the implementation of a prototype that illustrates the resulting interaction design.

HUDDLELAMP: EXPLORING ALTERNATIVE COMPUTER VISION ALGORITHMS FOR TABLET TRACKING

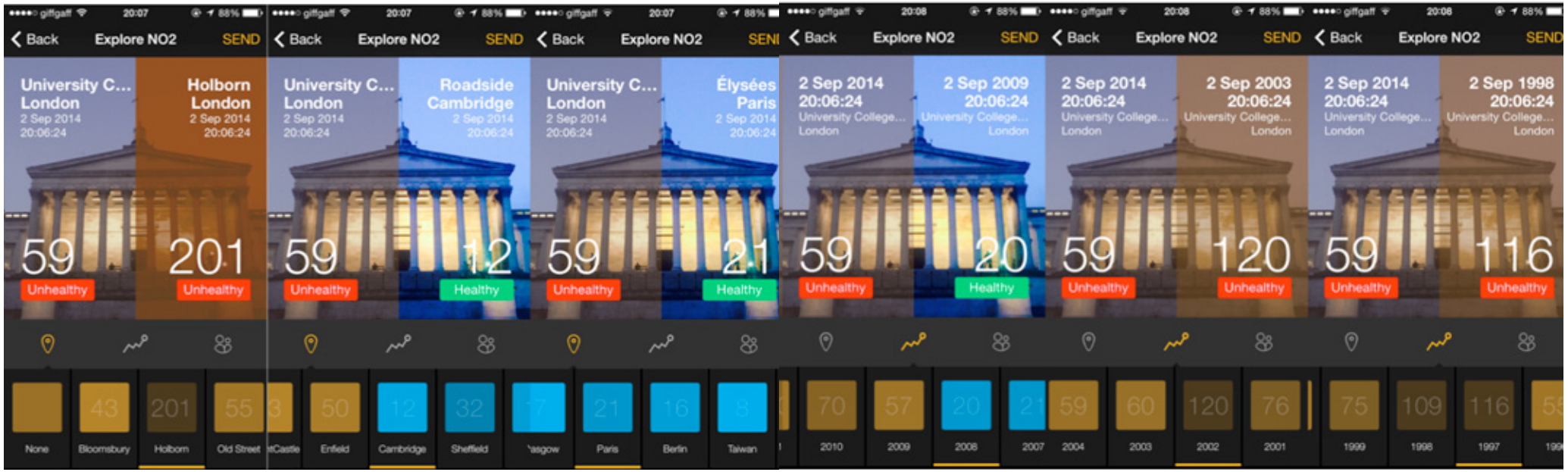
Francesco De Gioia (University of Pisa, Computer science undergraduate student)

Francesco explored alternative approaches and computer vision algorithms to reliably extract information about device and hand positions from a RGB camera image. Some of his explorations led to fundamental improvements in the reliability of HuddleLamp's vision system, particularly with respect to hand occlusion.

DESIGN OF AN ENVIRONMENTAL SENSOR NETWORK IN HYDE PARK TO AID IN BAT BEHAVIORAL STUDY

Tânia Calçada
Research Associate
Center of Competence for Future Cities of the University of Porto

A hardware design was proposed for an energy harvesting environmental sensor network within the park with initial experimentation undertaken as to its viability. Constraints were considered both from the networking layer and from the energy harvesting power budget perspective. An algorithm was then proposed for energy and topology aware Channel Assignment on Single-radio WSN. This centrally controls the channel on which nodes operate using information on topology and available energy to optimally distribute loads by the most efficient route.



UNDERSTANDING DEVICE PARTICIPATION IN COMMUNITY SENSING SYSTEMS

Yulin Wu, MSc
Imperial College

The project explored device participation patterns in SmartCitizen.me, a recently emerging citizen-centric sensing community emerging around a crowd-funded low cost sensing device. The work examined shipping data and the entire data base dump of time series and meta-data of the SmartCitizen.me platform, with the goal to understand the community uptake of such systems and the reasons for different device participation patterns across a global device community. Some of the finding were contributed to a CHI 2015 paper submission "Community Sensing Technologies: Leaving Users to Their Own Devices or Orchestration of Engagement?"

SOCIOECONOMIC IMPACT METHODS AND BUSINESS MODELLING FOR ENFIELD L3 PROJECT

Struan Noble, PhD Researcher - ESRC Environment, Climate Change and Energy Pathway Department of Economics, University of Strathclyde

Economic Impact Considerations and Overview of Methodologies to assess the resulting socioeconomic impacts arising from the London Living Labs Enfield Project which consists of a deployment of 100 air quality sensors in the Enfield Borough of London. The project also outlines strategies and considerations of how the sensor technology and resulting data and knowledge might be transferred through business models, lessons learned and potential future work that might be enabled by the Enfield Project.

FAST CONNECTION FOR OPPORTUNISTIC DATA COLLECTION AND RELAY OVER MOBILE PHONES.

Fengrui Shi -Department of Electronic Engineering and Computing, ETH Zurich.

Background study on different D2D technology specifications including Bluetooth, BLE, WiFi-Direct, DSRC, etc narrowed our focus to two specific radios: Bluetooth (classic) and WiFi-Direct due to the insufficient support of Android devices for BLE. Phone battery lifetime can and duty cycle and scanning time was researched. Important findings include: power consumption increases by 5 fold from a 1 second scanning time to 13 seconds; and degree to which WiFi-Direct can relay bulky data to increase energy efficiency. In order to characterize Bluetooth scanning time, an Android application has been built and real-world experiments carried out in the daily settings, .i.e. home, workplace and in the underground amounting to 20,000 logs being recorded (report). WiFi-Direct connection setup mechanisms, i.e., scanning mode, service discovery mode and autonomous mode, have also been studied. Understanding these systems in detail produces a smarter routing decision system for opportunistic relay using both radios, radio conditions and the number of active peers. This has been currently tested in a small number of devices scenarios.

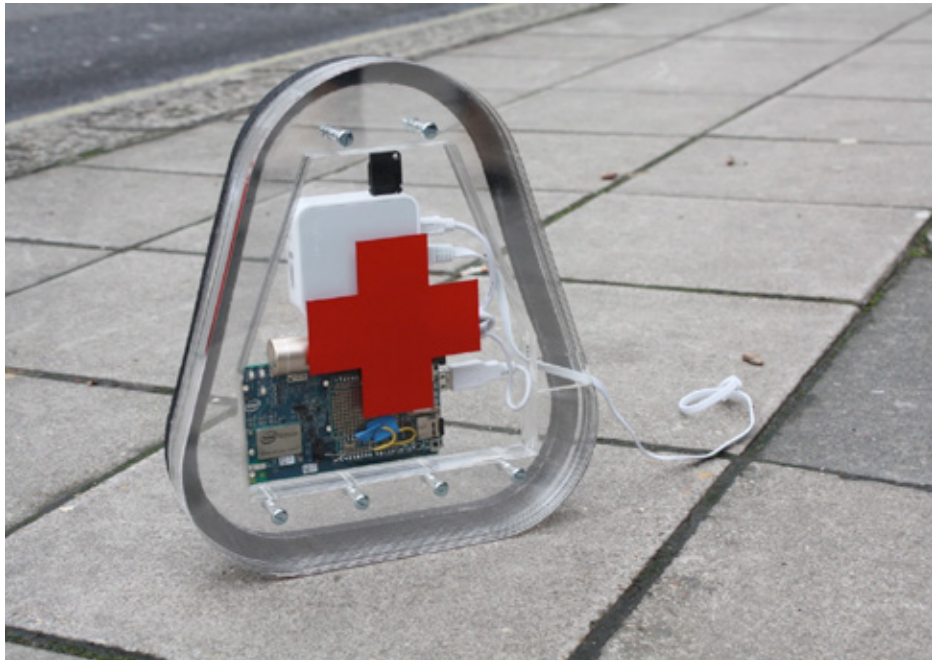
ICRI CITIES USER EXPERIENCE RESEARCH, LONDON LIVING LABS

Pedro Monteiro Doctoral Researcher - ESRC Environment, Climate Change and Energy Pathway IKON, Warwick Business School

Among its competitive advantages, ICRI Cities focuses on the creation of new technology via an ethnographic perspective, paying attention to the reflexive ways citizens engage (or fail to do so) with innovations in the urban technology landscape. Pedro contributed his perspective as an organisational sociologist to support projects related to the London Living Labs, including:

- Wearable Activity Trackers and the Quantified Community: Measuring Success – A meta-analysis of 40+ activity tracker case studies to define a baseline proxy could be used as a success metric for Walk the Talk's intervention design.

- ICRI Cities Competitive Landscape Review – A global meta-analysis of existing research institutes on the sustainable cities domain.



Data What? A Creative Evening of Community Data - convened the first community workshop using bespoke community data applications at the Six Brixton community centre in Somerleyton Road.

IOT AND SUSTAINABLE NEIGHBOURHOODS

Intel Design School Network, LLDC and Royal College of Art.

Co-hosted an Internet of Things course module with Design Products and Interaction Design Masters students at the Royal College of Art (RCA). The key question posed to students in the project brief was: "How can the Internet of Things contribute towards building a sustainable and thriving neighbourhood in an inner city?" Themes emerging from the cohort of 60+ designers were broadly grouped into the following themes: 1.Bringing communities together 2.Improving park experience 3.Environmental awareness. The module included a 2 day workshop on Intel Edison + Enableiot platforms.

FUTURE CITIES, FUTURE HEALTH

Intel Health, Intel Design School Network, Imperial and Royal College of Art.

As part of the Innovation Design and Engineering Masters programme this project was an investigation into the future of health in urban environments and a projection of how technology might support four theme areas: Food, Water, Air; Systems of Systems; Measuring and Mapping; and Cities of Data. The 40+ students developed physical computing design concepts based on Galileo and Arduino based platforms.

MAKING THE INVISIBLE VISIBLE: VISUALISING AIR QUALITY IN AN UNDERSTANDABLE WAY

Ye Lin, MSc ICT Innovation – EIT ICT Labs Masters Programme UCL Interaction Centre

"Visualising the Invisible" - Playful mobile application concepts for fixed urban AQ data visualization to help people understand air quality and relate air quality with real life situations. User interviews were conducted to understand people's perceptions about air quality and the needs and requirements for an air quality visualisation. Findings showed that participants used visual cues, such as photographs, to perceive air quality. However, as many pollutants are invisible, this visual check cannot be relied upon. The project developed and tested the InstaNO2 app, which proposed a photo-based air quality visual representation to visualise local air quality data using photograph filters explore the current NO2 level.

INVESTIGATING CITY AIR QUALITY: A CROSS-CULTURAL ETHNOGRAPHY IN OSLO, MUNICH AND SAN JOSE

Aksel Ness, Jennifer Heier and Tessa Hammatt, MSc Design Ethnography 2014 Duncan of Jordanstone College of Art and Design (DJCAD), University of Dundee

Investigating City Air Quality: Ethnographic research towards design for clean air", investigated issues around air quality in three major urban centers in Europe and North America: Oslo, Munich and San José, with a view to mapping the key landscape within each city to outline how different stakeholders, including city authorities, would make use of a next generation air quality system based on a distributed network of low to medium cost sensors and help define insights for how air quality sensing may influence our lives as citizens, business owners, and administrators of the near-future city, supported by patterns, trends and best practices.

JOKEBOX: HOW CAN IN SITU AGILE METHODS HELP US DESIGN INTERACTIVE SYSTEMS FOR URBAN SOCIAL INTERACTIONS?

Ji Hu, MSc UCL

Ji Hu collaborated in the development of a lightweight version of the JokeBox based on a wizard of oz that allows the researcher to control the device's interactive features on the fly. In 8 in the wild deployments we found that a flexible design is more suitable to the purpose of exploring human social interactions in complex spaces, which are navigated both through physical movement and interpretations of social context. These findings can help improve the usability of situated urban displays.

MAKING A DIFFERENCE - FROM ENVIRONMENTAL SENSING TO ACTION

MDes Service Design Innovation and MA Interaction Design Communication London College of Communications

Exploring the role of sensors in the city, LCC MDes Service Design Innovation and MA Interaction Design students developed a range of solutions to urban challenges. Six interdisciplinary teams of students developed projects that ranged from the increasing problem of food waste through to de-stressing intense public spaces such as Elephant and Castle tube station.

From the six projects Intel chose two projects to exhibit at its 'Intel Make Hackney Sparkle' exhibition showcasing our work in co-designing sustainable urban experiences focusing on IoT demos in conjunction with the Borough of Hackney at the TechMix Digital Festival (http://techmixmag.com/summer_festival) opened by the UK Secretary of Education and London Mayor catering to 10,000 visitors interested in London as "Tech City for Youth".

PUBLICATIONS

KEY PUBLICATIONS

C Smith-Clarke, L Capra, A Mashhadi: "Poverty on the Cheap: Estimating Poverty Maps Using Aggregated Mobile Communication Networks" *SIGCHI 2014*

CROWDMEMO WAS A COMMUNITY TECHNOLOGY INTERVENTION IN RURAL ARGENTINA THAT ACHIEVED SUSTAINED AND BROAD ENGAGEMENT EVEN AFTER RESEARCHERS LEFT THE FIELD, LEADING TO IMPACTFUL OUTCOMES IN PUBLIC POLICY, HERITAGE PRESERVATION, AND EDUCATION.

M Balestrini, J Bird, P Marshall, A Zaro, Y Rogers: "Understanding Sustained Community Engagement: A Case Study in Heritage Preservation in Rural Argentina" *ACM 14*

R Rädle, HC Jetter, N Marquardt, H Reiterer, Y Rogers: " HuddleLamp: Spatially-aware mobile displays for ad-hoc around-the-table collaboration" *ACM 14*

NOVEL METHODOLOGY TO ESTIMATE POVERTY INDICATORS ACCURATELY AND CHEAPLY, AT A VERY FINE LEVEL OF SPATIO-TEMPORAL GRANULARITY, USING AVAILABLE TELECOMMUNICATION DATA. COLLABORATIVE WORK WITH THE UNITED NATIONS GLOBAL PULSE AND POPULATION FUND LABS.

HUDDLELAMP ENABLES AD HOC CROSS-DEVICE VISUALIZATION AND EXPLORATION OF URBAN DATA. THIS PROJECT WITH THE UNIVERSITY OF KONSTANZ FEATURED ON MANY LEADING TECH BLOGS SUCH AS GIZMODO. COM AND OVER 50,000 VIEWS ON YOUTUBE. MORE INFORMATION: HUDDLELAMP.ORG

S Yang, JA Mccann: "Distributed Optimal Lexicographic Max-Min Rate Allocation in Solar-Powered Wireless Sensor Networks" *ACM Transactions on Sensor Networks*

THE FIRST FULLY DISTRIBUTED SOLUTION TO JOINT ENERGY, SENSING RATE AND NETWORK SCHEDULING FOR ENERGY HARVESTED WIRELESS SENSOR NETWORKS. ALGORITHMS EVALUATED VIA EXPERIMENTS ON BOTH SOLAR-POWERED MICAZ MOTES AND SIMULATIONS USING REAL SOLAR ENERGY DATA.

A FULLY DISTRIBUTED AND GENERAL ALGORITHM, REQUIRING NO PREDICTION, THAT COMBINES NETWORK SCIENCE PRINCIPLES AND LYAPUNOV OPTIMIZATION TECHNIQUES, TO MAXIMIZE GLOBAL SOCIAL PROFIT ACROSS A HYBRID SENSOR AND MOBILE PHONE OPPORTUNISTIC NETWORK. THIS ALGORITHM PERFORMS CLOSE TO (OR BETTER THAN) A PERFECT PREDICTION ALGORITHM AND OUTPERFORMS PURE BACKPRESSURE AND SOCIAL AWARE SCHEMES.

NOVEL DISTRIBUTED LIGHTWEIGHT ANOMALY DETECTION ALGORITHM TO IDENTIFY UNUSUAL DATA OCCURRENCES CAUSED BY SENSOR FAILURE OR BY FALSE DATA INJECTION. THIS ALGORITHM CAN UNIQUELY SEPARATE DATA ANOMALIES CAUSED BY GENUINE EVENTS FROM THOSE CAUSED BY FAILURES OR MALICIOUS ATTACK PROVIDING FIRST STEPS TO A LIGHTWEIGHT EDGE PROCESSING SOLUTION.

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VIDEOS

VOXBOX
http://vimeo.com/105861348

SMART CITIZEN LAUNCH
http://vimeo.com/92820531

SMART CITIZEN MANCHESTER LAUNCH
http://vimeo.com/98325653

SENSING LONDON
https://vimeo.com/107166719

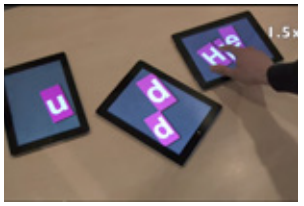
WALK THE TALK COMMUNITY DESIGN DAY:
https://www.youtube.com/watch?v=iyWWG-sKeK8

LOOP LAB RECRUITING PARENTS
https://www.youtube.com/watch?v=FBtSseMu7wg

ICRI AND FABLAB LONDON
https://vimeo.com/137962171

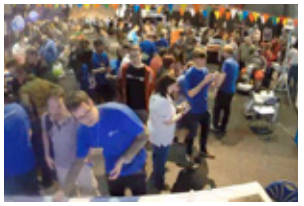
TOWER BRIDGE
https://vimeo.com/143856392

AIR QUALITY MONITORING IN ENFIELD
https://vimeo.com/142228034



HUDDLE LAMP
https://www.youtube.com/watch?v=XkmwG588zp0

INTERNET OF SCHOOL THINGS (DISTANCE)
https://vimeo.com/108297625



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CO2BY – AN ECOADVISOR FOR PARENTS AND CHILDREN
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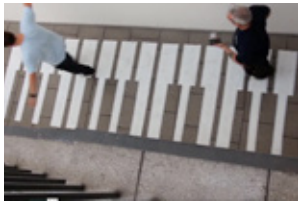
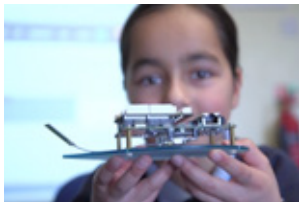
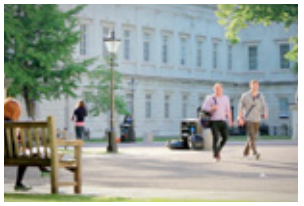


MELODY WALK – AN INTERACTIVE CROSSING
https://vimeo.com/98961591

BRIXTON WALK THE TALK
https://vimeo.com/142228035



IOT SCHOOLS ON BBC CLICK
http://www.bbc.co.uk/programmes/p02p9f20



ICRI CITIES INTRO
https://vimeo.com/79187226

ICRI PRESENCE ON THE WEB EXTENDED FROM HTTP://WWW.CITIES.IO/ TO THE FOLLOWING PROJECT PAGES:

HTTP://IOTSCHOOL.ORG/
HTTP://WWW.VOXBOXPROJECT.COM/
HTTP://HUDDLELAMP.ORG/
HTTPS://CROWDMEMO.WORDPRESS.COM/
HTTP://VISUALISINGMILLROAD.COM/
HTTP://QUANTIFIEDTOILETS.COM/

A SEARCH ON TWITTER FOR #BUBBLEAO REVEALS THE VARIOUS EVENTS WHERE THE INTEL GALILEO IOT BUBBLE DEVICE RUNNING ON INTEL IOT PLATFORM TOURED THE WORLD.

MEMBERSHIP OF ADVISORY BOARDS

- Digital Catapult – advisory network member and IoT demo lab advisory board
- Smart London Board, Greater London Authority – board membership and active contribution to their portfolio of projects
- EPSRC ICT Strategic Advisory Team – exploring potential interventions to deliver next generation research and innovation internet environments for UK research and industry
- HiPEDS Advisory Board - EPSRC Centre for Doctoral Training in High Performance Embedded and Distributed Systems at Imperial College.
- Advisory Board of a recently launched collaborative, transdisciplinary project in the area of learning analytics, science technology engineering and math, and hands-on laboratory learning - PELARS: "Practice-based Experiential Learning Analytics Research And Support"
- Consensus 2.0 Advisory Board - TCD, NUIG and Irish EPA Research Programme into Sustainable Consumption
- Imperial Cross-Departmental Committee on Sustainable Cities
- Review committee for Trinity College Dublin regarding Smart Sustainable Planet research
- Research Board for the Imperial Data Science Institute
- Advisor to Commonplace, a web-based tool for collecting people's views on local issues.

DISSEMINATION AND OUTREACH

- We have published 104 papers
- Presentation on ICRI and London Living Lab demo at Intel Developer Forum
- Participate in Intel UK Smart City Leadership team
- Google TEDx presentation 'Smart Sustainable Cities'
- Made 20+ videos documenting our projects (Huddlelamp had received over 50,000 views at Nov'14)
- Recognised as Intel Maker Ambassador for Intel contributions to European Maker Faires
- ICRI actively involved in organisation and sponsorship of 1st International Urban IoT Conference
- Funded and organised event at CHI2014 to promote ICRI activities
- Conducted design sprints with Future Cities Catapult to explore citizen pollution monitoring
- Delivered course on Intel Galileo at EU Senzations IoT Summer School
- Mentored a UK team on the Intel Edison Make it Wearable competition
- Curse support for Intel Design School Network Technologist in Residence at RCA and delivered four course modules to Design Interactions and Design Products students at RCA
- ICRI Cities Galileo-based IoT Bubbleao demonstrator toured across 4 continents as part of Intel's Future Showcase
- ICRI staff have 10,000+ followers on twitter

PRESS

- ICRI researchers interviewed in London and Dublin for Korean KBN TV program on Industrial IoT Innovations (broadcast July 2014 and distributed to middle and high schools across Korea)

- Intel Galileo and Project Distance featured in TechMix Magazine Coding special issue profiling Digital Skill Leaders helping kids learn coding in schools and inspiring digital talent.

- Tomas Diez was featured as one of the 10 social innovators to watch by both The Guardian and Nesta.

- David Prendergast named a 'Hero of the Fortune 500' by Fortune Magazine. http://fortune.com/heroes-of-the-500/dr-david-prendergast-34/

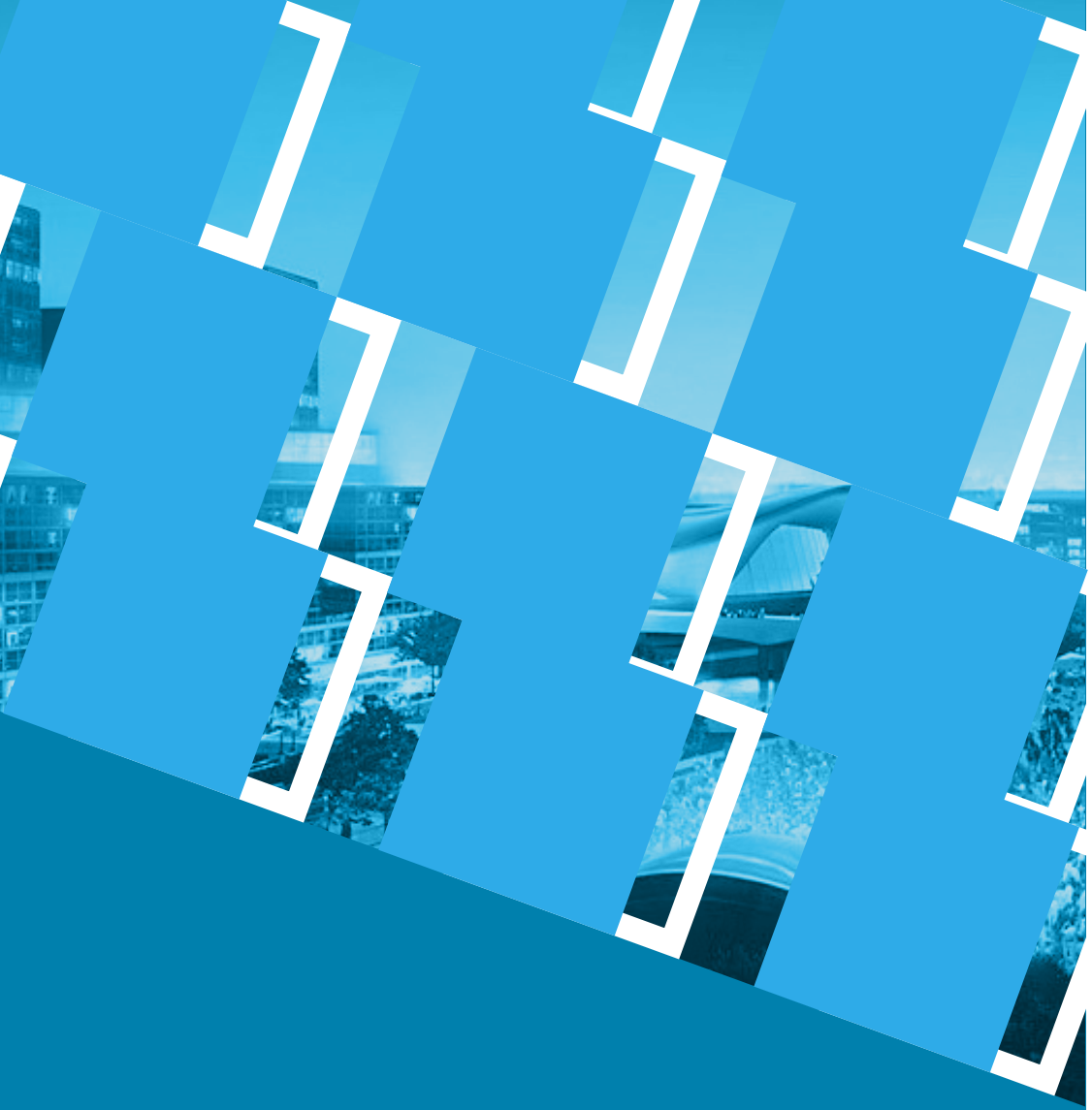
- The Visualising Mill Road project featured in Experimenta Magazine, Infosthetics and Fast Company "How These Simple Chalk Infographics On The Sidewalk Created A Neighborhood."

- Our sustained community engagement research garnered interest with a number of media outlets including two TV programmes and several newspapers including Zona Franca, El Mexicano, El Vigia and Frontera Ensenada

- Quantified Toilet project at CHI2014 covered by The Atlantic, Wired, Gizmodo, Mashable and others because of its high risk novel creative methodology

- The Internet of School Things project featured on BBC Click on 04.04.2015

ICRI PEOPLE



ICRI PEOPLE

INTERDISCIPLINARY

We are a mix of scientists, engineers, anthropologists and architects. The core team are hosted at Intel Labs Europe, the Computer Science department at Imperial and the UCL Interaction Centre.

OUR APPROACH

Based out of several locations across London the ICRI is led by a management team of Principal Investigators (PI's) from each organisation plus a managing sponsor and project director at Intel. The PI's are supported by a mix of postdoctoral researchers / research associates and PhD students. The former focus on project specific research, the latter focus on individual PhD activity informed by the vision of the institute. In addition to the core team we are continually welcoming visiting researchers and interns into the ICRI and aim to have 20% of staff flowing through the ICRI in that capacity.

LEADERSHIP

The management team report to a board of Directors chaired by the VP of Intel Labs Europe and is supported by a Board of Advisors from government, industry and academia.

FELLOW TRAVELLERS

Since its inception, the Institute has established a number of working relationships with local councils, the London Mayor's Office, the Future Cities Catapult and companies large and small. We have built strong collaborations with the Future Cities Catapult, companies large and small, and local government who share our efforts towards building the several London Living Lab prototypes.
We sit on the Connected Digital Economy Catapults advisory network, the Mayor of London's Smart London Board, the BIS Smart London Forum and engage in several academic communities through conferences, workshops and summer schools. It is through innovative collaborations that we are able to create truly original and future shaping research. Cities are wide and diverse environs that provide a myriad of opportunities and ICRI Cities are proud of the strength of its collaborative working relationships across the UK.

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Ji Hu
Chris Smith-Clarke
Tomas Diez
Emily Collins
Saskia Bakker

FUTURE AGENDA

FUTURE AGENDA

During the past three years our Living Lab approach has enabled us to explore a number of different socio economic and technical challenges through the deployment of novel connected devices across a variety of installations in London, as documented in this report. We have refined the vision for years 4 and 5 of the research institute and tasked ourselves to deliver use case inspired basic research to demonstrate the compute fabric needed to support the design of an urban Internet of Things at city scale.

We have identified three key technical IoT research areas which require further investigation (battery-less edge devices, tools for designing / deploying / maintaining IoT and adaptive communications), observed the challenges of sustaining user engagement (user acceptance, understanding, participation, ownership) and witnessed the importance of creating sustainable eco-systems of services (interfaces, interoperability, commercial viability).

OUR RESEARCH AGENDA MOVING FORWARD IS MOTIVATED BY THESE OBSERVATIONS AND DIVIDE INTO THE FOLLOWING PACKAGES OF WORK:

- ENERGY NEUTRAL SENSOR SYSTEMS
- MULTI-TENANCY TOOLS FOR URBAN IOT
- ADAPTIVE OPPORTUNISTIC COMMUNICATIONS
- ROAM.IO - ROBOTS FOR SENSEMAKING WITH CITIZENS
- SOCIAL STREAMS - SOFT SENSING FOR URBAN IOT
- IOT DEMONSTRATOR OF URBAN SOLUTIONS

WE CONTINUE TO BUILD ON OUR SUCCESSFUL LIVING LAB MODEL AND WILL FOCUS OUR EFFORTS IN 2016 / 2017 IN LONDON'S QUEEN ELIZABETH OLYMPIC PARK (QEOP).

The Living Lab at QEOP is located in East London and surrounding boroughs - Hackney, Newham, Tower Hamlets, Waltham Forest. This vast site was the main location for the London 2012 Olympic Games and is now managed by the London Legacy Development Corporation (LLDC) which is responsible for the long-term planning, development, management and maintenance of the Queen Elizabeth Olympic Park and its impact on the surrounding area. It is their task to transform and integrate one of the most challenged areas in the UK into sustainable and thriving neighbourhoods. The core team of Intel, UCL, Imperial and Future Cities Catapult will work closely with QEOP based clients (LLDC as development company, Cofely as Facilities Manager) and stakeholders (Smart Sustainable District project - Institute for Sustainability, Mayor's Office, Smart London Board). Our goal is to continue to deliver use cased inspired basic research that explores the socio, economic and environmental sustainability of Urban IoT.

AFTERWORD

London Legacy Development Corporation is using technology on Queen Elizabeth Olympic Park to help deliver the legacy of the 2012 Olympic and Paralympic Games. Given the wide range of stakeholders on the Park, including housing developers, employers, leisure and sport venue operators, we see innovative technology solutions as critical to delivering our citizen and visitor engagement and sustainability objectives. We have a range of technology organisations (commercial, not for profit, education, government) involved and the Capstone programme is an excellent example of different organisations working together to deliver against real world case studies. This complements the overall Smart Park programme and the EU funded Smart Sustainable Districts programme. The planned cultural and education quarters (V&A, Sadlers Wells, UCL, UAL) gives even more impetus for using technology and digital tools in operating the Park and in engaging visitors. ICRI comes to the Park with tools that have been tested over the last few years and are therefore ready to meet live business challenges. Additionally, the planned cutting edge technology research positions the Park as a true demonstrator space for Smart solutions thereby contributing significantly to developing market ready products, supporting the local economy and in delivering the Greater London Authority's Smart London Plan.

JIM WOOD, DIRECTOR OF IT AND INFORMATION SERVICES, LONDON LEGACY DEVELOPMENT CORPORATION

In 2013 the Mayor of London published the Smart London Plan. This outlined how London would harness the creative power of new technologies to serve London and improve Londoners' lives. Since then, we have made much progress. Today, as we plan for 10 million citizens by 2030, London is showing how the power of data and technology can help support growth. However, there is still- and always will be- much more to do.

No other city in the world matches our cluster of top performing universities, ideas, talent and capital. Yet we can do more, by bringing together London's academics, industry, public bodies and citizens to work on the grand challenges and opportunities we face in health, transport, energy, environment and developing digital infrastructure itself.

Technological innovation is changing London. This provides economic, social and political opportunities. Technology can help to transform Londoners' experience as well as the efficient use of infrastructure, the quality of homes and the enjoyment of places to work and play.

Our technology industry is renowned for its innovation and entrepreneurial energy. We have the opportunity to tap into talent across all scales and types of technology businesses. That is why investment in the sector is so high – ten times more than just five years ago. It is also why London is such an attractive city for inward investment. However, more collaboration is needed between the City and technology entrepreneurs to help London to remain at the forefront through investment in new ventures. Fintech is an important part of this mix. By technologists and financiers innovating together, we will unlock capital, sustain talent pipelines and help pioneering start-ups to scale up.

ICRI is an exemplar of the types of collaboration we wish to promote further. It provides deep scientific knowledge in collaboration with application-oriented demonstration projects to create the infrastructure and tools upon which the next generation of Smart London systems can be built.

PROF. DAVID GANN CBE
VICE PRESIDENT (DEVELOPMENT AND INNOVATION), IMPERIAL COLLEGE LONDON, AND CHAIR OF THE SMART LONDON BOARD

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ICRI 2016

Revision 1

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The Narratographer, Tim Green, Evo Flash, DncnH, EG Focus, Pseudonomad, Nana B Agyei , Ed Webster, Nate Maingard, George Alexander Ishida , Pat Pilon, [Duncan], Robert Pittman, Martin Pettitt ,Dario Sušanj, PRODaniel .Martin., Steve Gardner, Pavlo Boyko, Davide D'Amico, Charlie Marshall, Jason Farrar, Leo, The Soundmonster!, Jared Tarbell, x6e38, Danny Harrison, Chris JL, Troy_williams, r2hox