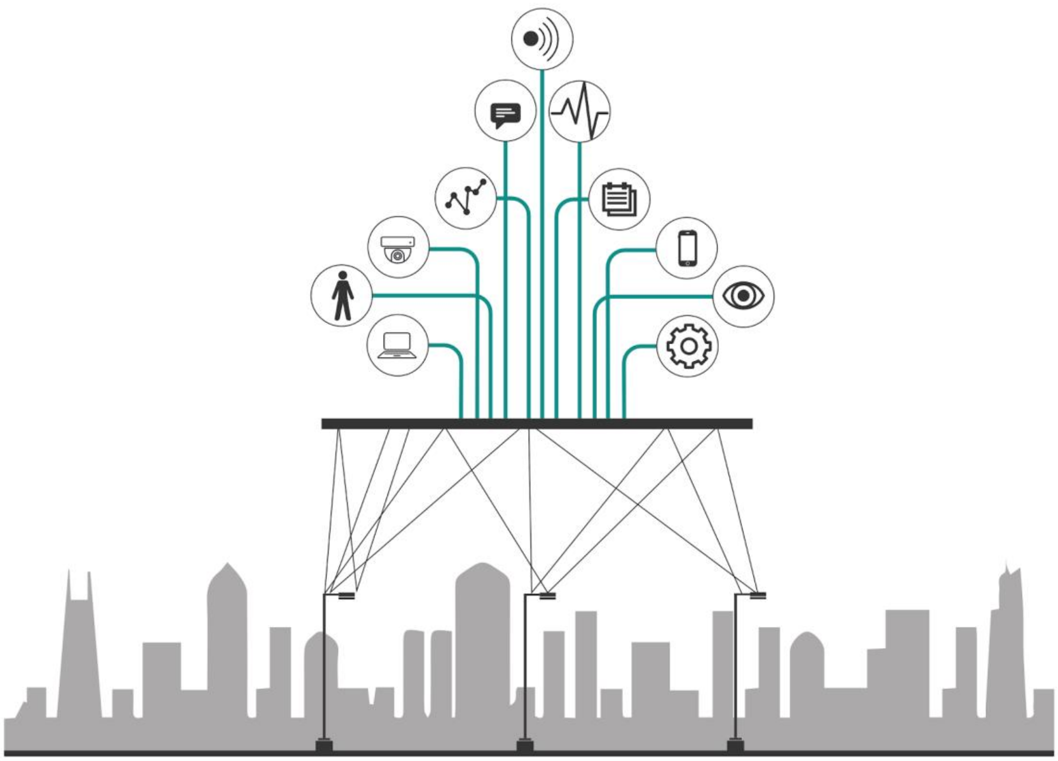
Appendix 1: Ideation Report for Philips Lighting-SCL Research Collaboration



Ideation Report: Philips | Senseable City MIT

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Foreword

Streetlights are one of the most ubiquitous and interconnected infrastructure of modern cities. For the last century, with the widespread use of electricity as a commodity, lampposts have populated every street, side road, highway or cul-de-sac. In more recent years, and primarily motivated by an increasing demand in energy efficiency, HPS sources of light are being transitioned to LED technology, and in turn are becoming digitally enabled programmable units. Paired with networked computing capabilities, we can leverage the ubiquitous presence of LED streetlights by transforming them from mere sources of light into urban sensing platforms.

This project, launched on September 30, 2015, is part of a five-year partnership between Philips and the Massachusetts Institute of Technology, focused on health and urban technologies. This project combines Philips long expertise in lighting technologies and Senseable City Lab work on sensing technologies and data analytics. The objective of the project is to create a modular smart sensing architecture that transforms streetlights in a pervasive network of urban data collectors and actuators.

The project is divided into three phases:

Phase one is the *Ideation phase*. During the first three months of the project, the Senseable City Lab, working closely with the Philips team, explored around fifteen sensing scenarios and technologies, based on different urban phenomena. For each alternative idea we defined research questions, possible sensing packages, and urban scenarios where these technologies could be applied. This report summarizes phase one. The first draft of this report has been a collaborative process between the Phillips team and Senseable City Lab team. Based on the process, a joint decision was made about the direction of the project. Four ideas have been selected to move forward to the development phase and will be further developed by the team in phase two.

Phase two is dedicated to the architecture design and hardware prototyping. This phase starts with the joint decision between the Philips team and the Senseable City Lab team on which sensing scenarios we want to focus in the forthcoming months. For the next six months, based on the sensing scenario, we will closely work with the Philips team on the sensor configuration and hardware architectural design, data and back-end architectural system design, initial prototyping and prototype testing in Cambridge.

Phase three includes on-site prototype testing, data collection, and behavior automation design. Prototype testing will be done primarily in Cambridge, and will result in the production of capable test prototypes, publication of research findings, and development of data visualization. Pilot projects are aimed to be done on campus at MIT and possibly in Eindhoven with collaboration and pending approval of Phillips. Further development of prototypes in potential cities will be decided as the project progresses and will be implemented specific to the ideas and on an urban scale.

Based on the results of the first year of research, Philips and Senseable City will jointly choose sites for the full deployment of the sensing packages.

Introduction

Street lights influenced how cities changed. It reshaped urban life and redefined the way a city was used after dark. It increased safety, fostered economic growth and made cities more vibrant. The street light became a ubiquitous infrastructure that fulfilled a newly discovered need and aided in the development of cities. It is constantly evolving to become a more efficient system in the city. The introduction of LED technology was one that revolutionized the lighting industry and lighting in cities by providing the same level of lighting for lower costs, but more important by integrating streetlights into a larger information network. By 2030, the adoption of LEDs in the U.S. would save us $30 billion dollars a year, reduce gas emissions equivalent to 40 million cars, and decrease our dependence on energy plants that use fossil fuels.

As a digital technology that also provides light, the potential of streetlights in cities has yet to be fully explored. By utilizing and merging new technologies to the existing infrastructure, lamp posts have the potential to address real problems that can redefine urban life. To be able to successfully redefine urban life, an understanding of how a city changes over time should be identified. These can be explained in the urban phenomena that cities experience as they develop.

In order to explore the complexity of the urban world, we propose focusing on some of the most relevant emerging urban phenomena. This requires experimental ways of sensing, interacting, and understanding the relationship between the natural environment and the built environment, as well as how human beings interact with and within these environments. The most valuable element of understanding these urban phenomena is understanding that lamp posts can be found in all of them and all these phenomena address different challenges and are defined by their own criteria. The urban phenomena:

Urban settlements can be defined as a number of people living in high density areas, sharing economic functions and infrastructure. However, this definition frames a single component of the complexity of urban phenomena.[25] This definition encapsulates anywhere from 2,000-inhabitant settlements in Botswana to megalopolises such as New York City or Tokyo. We have identified urban phenomena which present some of the most important challenges for cities.

Intense urbanism can be areas with extreme population density, overlapping transport infrastructures, an abnormal concentration of global companies, or a significant population growth during a short period of time. Such intense urbanization processes concentrate the virtues and vices of the urban phenomenon, including high levels of air pollution and traffic, media interfaces as part of urban landscapes, and noise and light pollution.

Ephemeral Urbanism addresses a temporary settlement. It can sometimes be a short temporal situation such as a festival congregating ten of thousands to millions of people, or it can be a short-term situation that shifts slightly into a long-term settlement that lacks infrastructure and political

[25] United Nations (2005). *Demographic Yearbook*. New York: United Nations.

organization, such as refugee camps. In both cases, these situations demand provisory infrastructure, crowd management tactics, and health care related to the potential contagion effect.

Dispersed Urbanism is characterized by close social, economic, and political interdependency of relatively low-dense settlements, found in large territories such as archipelagic countries. These settlements share common features in such a way that their resilience capacity relies on the strength of the connections between them.

Urban environmental awareness becomes important when the delicate balance between the natural and built features of a settlement may lead to the emergence, permanence, and eradication of human settlements. Lamp posts can be designed as knowledge platforms that collect environmental data and also serve as actuators improving urban resilience.

Lighting is a key feature in all these phenomena, and lamp posts can be enhanced as sensors and actuators. Streetlights have four assets: they are ubiquitous, evenly spaced throughout the city, blended in with the urban landscape which does not make them feel misplaced, and have guaranteed energy supply - either through large electricity networks or solar panels mounted on the poles. Lamp posts can start mediating the interactions among the natural substratum where the cities are built, the technological artifacts that make the city, and human beings.

However, despite their ubiquity, lamp posts, even smart ones, do not interact with the city as much as they could. They only respond to the city through light. Lamp posts can start sensing the city and gathering data from their urban surroundings. They can start interacting with the city in useful and playful ways and create new experiences. Fostering these experiences can redefine what the lamp post can achieve and be used for beyond only illuminating cities. Lamp posts could watch the city, smell it, hear it, even touch and taste it.[26]

This white paper will focus on transforming lamp posts into knowledge platforms. Here the proposed ideas focus on some challenges presented in different phenomena we could address using the ubiquitous street-light infrastructure as sensing and actuating systems. We frame these ideas using three main themes: Environmental Sensing, Human Sensing, and Urban Transformations.

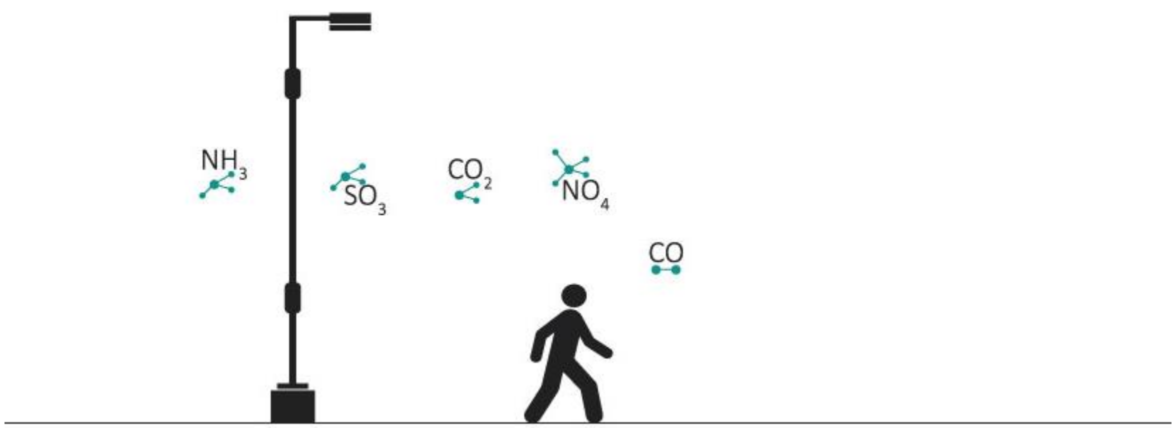
[26] Moser, W. (2015, September 17). Chicago's "Array of Things" Takes Another Step Towards Reality. *Chicago Magazine*. Retrieved from http://www.chicagomag.com/city-life/September-2015/Chicagos-Array-of-Things-Takes-Another-Step-Towards-Reality/

Theme 1: Environmental Sensing

The following projects focus on the complex relationship between manmade and natural environments. Rapid urbanization, the rise of the automobile and lack of environmental policies have created harmful environmental conditions in many cities that are the cause of millions of premature deaths every year.[27] Cities around the world aim to become desirable places where their populations can thrive. In order to do this, a balanced ecosystem must be achieved. Being able to gather reliable environmental data with good coverage and resolution is a critical step in this direction. We believe that streetlights can play a key role in this given their ubiquitous locations and form characteristics. This data can be used in multiple services as well as for planning and policy decisions that can have a positive impact in the lives of millions.

Idea #1: Air quality monitoring (2D and 3D)

Using pervasive air quality sensing on street light infrastructure to collect real-time high spatial and temporal resolution air quality data (2D and 3D) to inform urban air quality modeling efforts and public health short- and long-term responses.



Problem Statement

Urbanisation, air pollution and health: It is estimated that ambient air pollution leads to approximately 3.7 million premature deaths annually.[28] On an urban scale, air quality has typically been measured using sparsely located yet highly accurate monitoring apparatuses. These are expensive to set up and run, and only yield data with low spatial resolution. Using a larger number of smaller sensors in space has gained traction in recent times, and can foster novel applications, such as urban air-pollution mapping and localization, adaptive traffic regulation, and detailed measures for both personal and population exposure studies.

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27 http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/

28 The World Health Organization compiled a fact sheet on ambient air quality and health at http://www.who.int/mediacentre/factsheets/fs313/en/

Potential Benefits

Real-time high spatial and temporal resolution air quality data is required to address two main problem areas: public health and urban air quality modelling.

Public Health:

- Detailed real-time maps and forecasts of pollution levels can be used for informing urban populations of current air pollution levels in their vicinity, especially for people with pre-existing cardiovascular and respiratory health conditions that are exacerbated by air pollution. People can therefore make informed decisions about their behavior or commuting pattern and take steps to minimize their exposure (as an example, see the Airscapes Singapore project which is accessible at <eoe.airscapes.io>).
- Fine-grained air pollution maps can be used for prioritizing specific urban areas (at certain times of the day, etc), and separating people from highly polluted areas (or sources of pollution).

Urban Air Quality Modelling:

- Fine grained air pollution data from fixed networks is required for calibrating urban air quality models in streets and intersections. These may include urban street canyon models which are based on dispersion of emissions from a variety of sources.
- Air quality monitoring at various heights would be more beneficial for calibrating models than street-side measurements.

Areas of Research

Areas of research include developing exposure models to be used in personal and population exposure studies. This will also inform environmental epidemiological research studies linking air quality and human health. Other research areas are in the development of air pollution dispersion models for identifying sources of pollution and for testing the effectiveness of passive barriers for separating people from vehicle pollution.

Practical Technologies

We will mount air quality monitoring apparatuses on modular sensing platforms at various heights on the street lighting infrastructure to enable both 2D and 3D mapping of air pollution concentration levels. The following sensors are available and have been well tested by various research groups:

- Alphasense electrochemical sensors (for measuring NO_2, SO_2, O_3 and CO).
- Alphasense Particle Counters (for monitoring PM_{10}, $PM_{2.5}$ and PM_1).

The first are chemical gas sensors which measure the concentration of gaseous species by analysing reactions between the sensing material and target gases, such as ozone (O_3), carbon monoxide (CO), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2). The operating principle on which the particle counters are based is laser light scattering technology to count individual particles and calculate the equivalent mass concentration using a proprietary algorithm. Other sensors which may be used are micro-electro-mechanical systems (MEMS) made of microfluidic, optical and nanostructured elements, allowing them to be compact, lightweight and inexpensive (White et al. 2012).

Case Studies

The Senseable City Lab has undertaken a project called Airscapes Singapore which monitors air quality through a large number of sensors distributed across a group of participants. Similar works by the lab and other institutions have been done but so far there has been no wide-scale corporate implementation. Kumar et al. summarize recent state-of-the-art apparatuses and experimental research in air quality sensing.

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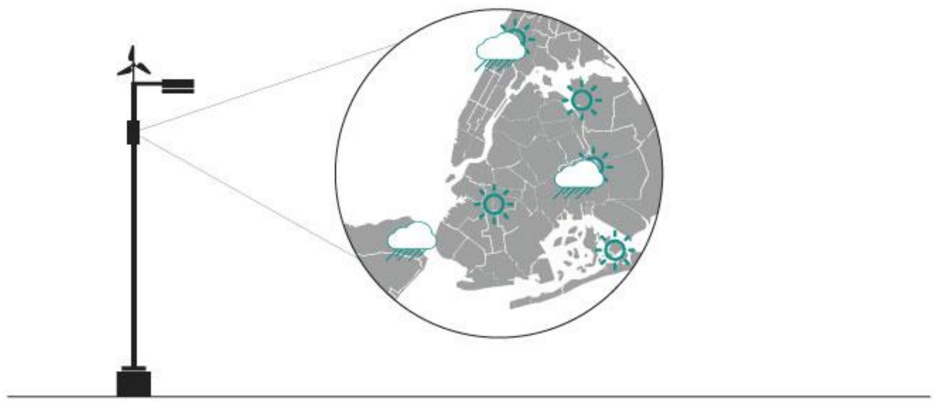
White, R. M., Paprotny, I., Doering, F., Cascio, W. E., Solomon, P. A., & Gundel, L. A. (2012). Sensors and "apps" for community-based: Atmospheric monitoring. *EM: Air and Waste Management Association's Magazine for Environmental Managers, (May)*, 36–40.

Idea #2: Micrometeorology and microclimate sensing

We want to monitor a number of meteorological and microclimate parameters in high spatial and temporal resolution. Meteorological sensing refers to short term weather detection and forecasting, whereas climate sensing refers to longer term environmental information. Developing high resolution micro-meteorological models and forecasts is useful in the context of urban planning and design.



Problem Statement

Micro-weather measurement and forecasting: There is a need for short-term weather prediction (<30 minutes) in very high spatial resolution, especially within cities. Currently, weather forecasting is still at the scale of the city, and forecasting is done by large weather stations at one location, rather than a high density network of dispersed sensors that can accurately report weather at a more precise scale at high resolution.

Potential Benefits

Micro-weather forecasting: 'Weather routing' or predicting weather along a user's planned route will be common in the future with this type of technology. Additional uses, like relaying important information at the hyper-local level of rain or sunshine status that can help people maximize and enjoy their use of public spaces, could be developed.

Public health and livability: Urban heat islands are caused by various environmental and air quality factors due to human activity. Included in these are potentially higher levels of air pollution. At this point, there are no methods of accurately detecting urban heat islands. Understanding micro-climate areas of the city and comparing it with citizen information will allow planners and urban officials to understand how environmental conditions affect how people use, live in, and move through the city.

Building Energy Management Systems: In order to function optimally, Heating Ventilation and Air Conditioning (HVAC) systems require information about the meteorological conditions in the vicinity of the building or complex, radiant and convective heat fluxes between the building and the outdoor environment, and information regarding moisture fluxes.

Areas of Research

Areas of research include: environmental sensing, meteorological forecasting, human relationships to the environment, and interfacing with related external parties.

Practical Technologies

We will mount micro-weather station apparatuses including a number of sensors on the modular sensing platform, which attach to existing street light infrastructure. A Kestrel-type device could also be used, or more likely something cheaper which would include similar capabilities, and which would be compatible with the overall modular sensing platform we are developing.

A Kestrel-type device includes the following sensors in a small compact device:

- Anemometer (e.g. for measuring Wind-speed/Air Flow)
- Thermometer (e.g. for measuring Ambient Temperature, Global Temperature (Tg), etc.)
- Barometer (for measuring Pressure)
- Compass (for logging the direction of the instrument and the wind, etc.)
- Relative Humidity (for measuring the moisture content in the air, etc.)

The above sensors are capable of measuring and/or leading to the derivation of the following parameters: Direction/Heading, Air Density, Air Flow, Altitude, Barometric Pressure, Wind Direction, Crosswind, Headwind/Tailwind, Wind Chill, Air, Water, and Snow Temperature (ºF or ºC), Delta T, Density Altitude, Dewpoint, Evaporation Rate, Heat Index, Moisture Content/Humidity Ratio ("Grains"), Relative Air Density, Thermal Work Limit (TWL), Outdoor Wet Bulb Globe Temperature (WBGT), Web Bulb Temperature - Naturally Aspirated (Tnwb), and Wet Bulb Temperature - psychrometric.

Other apparatuses that could be used for monitoring various meteorological parameters and providing a complete micro-weather station service include:

- Precipitation monitor (for identifying falling precipitation)
- A rain-gauge would also be required for measuring rainfall
- Disdrometer (for measuring drop size distribution)
- Transmissometer - for measuring visibility
- Ceilometer - for measuring cloud ceiling

In terms of Microclimate, we would also measure etendue and lighting/shading parameters.

Case studies

The Senseable City Lab has done a project called Airscapes Singapore which monitors environmental data through a large number of sensors distributed across a group of participants. Similar works by the lab and other institutions have been undertaken but so far no wide-scale corporate implementation has occurred.

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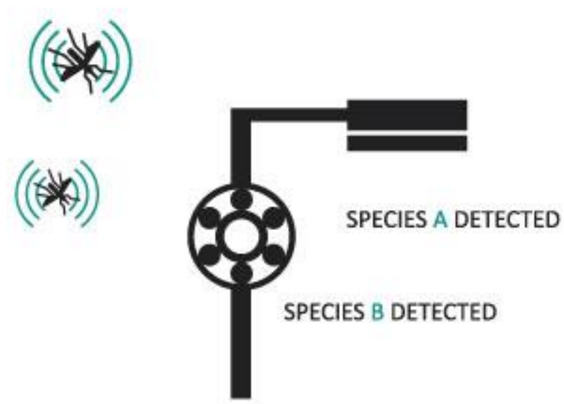
Idea #3: Bioacoustic mapping of the ecology of urban environments

Using acoustic monitoring devices, we would be able to detect and map out where different natural ecosystems exist and in what abundances. Specifically, we intend to use bioacoustic methods to map populations of biological agents that could become disease spreading vectors by identifying their unique acoustic signals. An example are mosquitoes, a well-known vector for malaria and dengue transmission.



Problem Statement

A city is a platform of different layers and environments. One of the most valuable layers is the natural world layer. At times this layer is overpowered and quieted by the built environment imposed upon it. But this layer often has a crucial effect on the city and its citizens. People often forget that the natural environment is a reservoir of important data waiting to be collected and used to better the future development and health of cities. Our project aims to use bioacoustic methods to collect and analyze this layer.

One example of a highly relevant and pressing biological agent to study would be mosquitoes. Mosquito-borne diseases are highly common in some areas of the world, and can be deadly. Over one million people die from mosquito-borne diseases worldwide every year and these diseases can also affect dogs and other animals, resulting in a continued proliferation.[29] There are a number of nonprofit organizations committed to studying mosquitos and providing resources to help prevent the spread of these diseases.[30] A study conducted in 2011 found that bioengineered mosquitoes could help control the spread of malaria by replacing wild-type mosquitoes and drastically reducing the number of infected individuals (Diaz et al., 2011).

Potential Benefits

[29] American Mosquito Contol Association at http://www.mosquito.org/mosquito-borne-diseases

[30] Gates Foundation at http://www.gatesfoundation.org/What-We-Do/Global-Health/Malaria, World Health Organization at http://www.who.int/mediacentre/factsheets/fs094/en/, and Malaria No More at https://www.malarianomore.org

Implementing bioacoustic technology will allow researchers to map and study biological agents of interest in high resolution. This data could be used by organizations that have interest in disease prevention and response, such as the Red Cross or CDC, in addition to local and international government agencies. Being able to detect ecology systems through smarter technologies is critical for future development to help detect, track, and effectively respond to the transmission of vector-borne diseases.

Area of Research

Bioacoustics itself is not a new field, but our study is a novel way to collect data from an untapped source. There have been studies conducted on identifying insects and animals by their natural sounds. Our method will combine microphones and machine learning algorithms to detect and identify mosquito species based on their wing beat pattern. Scaling this technology to a high-density network around a city would provide detailed maps for researchers to study mosquito species which could then be used to combat the spread of mosquito-borne diseases in methods that have never been available before.

Practical Technologies

These sensors would be placed on street lights which provides a high density of sensors in a city. The technology to implement this bioacoustic sensor requires only a sensitive microphone and processing board. A machine learning algorithm processes the sounds from the microphone and notes that it has detected specific species. Further additions can be included in this package. For example in the case of mosquitoes, methods to remove specific species could be included or real-time alerts could be sent to users in the immediate area if certain virulent mosquitoes were detected.

Case Studies

Davide Zilli has conducted two studies on identifying insects by their natural sounds. The first was identifying a rare species of cicadas (Zilli et al, 2014) and the other was identifying different types of mosquitoes based on their wing beat patterns.[31] Both were implemented on smartphone apps and the mosquito detecting algorithm was implemented on a simple wearable band.

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Zilli, D., O. Parson, Merrett, V., Rogers, A. (2014). A hidden Markov model-based acoustic cicada detector for crowdsourced smartphone biodiversity monitoring. *Journal of Artificial Intelligence Research, 51*: 805-827.

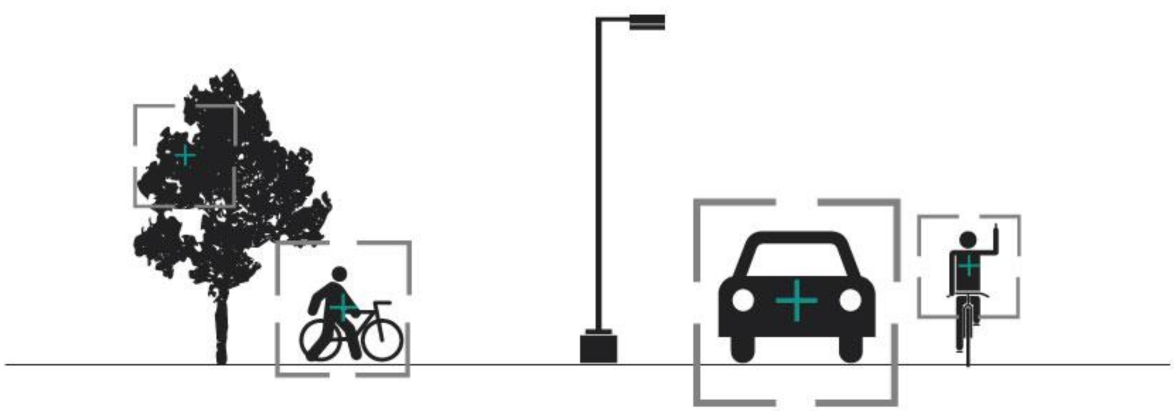
[31] The project can be viewed at his website: http://humbug.robots.ox.ac.uk/

Theme 2: Human Sensing

Cities are more than infrastructure. Cities are also the people and societies that inhabit them. Everyday people's actions, movements and experiences are influenced by their urban environments and social contexts. Understanding these behaviors --which are often invisible to the naked eye-- are of great interest to governments and companies around the world. However, it is difficult to consistently gather data about how people use the city at a normalized large scale and therefore determine exactly what actions and activities are conducted in urban spaces in order to maximize their fullest potential. Digital technologies can be of great use in detecting and tracking these behavior patterns and produce knowledge that could help make cities more liveable and functional for the future by developing new services, experiences and forms of spatial designs. As a research project we can study the technological feasibilities of integrating these types of systems, and also investigate the social and legal levels of acceptance for these types of technologies when deployed at an urban scale, framing the contemporary relevance of this work. The following projects focus in leveraging streetlights as hubs of human/urban knowledge.

Idea #4: Networked digital cameras and A.I. for better understanding of urban spaces

We want to leverage the high-density and regular placement of streetlight infrastructure to create a platform for monitoring urban flows and behaviors utilizing visual data. These types of flows include pedestrian and traffic information, social interactions, and crowd behaviors. For this we want to place a modular digital camera system and utilize machine vision and deep learning methods to automate the detection of identifiable patterns and urban elements, along with high-level contextual understanding of urban space utilization at multiple temporal and spatial scales.



Problem Statement

Cities are continuously struggling with how to better understand the behaviors of its citizens. This spans from transportation and social behavior to the monitoring of ephemeral urban events and gatherings. The ability to understand this at a high resolution will aid in a variety of urban services and help designers and planners understand how people use the city to focus efforts in areas of need.

Potential Benefits

The detection, analysis and aggregation of urban flows and people's behaviors in urban spaces, using a variety of data capture configurations and analyzing the output using A.I., can help us to answer multiple relevant questions for cities, such as: How is traffic flowing? Is there an accident in the vicinity? Are there available parking spots on the street? Where are the hotspots in a commercial street? Where do people congregate in a public space? Are there policemen around? What is the frequency of public services?

This data could also be correlated with information collected by other proposed projects, such as understanding how pedestrians respond to different microclimates, for instance. Accurate human behavioral data related to urban characteristics can be used to test or supplement many kinds of urban research and practices.

Area of Research

Continuous advancements in digital image sensor resolutions as well as the growth of computing processing capabilities, alongside with increasing developments in A.I. approaches such as machine vision and deep learning, allow us to envision the integration of smart large-scale visual intelligence systems capable of doing both low-level element recognition as well as high-level understandings of urban scenes. Unlike most current CCTV systems, streetlights hold a strategic advantage when configuring an urban scale standardized visual intelligence platform given their widespread locational placement.

Practical Technologies

We intend to develop a modular networked camera system capable of integrating multiple digital image sensors functioning in high synchronicity. The system will have a hybrid architecture that will do low-level image processing using onboard computing capabilities while relaying data to the cloud for advanced image processing methods. Multiple optical configurations will range from distributed FOVs over targeted spots of high interest to omnidirectional optical arrays for standardized coverage of urban spaces. The camera will record in a variety of resolutions and frame rates in order to allow for a flexible research process of procedural image and data handling optimization.

Additionally, a variety of artificial intelligence methods will be used for both low- and high-level image analysis data gathering automation and interpretation of urban scenes. We intend to use computer and machine vision techniques for low-level element detection and tracking such as persons, automobiles and crowds among many other urban elements; along with neural networks and deep learning to integrate high-level semantic structures in order to automate contextual analysis of urban scenes.

Case Studies

CCTV cameras already have a ubiquitous presence in major cities and are optimized for security and traffic monitoring. They are increasingly being coupled with machine learning algorithms to detect identifiable patterns and produce automated actions in cities. In 2014, São Paulo partnered with Microsoft to deploy *Detecta*, a system that monitors the city from sources such as video feeds and emergency calls and uses machine learning to detect crimes. It then provides relevant information to officers in the area.[32] London, with roughly 5 million CCTV cameras monitoring the city, has installed smart cameras near traffic lights with computer vision analysis to improve pedestrian flows by regulating traffic lights to allow more time for pedestrians to cross safely.[33] Finally, Chicago has plans to equip streetlights with modular sensing nodes that can contain cameras, environmental sensors, accelerometers, and other sensors. The city plans to use the nodes to monitor the city's environment and activity as well as open source the data to encourage citizens to develop tools and applications for the public.[34]

The majority of these camera systems are optimized for enforcing security and handling traffic rather than studying human activity. As such they hold important but limited value to both city officials and other public and private stakeholders. Our project aims to use more powerful artificial intelligence technologies to study cities at the human level and analyze the specific activities that citizens are engaged in over time to better inform urban planners and city officials.

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[32] http://www.zdnet.com/article/sao-paulo-invests-4-3m-in-microsoft-crime-fight-system/
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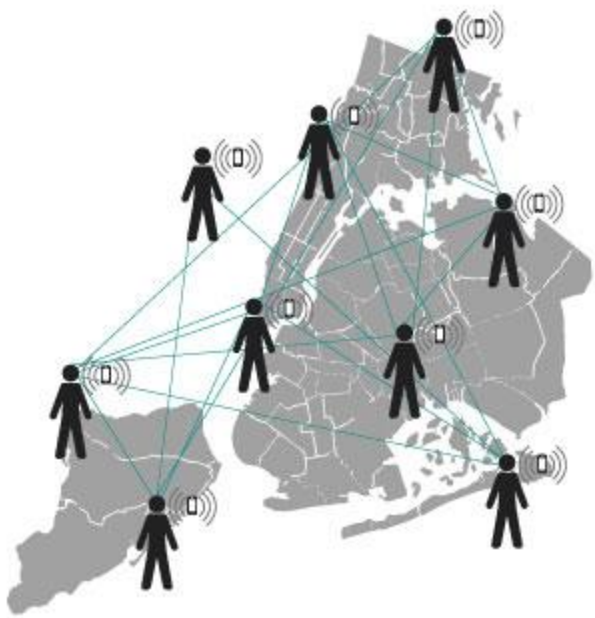
[34] https://arrayofthings.github.io

Idea #5: Crowd monitoring through mobile device detection

Deploying crowd monitoring systems to monitor the presence and location of mobile devices using a hybrid of techniques.



Problem Statement

A system for detecting mobile devices addresses the problems of extracting accurate yet anonymous information of crowds, analyzing their mobility patterns, and gathering social characteristics, such as correlating the detected devices to their country of origin - useful information for tourist sites. The analysis of this data could create forms of interactions with the urban surroundings, including the provision of better public services, and deployment of businesses and services.

Potential Benefits

Since users have different active radio interfaces (GSM, WiFi, and Bluetooth) over time, our research uses the development of cross-correlation algorithms, which combine inputs from different radio sniffers (possibly cameras also) to accurately count the number of people in a crowd. Due to encryption in GSM messages and lack of mobile identity in most exchanged messages, our project includes the development of low-level signal analysis (inside the physical layer) to refine the number of counted mobile devices without the need to extract any identity.

Areas of Research

Mapping and extrapolating data from mobile devices to infer information about the general population, and not just those with detectable devices.

Practical Technologies

We will use light poles infrastructure as i) a stand for sensors and ii) a power source for the various processing boards. Collected information could be transferred over power lines or GPRS/HSPA connections using a third processing board. Mounting hybrid nodes, which includes different radio interfaces, such as WiFi, Bluetooth, and GSM, on light poles could be responsible for passively overhearing radio signals from mobile devices and anonymously detecting the number (and possibly locations) of active devices within the overhearing range.

Case Studies

S. Alyafawi has implemented a GSM SDR sniffer that works for both uplink and downlink channels. Alyafawi has also used linux-based tools to sniff WiFi and Bluetooth packets. However, each sniffing module was operating separately due to the high cost of equipment. With our new model, all sniffers can operate in real-time using one low-cost and energy-efficient hybrid board with further processing resources for onboard statistical analysis and control.

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Idea #6: Soundscapes: a spatio-temporal mapping of the social sounds of the city

The soundscape is the component of the acoustic environment that can be perceived by humans. We want to use microphone networks to map not only specific key events (as in the idea above), but also the entire city to see how the entire environment is composed of dynamic sounds, both of which have an effect on humans, and which are produced by humans and social interactions.

Problem Statement

Noise pollution in cities is significant enough to cause pervasive negative mental health impacts on its citizens (Stansfeld, 2003). Mapping soundscapes across the city and relating it with other urban features, such as land use, demographics, and traffic and street design will provide a better understanding of the relationships between noise and social behavior at a large scale. This information can be used to study ways to improve and prevent mental health cases related to noise pollution and analyze how public spaces are used.

Potential Benefits

Simply put, this project will allow us to better understand people within cities. It will provide a more detailed understanding of different demographics and social groups of people, and how they interact and function within a city. We will be able to map where social hotspots are in the city; what unplanned and ephemeral phenomena are occurring; as well as potential areas that may be unsafe (either in the presence of harmful sounds or the lack of presence of people or "eyes on the street"). Additionally, we can detect and find ways to mitigate sound pollution, and support positive environmental or perceptual sounds.

Area of Research

Specific audio-signal detection, matching and processing; vocal command interpretation and processing; location triangulation; communication and interface with outside parties.

Practical Technologies

Street lighting infrastructure is useful because of its regular distribution of poles, which makes location triangulation of audio signals possible. The technology needed would be: Audio sensors or microphones mounted in a 360-degree orientation at one or two fixed points along the pole. Potentially, one microphone package would be located at around head-level (or vocal detection) and one at a higher point above the crowd (to detect more general sounds and avoid specific interference at street-level). Also, we would have communication and interfaces for outside parties: law enforcement, emergency responders, taxi dispatchers, etc.

Case Studies

Lindquist and Lange (2014) provide an overview of research demonstrating the potential for using multisensory experiences for the design, evaluation and assessment of landscapes, facilitated by environmental simulations. Zhang and Kang (2007) present an intensive literature review, in which the soundscape description, evaluation, and creation in urban open spaces are systematically examined in terms of four basic elements: sound, space, people, and environment. Factors affecting soundscape evaluation in urban open spaces, including acoustic–psychological–social characteristics of various sounds, acoustic effects of space boundaries and elements, social–demographic characteristics of users, and general physical–environmental conditions are identified and, consequently, a system for soundscape description is established. Potentials of creating and designing soundscape in urban spaces are then discussed in terms of sound and space.

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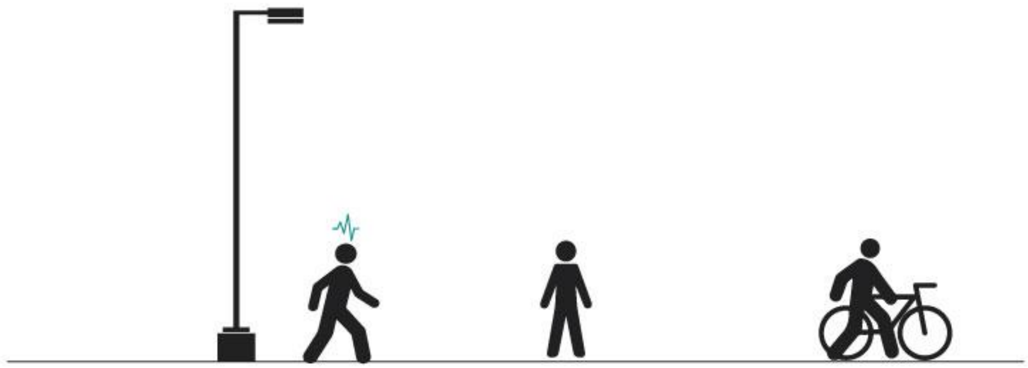
Idea #7: Stress maps of cities

We propose integrating sensors such as thermal and galvanic sensors capable of measuring and monitoring involuntary physiological responses to stress in streetlights, in order to map and monitor city stress levels.



Problem Statement

Imagine a city that can detect the level of stress an individual experiences. Sudden sounds, light and events can all play a part in increasing the level of stress we experience. If there was a way to detect the change of stress levels in a city, could there be a way to map the change in stress, and then introduce ways in which the city responds to prevent this change of stress, providing the public with the ability to remain in stress-free zones.

Potential Benefits

Health in cities and individuals is increasingly becoming a more popular idea to monitor. The proliferation of health centric wearables such as Fitbit show the public's interest in monitoring their health in new ways. At a city scale, having the ability to monitor stress levels will provide us with data that can help and influence city development. This project aims to conduct a social behavioral study by monitoring daily activities in cities.

Area of Research

People who live in large cities are proven to suffer from the most stress (Adli, 2011). Adli adds that 40% of people in cities have a higher risk of developing mood disorders. The quality of the built environment affects the mental health of urban citizens (Ochodo et al, 2014). Knowing this, can we make decisions through design that influence the feeling of stress? Our hope is to measure stress levels in cities to learn how to reduce stress levels and improve the mental health of people who live in urban environments.

Practical Technologies

Stress can be detected by measuring involuntary physiological changes such as variations in body temperature, iris dilation and heart rate. There are a number of sensors that can be used to measure these changes. Thermal sensors can detect changes in body temperature due to stress. When the temperature of a person suddenly rises, it may indicate a high level of stress (Marazziti, 1992). Monitoring heart rate can be done in several ways, the most popular being using galvanic skin response sensors or heart rate monitors (Yamakoshi, 2008). These sensors can be installed in the walk signal button at stop lights or have readers installed on street lights.

Most of the projects that measure different stress levels are usually confined to extremely controlled environments and use sensors and technologies that must be placed at optimal locations to measure heart rate such as wrists or fingers. Additionally, there are an increasing use of distributed sensors located in smartphones or wearables that can raise privacy concerns, often they use incompatible architectures and can be the cause of systemic bias when sampling. Using passive technologies and integrating sensors into existing pervasive infrastructure would allow us to bypass these restraints.

The Senseable City Lab previously partnered with Audi to implement a stress detection project with drivers in Boston.[35] The experiment used physiological sensors and face/body tracking technologies to measure the stress and frustration a driver experiences during peak traffic hours in Boston. The results showing stress levels between different daily activities performed, and driving.

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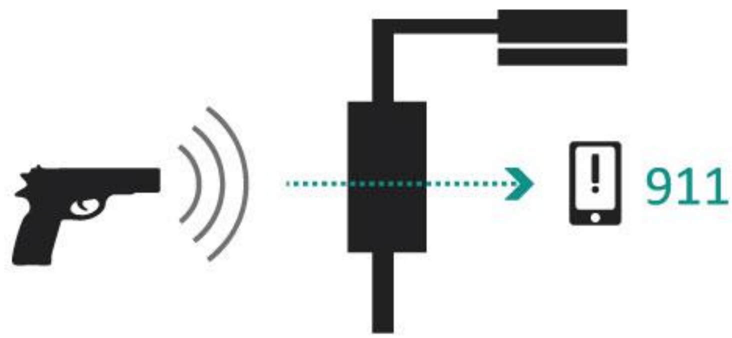
[35] http://senseable.mit.edu/rfi/

Idea #8: Responsive environments: audio detection and emergency situations

We want to use microphones and audio sensors distributed across the city to make the urban realm a responsive environment. We will use the system to detect various social phenomena, such as emergency situations, and vocal commands, through mapping and processing unique sound patterns.



Problem Statement

Safety in cities is one of the major themes of this project. Crime and energy events are issues in cities. Resilience combines the need for the prediction of and response to large-scale urban problems. To move toward a safer and more resilient city, automated, real-time emergency responses are necessary.

Potential Benefits

In emergency situations, such as one involving a car accident, a gunshot, or a person asking for help, the sound pattern of the event can be detected and triangulated to offer immediate real-time detection of the location of an event that requires an emergency response.

This sensor system will be able to detect voices and vocal commands -- in any situation from an individual calling for help to a person trying to call a taxi -- in order to make the city a responsive environment (think Siri but on an environmental level, unconstrained to the phone in your pocket). This project offers decision-makers the possibility of moving from reactive to proactive situations using speech recognition algorithms. The advantage of this solution over other emergency stations (telephones or blue buttons) along the street is a faster and more reachable system for detecting threats. Especially in many scenarios, reaching such stations is not possible or might not be the first action in the case of a threat.

Area of Research

Specific audio-signal detection, matching and processing; vocal command interpretation and processing; location triangulation; and communication and interface with outside parties.

Practical Technologies

Street lighting infrastructure is useful as its regular distribution of poles along streets and public spaces makes it an ideal platform for audio detection. Due to the known locations of each pole, location triangulation of audio signals is also possible.

The technology needed for this would be:

- Audio sensors or microphones which are mounted in a 360-degree orientation at one or two fixed points along the pole. Potentially, one microphone package around head-level (or vocal detection) and one at a higher point above the crowd (to detect more general sounds and avoid specific interference at street-level)
- Audio processor unit
- Cloud processing for machine learning and natural language algorithms.
- Communication and interface to outside parties: law enforcement, emergency response, taxi dispatch, etc

Case Studies

ShotSpotter is an audio network system that has been implemented in a number of cities this year, including New York and Washington, DC (Schlossberg, 2015). The technology is a network of audio sensors which detect and triangulate the location of gunshots for real-time emergency response. A large set of literature studies and applications are discussing the concept, implementation and deployment of speech recognition systems. For example, inside every Android/OS smartphone, there is a speech recognition system that works to translate words into commands. The SDR concept adopted in our solution, which adds flexibility, expandability, and low cost, together with being integrated as a complete system with other modules, such as cameras and radio sniffers, make our solution unique.

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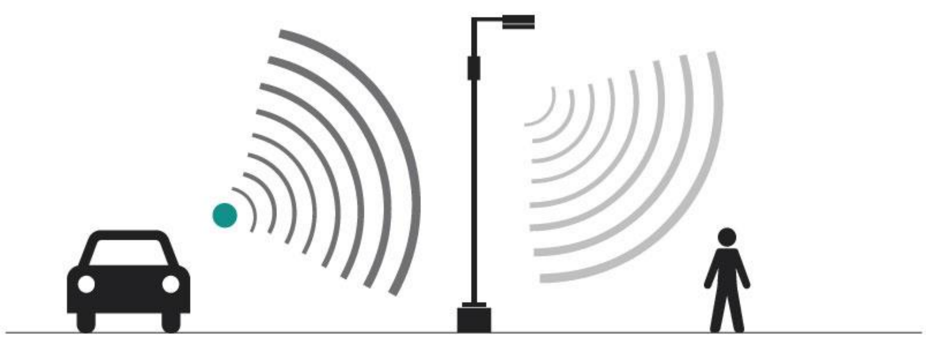
Theme 3: Urban Transformations

Technology and urban form are highly related. The automobile, the elevator and the telephone are clear examples of technologies that had profound impact on the form and infrastructure of cities in the 20th century. Today many cities around the world are reclaiming spaces and transforming them into mixed/multi-use environments; a clear divergence from the modernist ideal of functional separation of spaces of 20th century cities. Digital technologies such as wireless connectivity and locational media facilitate their repurposing. In the 21st century city, we will see a more profound exchange between the physical infrastructure and the digital space; a constant interaction between the city of bits and the city of atoms.[36] An interconnected street light system can help deploy new experiences that focus on increasing the pleasurable use of public spaces, given that the design of public spaces can also largely dictate how people use them.[37] For example, we can reduce stress levels and economically reactivate spaces by attenuating unpleasant externalities such as noise pollution, or by introducing new dynamic levels of playfulness into the urban fabric. We can also create new interfaces that use digital light platforms as sources of information, bringing immediate human-urban points of interaction. The next projects exemplify how these new dynamics could be deployed on the ground.

Idea #9: Active Noise Control (ANC) in open urban environments

We aim to introduce a system that uses sound detection (microphones), real-time processing and anti-noise actuation (speakers) to attempt open-air noise reduction within cities, using street light poles as a structure for mounting the technology. The proposed system can be used to reduce unwanted noise pollution from traffic for pedestrians on sidewalks and in parks. The structure would be an array of microphones, a set distance from an array of speakers acting as a noise shield, which, if a person stood in the path of the speakers, sound would be reduced as an "area of silence".



[36] Mitchell, W. J. (1995). City of bits. *Space, Place, and the Info*.

[37] https://my.vanderbilt.edu/greencities/files/2014/08/William-H.-Whyte-on-what-makes-public-spaces-fail-what-makes-them-succeed.pdf

Problem Statement

Sound pollution is an ongoing health concern in cities. The duration of exposure to certain frequencies in cities have been proven to have adverse effects on the health of individuals (Stansfeld, 2003). To minimize these effects, people tend to isolate themselves from their surroundings by using headphones or alternative methods that help dampen the sounds in the immediate environment.

Since cities tend to be unpredictable environments, the implementation of active-noise control becomes more challenging. There has been no substantial research or experimentation done that proves that ANC is possible in random, unpredictable environments. As such, we are unsure of how feasible a solution is. To our knowledge, the only successful studies have been in experimental cases in controlled cases with a known, single, pure-tone sound source (which is much different from random and unpredictable environmental noise).

Potential Benefits

Decreasing noise pollution in cities can directly increase the health of its citizens, as noise pollution has adverse mental and physical health effects related to stress, hearing loss, and mental well-being (Stansfeld, 2003). Additionally, our hypothesis is that this technology would encourage citizens to spend more time outside in urban environments, increasing social interaction and as a result, mental health. If we are able to successfully implement it, or achieve some sort of significant result, it would be a major technological breakthrough.

Areas of Research

Human behavior: This technology would allow us to study how social interactions and behaviors in urban spaces are influenced by noise.

Active Noise Control (ANC) theory: The most relevant research that comes the closest to successfully coming up with a solution is the idea of using electronically controlled acoustic shadows (ECAS). It is a linear spatial sequential setup that allows the creation of an "acoustic shadow" of the sound source, which in theory creates a silent space (Wright, 1996). Current research has not extended to the practical urban environment, and research has been done successfully only in controlled laboratory environments with a single known sound source.

Practical Technologies

To create this "acoustic shadow" the linear spatial sequence is set up. The sequence of this system works by allowing the ANC device to reduce the waves created by the sound source by emitting an anti-noise wave in the same direction as the source causing a destructive interference, resulting in sound reduction for the listener located in the created "acoustic shadow".

We may be able to imagine a setup where, in an urban park, we can line the ANC speakers along street light poles between the park and the sidewalk, then line the ANC sensors along street light poles between the sidewalk and street, and potentially be able to reduce the noise of the traffic for listeners in the park.

Case Studies

Background literature and case studies for this idea are limited. Experiments were done successfully only in controlled environments with a single known sound source. What is available in case studies, are alternative methods and technologies that do not achieve complete ANC, but sound dampening and/or masking. These methods introduce white noise/pink noise or introduce positive sound control, which can be other directions for this project if ANC is not successful.

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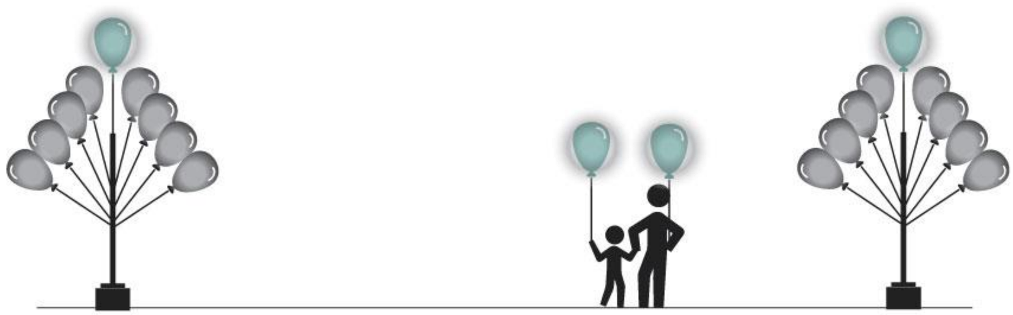
Idea #10: Personal light sources: drones and los globos de luz

We propose two personal lights sources, interactive and playful devices that follow individuals and provide personal lighting for citizens to reclaim dimly lit public spaces. Our first project is to introduce networked companion drones with lighting capabilities to follow citizens. The second is to create a personalized lighting experience through LED balloons, or l*os globos de luz*, which users would carry with them in the dark. Both projects provide pedestrians with individualized and interactive lighting experiences that supplement existing infrastructure and will draw attention to the space by creating unforgettable and playful memories.



Problem Statement and Area of Research

Lighting plays a key role in defining how people interpret the safety of a space and thus, how accessible the space becomes during the evening and night time. These playful projects have two goals. First, thoughtful lighting displays can attract people to the area which in turn boosts economic development. For example, San Francisco partnered with artist leo Villareal to implement smart LEDs on the Bay Bridge to successfully draw in millions in tourism revenue.[38] We could create social engagements and experiences through new and playful mediums while complementing the surrounding light infrastructure. Second, we intend to incorporate galvanic sensors on the handles of the balloons, with which we could gather data from users to understand their behavior and perception of public spaces and events.

Potential Benefits

Phillips has already collaborated on a number of lighting projects around the world that redefine how public light is used and how people interact with it.[39] Many of these projects incorporate sensors in their actuations to provide smarter lighting solutions and customized experiences. However, these installations are usually stationary and limit how people interact with them. Providing people with

[38] The Bay Lights project in San Francisco at http://www.wired.com/2012/05/bay-lights/ .

[39] Book published by Phillips about lighting projects and the experience of light in cities at http://images.philips.com/is/content/PhilipsConsumer/eBooks/LightingUniversity/LU20150211_001-ECT-global-Light_For_Public_Space.pdf

new opportunities to interact with public light in a playful manner will certainly attract them to these areas. Furthermore, seamlessly incorporating sensors into these environments will allow urban planners and interested parties to study these spaces in fine detail.

Practical Technologies

The key aspects of our technological approach are to incorporate sensors and use the existing lighting infrastructure. Embedding sensors provides a twofold benefit: gathering high resolution information about the health of cities and information about how people use public spaces.

The first project is to introduce networked companion drones for pedestrians in dimly lit spaces such as parks. Pedestrians can call a companion drone from a nearby streetlight via an app to follow them overhead and provide a personally lit space. The drones travel only within a specified area to conserve battery power but a neighboring drone will replace it to provide a seamless experience for the user. Drone docking stations will be located on top of streetlights to take advantage of existing power sources and real estate. The drones will be equipped with sensors such as directional microphones, cameras, speakers, 4G connection, GPS, and LEDs. If their users are in danger, the drones will distract potential attackers by emitting a high frequency sound, record video evidence, call for help, and flash their LEDs. The GPS locations, dates, and times that the user accesses a companion drone provides a high resolution of pedestrian routes and popular locations during specific times and dates. Urban planners could use this to introduce more docking stations for popular areas of study why certain phenomena occur in areas.

Our second idea proposes a personalized lighting experience through a poetic and endearing medium: LED balloons or los globos de luz. These softly lit orbs would be available for the public to pull along through public spaces. We imagine that these balloons would be available at docking stations on street lights and pedestrians could simply borrow a balloon to use in these spaces. Unlike traditional balloons, los globos would not use gases to keep them afloat, but rather a small fan to inflate them or a thin rod to keep them suspended. Diverging from the traditional balloon form allows this medium to exist without constant maintenance and prevents it from producing waste. At the end of the string, a small handle would be equipped with sensors, which would enhance users experience (such as changing the color of their balloons), but mostly importantly, they would gather data about routes (GPS) and heart rates (galvanic sensor), providing valuable information about the stress levels of cities. For example, decreasing heart rates could reveal how certain areas induce calming effects or increases in heart rates could reveal safety concerns in other areas or areas that couples tend to congregate in.

Case Studies

Runners in Sondermarken Park, Copenhagen, can use an app and LED bands on low-level street lights to help them keep pace. This lighting installment encourages citizens to partake in healthy habits and provides an interactive experience. 'Swing Time', an interactive art installation in Boston was built to attract people to use a temporary park that would eventually become a building site. However, the popularity of the site grew due to the novelty and playful nature of the LED swings and is now a "first-of-its-kind outdoor interactive space."[40] CYCLIQUEL was a lighting installation that equipped 256 helium balloons with LED lights and synchronized them to music. The exhibit was aimed at "removing its viewers from reality and placing them in a surreal world of blinking lights and fantasy balloons, this light."[41] Researchers at Cornell and MIT created drones to help photographers light their scenes by autonomously assuming desired positions.[42]

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[40] Swing Time project at http://www.hyarchitecture.com/projects/114

[41] Cycliquel project at http://blog.lightopiaonline.com/lighting-articles/cycliquel-led-balloon-art-via-256-balloons-with-leds/

[42] Article published by the MIT News about this project at http://news.mit.edu/2014/drone-lighting-0711

Other Potential Ideas

Idea #11: 3D mapping of urban environments using LIDAR sensors

We propose using LIDAR sensors mounted on street lights to map out an accurate, real-time, self-updating 3D model of the urban environment. LIDAR is a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light. By setting up a LIDAR sensor at each street light and measuring the distance around it in all directions, a robust 3D map of the entire detected city, stitched from the 3D scans at each street light, can be obtained. Because LIDAR can update the 3D model in real-time by constantly gathering information, temporal elements (such as cars, people, etc.) can be detected alongside the permanent built environment. Focusing on urban services, the following benefits are possible:

- Detecting street cleanliness by monitoring in real-time for trash, snow, suspicious objects, and so on
- Flow analysis of traffic and urban services (although the computing power required for this would be inefficient)
- Availability of parking spots
- Real-time detection of road obstructions and emergencies
- Detection of long term urban change and development

Idea #12: Sound-wave propagation analysis to map urban flows and infrastructure

We propose using high-sensitivity microphones at the base of streetlights to detect the vibration patterns of different activities through the ground. We will install high-sensitivity microphones that touch the ground at the base of the streetlights -- with a sound transductive surface and an isolating acoustic chamber to minimize data capture error -- essentially creating a 2D sonar mesh. The microphones would capture the acoustic signatures of activities on the ground: footfall of people, vehicle movement. Additional sound variations (ex. variations in signature frequency over time, or events such as cars falling in pot-holes) could be also used to monitor infrastructure wear and tear for maintenance cycles. We would isolate these sound sources and classify them by using machine trained algorithms. We would use triangulating of time delay and sound intensity along with the measurement of doppler effect to relative position in space. Using these techniques we could have an accurate, real-time, non-intrusive method of tracking urban elements in the city.

Idea #13: Local warming of open spaces

We propose using street lights as personal heating devices for individuals in open space urban environments. We can use an infrared wave emitter mounted on the streetlights, which can emit a focused ray of warmth that follows a person through space by using cameras and motion control sensors. In doing so, heat is applied actively and directly to a user instead of passively heating the entire area. This provides benefits in energy efficiency as well as a more comfortable and consistent heating experience for the user. These are technologies that have already been integrated in the lab for projects such as Local Warming,[43] which was presented at the Venice Biennale in 2014. In an outdoor urban environment, the same technologies could heat pedestrians individually throughout the year. Imagined in public spaces, these local warming street lights can heat crowds or gatherings in large open spaces, to increase social value of these spaces during the winter and at night. The position sensors required can be used jointly with other projects proposed here to monitor urban flows and social activity.

[43] http://senseable.mit.edu/localwarming2014/

Towards New Forms of Lighting

As we develop ideas for the present, it may also help to orient ourselves to visions of lighting for the future. While this project is framed around exploiting the infrastructure of current lighting systems in cities, it is also possible to orient our focus toward new, dramatically different forms of lighting. A few brief visions for new forms of lighting are as follows:

Bioluminescence & organic light

While the science is still catching up to the concept, there have been projects based around the idea of lighting as an organic, biological, growing system. Bioluminescence genomes can be inserted into living systems to cause them to glow. One project by Dann Roosegaarde imagines a city of glowing trees replacing or augmenting the current lighting systems.[44] Another by Jacob Douenias and Ethan Frier, imagines the use of bioluminescent algae as a light source;[45] but they could also be used as a biological sensor that can be trained to change its color and luminescence based on various environmental factors. This algae system is liquid and can potentially be used to fill any container of space, moving away from a distributed network of point sources for light (as in current street lighting systems) and toward diffuse volumes of light (large wall panels, for instance).

Pixels

Shifting the focus of lighting away from a lower distribution of point-lights of high intensity (as in the current system) towards a higher distribution of point-lights of lower intensity, we can imagine lighting as pixels. The benefits of a diffuse pixel lighting system include a more evenly distributed light field, as well as a network for sensing and actuating at higher resolutions which may provide opportunities for the future. An extreme example images an entire physical environment of embedded pixels which can be turned on and off and adjusted by color, creating a dynamic lighting and display system across the entire city.

Canopies

Another form of dispersed lighting similar to pixels would be a move toward large panel lighting systems replacing point-light bulbs. Such systems could lead to a more even lighting in cities, which could have enormous benefits for safety and emotional well-being. Even with keeping the current pole infrastructure, replacing bulbs with larger panels could be a significant lighting change. A more extreme case is to image a more continuous lighting panel canopy. Paired with Philips technology, this canopy could be used to replicate sunlight at night to create a 24-hour day in certain areas of the city.

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[44] An interview with Roosegarde about this project at http://www.dezeen.com/2014/03/24/movie-sxsw-daan-roosegarde-glow-in-dark-trees/

[45] More information about Frier's projects can be found at http://www.ethanfrier.com/living-things/

Appendix 2: Location of the Curbside Metered Parking Spaces in Cambridge, MA.

Appendix 3: Survey instrument for NEMA Participants

Smart Street Lights Survey - NEMA Affiliates

The following survey will be used in an MIT research study on intelligent infrastructure systems, in particular smart street lights and their challenges for adoption by cities..

Participation in this study is voluntary, you may choose to respond or not to any of the questions in this survey. Thank you for your support.

1. Does your company currently provide any type of smart street lights solutions?

☐ Yes ☐ No

2. If you responded 'Yes' to the previous question. Could you describe what smart street lights solutions your company provides?

____

____

3. How likely do you think is your company, to adopt a smart street lights solutions strategy within the next 5 years?

☐ Already have one ☐ Very likely ☐ Likely
☐ Unlikely ☐ Very unlikely ☐ Will not pursue one

4. Could you list, what you believe are the three most important attributes of smart street lights (in order of relevance)?

Attribute 1. ______________________________

Attribute 2. ______________________________

Attribute 3. ______________________________

5.How important do you think digital applications delivered via street lights will be for your company within the following 5 years?

☐ Very important ☐ Somewhat important
☐ Not that important ☐ Not important at all

6. Have cities that you work with asked for any of the following smart street lights functionalities? (check all that apply)

- ☐ LED Lights
- ☐ Better energy efficiency
- ☐ Wireless connectivity / WiFi
- ☐ Sensor driven applications
- ☐ Surveillance applications
- ☐ Have not asked for any
- ☐ Other: ______________________

7.How have cities acquired smart street lights solutions from your company? (check all that apply)

- ☐ Tender process
- ☐ Light as a service
- ☐ Concession of light pole
- ☐ Have not purchased any
- ☐ Other: ______________________

8. Have cities that you work with, raised any concerns in regards to smart street lights implementations? (check all that apply)

- ☐ Additional costs and complexity
- ☐ Lack of perceived benefits
- ☐ Privacy concerns
- ☐ Technology becoming obsolete
- ☐ Data ownership concerns
- ☐ No concerns have been raised
- ☐ Other: ______________________

9. Has you company established strategic partnerships with any of the following for the development of smart street lights solutions? (check all that apply)

- ☐ Universities/Research Centers
- ☐ Telco Operators
- ☐ IT companies
- ☐ Transportation solutions companies
- ☐ Urban tech companies
- ☐ Have not established partnerships
- ☐ Other: ______________________

10. Please put your contact information if you'd like to be reached for further research:

Name: ______________________

email: ______________________

Appendix 4: Semi-structured interview questions sample

Script:

Thank you for taking this interview. You have been selected to participate given your previous participation in smart light related initiatives. The purpose of our research is to understand what are the key challenges in turning these projects into reality and it is part of my PhD dissertation work. The interview should take approximately 45 minutes of your time, depending on length of the responses. The interview will be recorded. At any time, you can refuse to answer any question or stop the interview altogether. You also have the right to request that your name be removed from this research. You understand that this participation is voluntary and that there is no monetary compensation involved. If you agree to this, then we can begin.

Survey questions (secondary questions indented):

1. Can you please state your name and position?
2. Could you tell me a bit about smart infrastructure projects that your organization is currently working on or has worked on previously in the past?
3. Specifically, do you have a smart streetlights program or strategy in your city or are you thinking of developing one?
    a. If so, can you tell me what you're doing in this regard?
    b. Do you perform additional functions that fall outside of providing illumination?
4. Who do you consider are the relevant stakeholders that should be involved in a smart lighting transformation project?
    a. Who should lead the effort in implementation?
    b. Who should own the infrastructure?
    c. Who should operate it?
5. City Hall is usually structured in siloed functions and areas. Do you think it should evolve to address these new types of infrastructure systems?
    a. If so, how?
6. Because they're data driven, digital infrastructure systems have the capacity of evolving in the future as people find and develop new uses for the data over time. How do you plan for this outcome?

    a. Given the critical role of data in this regard, then who do you think should own the data and its algorithmic byproducts?
    b. How do you regulate access to this infrastructure and its data by the general population?
    c. How do you make sure that the city benefits the most from this data in an equitable way?
7. As we place more sensors in infrastructure, we're capable of gathering more data from our surroundings and potentially from humans. How do you address concerns over privacy?
    a. How do you balance the need for privacy with the needs of the city in regards to providing new data driven services to its citizens?
8. How do you consider cities should involve the general population in creating the future of street lights?
    a. In your experience, do people actually want something extra from their street lights?
    b. Have you asked them?
        i. If so, what do they want?
    c. What are the concerns they have raised?
9. What are the procurement models you have used in the development of these smart lights projects?
10. Any other comments and suggestions you might have for cities thinking about doing an intelligent street lights project?
    a. Do you have any contacts that you could provide me in these cities?

Thank you for your time.

Appendix 5: COUHES Authorization for Experimental Procedures

For the different data gathering, experiments procedures and sensor protocols presented in this work I applied and received the following COUHES exemptions and addendums.

COUHES Protocol Number	Date
1602377694	02/23/2016
1612793005	12/22/2016
1612793005A001	07/03/2017
1612793005A002	12/18/2017