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Assessing the effects of mobility on air quality: The Liverpool Smart Pedestrian project

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Abstract

With the drastic increase of their urban population, cities face huge challenges to maintain and update their infrastructures. Assessing in real time the effect of urban policies will be a key tool in the future of urban planning. In this paper, we discuss of mobility and its impact on air quality. We introduce a pilot project in which low cost IoT sensors are used to monitor flow of cars and pedestrians and concentration of particulate matters within the Australian city of Liverpool.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: Smart City, Pedestrians and vehicules flows, Air Quality, IoT, Sensors

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1. Introduction

According to the results of the 2017 World Population Prospects published by the United Nations, the world's population numbered nearly 7.6 billion as of mid-2017. This means an adding of approximately one billion inhabitants over the last twelve years (United Nations, 2017). It is expected that the world population will reach nearly 10 billion by 2050. By 2030, urban areas are projected to house 60 per cent of people globally and one in every three people will live in cities with at least half a million inhabitants (United Nations, 2016). This increase in the urban population is a huge challenge for every city, implying to rethink urban policies to welcome this new population into the city.

The concept of *Smart Cities* is a direct result of this need to reshape cities. While there is no consensual definition of what a Smart City is (Albino et al., 2015), it commonly involves the usage of Information and Communication Technologies (ICT) to design technologies which should respond to people's needs through sustainable solutions for social and economic challenges. But this common vision of a Smart City hides the fact that each Smart City is a unique city, with its own and sometimes unique problems (Anthopoulos, 2017). The Internet of Things (IoT) offers innovative solutions that can show how the city lives and identifies its problems (Kim et al., 2017), enabling stakeholders to not only take decisions to improve the quality of life of the citizens, but also to assess the impact of those decisions through the real-time monitoring of the city's assets.

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In this paper we focus on two city assets, mobility and air quality, to study how those two components of a city are correlated. The paper is organized as followed: Section 2 introduces the challenges of mobility and air quality monitoring through IoT. Section 3 offers a review on the monitoring of mobility through IoT, while Section 4 focus on the monitoring of air quality. Finally, Section 5 introduces our own project monitoring mobility and air quality in the Australian city of Liverpool.

2. Mobility and Air Quality

Smart mobility commonly refers to the use of ICT in modern transport technologies to improve urban traffic (Albino et al., 2015). (Benevolo et al., 2016) claim that the idea behind Smart Mobility is to not only to support the optimization of traffic flows, but also to collect citizens' opinions about livability in cities or quality of local public transportation. Thus, mobility is more than just a matter of traffic, as mobility also has social, environmental and economic impacts. Thus, cities stakeholders can look at mobility not only to see how things are moving within the city, but also as a way to build a more sustainable future. For example, (Jain and Tiwari) have identified sustainable mobility indicators for Indian cities and have concluded that pricing policy, urban form and infrastructure are levers of sustainable mobility.

Designing new infrastructures to enable the smart and sustainable vision of mobility is a complex problem. For example, (Del Moretto et al., 2017) have studied two alternatives for a sustainable mobility linking 3 campsites in the Region Toscana in Italia. Their work aimed at identifying solutions which are sustainable from both the environmental and the economical point of view in order to meet the mobility needs for three considered campsites. In order to assess the impact of each solution on the environment, they have to take into account multiple factors such as atmosphere, aquatic environment, ground and underground, vegetation flora and fauna, ecosystems, landscape, noise, electromagnetic pollution, or public health. This work is illustrative of how mobility and environment are intrinsically correlated.

Mobility is certainly a key aspect to build a better and sustainable future. By offering alternatives and low-polluting means of transport a city can not only increase its livability, but it can also boost its economy. Indeed, (Neidell, 2017) has shown that higher levels of air pollution reduce worker productivity, and that even when air quality is generally low improvements in air quality have led to significant increases in worker productivity. The study focused on the productivity of fruit pickers at a farm in California and have outlined the following results:

- Poor air quality does not affect a worker’s decision to work or the number of hours worked, at least on a daily basis, for the levels of pollution found in nations with the highest levels of environmental regulation.
- Air quality standards that lower pollution levels would likely lead to improvements in worker productivity.
- Poor air quality reduces worker wages in settings where pay is based on performance.
- Reduced worker productivity occurs at levels of pollution well within current air quality standards and guidelines.

While some limitation may applies to these results, they suggest that in a near future, air quality, and other environmental factors, might become important in distinguishing between cities to attract industries.

In a recent study, (Anjanovic and Haas, 2017) assessed the impact of different policy measures implemented in passenger car transport in the EU-15 on GHG emission. Their study has shown that in total, GHG emissions could be reduced at least by 33% in 2030 in a selected Policy scenario compared to a business-as-usual scenario. However, traffic, is a really complex system and the consequence of a Policy might sometimes lead to counter-intuitive results.

One example is the work of (Davis, 2017). He looked at the impact of license-plate based driving restriction policy as an effort to address urban air pollution in Mexico City. License-plate based driving restriction is an increasingly common response by cities to air pollution. The author studied hourly data from pollution monitoring stations to measure the effect of the expansion to Saturday of the restriction policy on air quality. The result was that “*Saturday driving restrictions fail to improve air quality in Mexico City. Across eight major pollutants, the program expansion* *had virtually no discernible effect on pollution levels. These disappointing results stand in sharp contrast to estimates made before the expansion which predicted a 15% decrease in vehicle emissions on Saturdays*". As explanation of this failure, the author pointed-out that he found no evidence that the expansion was successful in getting drivers to switch to lower-emitting forms of transportation.

The increasing popularity of electric cars can be seen as a solution to poor quality in cities, but this solution also has some drawbacks. In their work, (Yu and Stuart, 2017) showed that the effects of compact growth and electric vehicles on future air quality and urban exposures may be mixed. They claim that compact form lowered NO_x exposure but increased exposure to butadiene and benzene, while electric vehicles increased NO_x exposure, but lowered exposure to the other pollutants and argue that multiple pollutants and source types need to be considered during urban design. (François et al., 2017) go further in an environmental assessment of urban mobility in the French town of Lyon. In their results, they show that if only GHG emissions are considered, electric vehicles appear preferable to diesel or gasoline cars. However, if the costs and impacts of vehicle fabrication and energy production are taken into account, electric vehicles have greater impacts on metal depletion and energy consumption than conventional vehicles.

As a matter of fact, a more holistic approach that fosters economic, social, environmental sustainability to mobility is needed (DallAra et al., 2018). But in order to achieve such vision, stakeholders needs the tools to understand what is happening in the city and to assess the impact of their decisions. Traditionally, urban planning has been made with a top-down approach, decisions being directly taken by stakeholders. If traffic flows needs to be improved, the solution was to build a new road. But nowadays, "*there is no good reason to believe that the building of new roads will lead solely to a displacement of traffic, but rather that there is an associated need to embed the potential benefits of that displacement in planning and management of inner urban areas*" (Hood et al., 2018).

We see in the Internet of Things (IoT) not a complete solution to mobility challenges, but the possibility to deploy large scale sensors to provide real-time feedback about the city. Information from those sensors can help stakeholders to make the best decisions and to assess the impact of their policies. In the rest of this paper, we focus on mobility and air quality. In the next section, we propose an overview of IoT based approaches to monitor mobility.

3. Monitoring Mobility

Traffic count has been the first method to monitor and model traffic in a road network (Dupuy, 1975). This can be done either manually by observers along the roads of interests or automatically by devices, the latter allowing a high frequency rate as well as the permanent monitoring of the traffic counts if needed (Commenges, 2013).

Traffic counter devices include pneumatic road tubes laid across the roads, piezo-electric sensors and inductive embedded in the road loops as well radar-based off-roads sensors (Zwahlen et al., 2005) (Middleton et al., 2007). Most of those sensors can be adapted to track bicycles and pedestrian (Ryus et al., 2014).

Recently, the advent of IoT enabled the development of new traffic and pedestrian counting technologies relying for instance on smartphones tracking, NFC, GPS and connected traffic counters (Antoniou et al., 2011). Those new sensors can also be deployed in a meshed configuration (Akyildiz et al., 2002) (Servigne et al., 2009).

This new generation of connected sensors allows then the collection of a greater amount of data at a very fine level. This offers two main benefits: a better representation of the traffic in a road network and the emergence of data-driven traffic model (Antoniou et al., 2013).

(Romero et al., 2018) propose a literature review of various sensing technics used for traffic detection and surveillance. They compared various technologies, such as inductive loop, magnetic induction or video image processing, pointing out some of the advantages and drawbacks. As conclusion, they highlight that the sensors based on video cameras offer a relatively low installation cost with little traffic disruption during maintenance whereas other methods such as inductive loop, RADAR and microwave detectors suffer from serious drawbacks.

With the drastic reduction in the cost of electronic components, and recent advances in machine learning and images processing, it is now possible to develop at relatively low cost edge computing solutions to monitor traffic. For example, (Ki et al., 2017) use CCTV in an urban traffic information system to determine traffic speed and volume and combine this information with on board wireless equipment to estimate travel speed.

As cities have been massively investing in CCTV networks, retrofitting the already existing CCTV infrastructure to transform classical CCTV into smart CCTV is then a promising approach to real-time monitoring of traffic.

4. Monitoring Air Quality

Recent reviews have shown that the drastic reduction in the cost of electronic components now allows the use of low-cost sensor to monitor air quality (Lewis et al., 2016) (Jiao et al., 2016). These low costs sensors enable the monitoring various aspects of air quality, such as particulate matter (PM) (Borghi et al., 2017) or gaseous pollutants (Spinelle et al., 2017). The data collected with these sensors allow the design of a wide range of applications from real-time monitoring of indoor air quality (Benammar et al., 2018) to the monitoring and mapping of air quality at a regional scale (Mráz et al., 2018). One example of such a deployment is the work of (Penza et al., 2017). They have deployed 11 sensors (10 stationary and 1 mobile) to monitor air quality of Bari, Italy. The idea was to design low-cost sensor-systems to raise citizens' awareness of the environment. They found that these low-cost sensing solutions are promising for air quality monitoring but need intensive re-calibration in long-term operation for better accuracy, and that a co-location of low-cost sensors and reference instruments is a valid approach to improve data quality.

Another review (Morawska et al., 2018) analyzed 17 large projects around air quality monitoring and found that the usage of low cost sensors has led to a paradigm shifts. While those projects are typically conducted by consortia of organizations, ~30% of them were commercial and/or crowd-funded. They see in this proportion of crowd-funded projects a sign that there is a democratization in air quality monitoring, which previously had primarily been implemented by government organizations. Another sign of a paradigm-shift is the growing use of machine learning or other advanced data processing approaches to improve sensor/monitor agreement with reference monitors, so that low cost sensors can be used in conjunction with traditional instruments to extend their coverage.

Citizens and community involvement are a key aspect of Smart Cities, and air quality seems to be a good case for this. Another example of citizen involvement in air quality is the work of (Corno et al., 2017). The authors propose an IoT Crowd Sensing platform that offers a set of services to citizens by exploiting a network of bicycles as IoT probes. Each bike is equipped with sensors offering different services such as real time remote geo-location of users' bikes, anti-theft service, information about routes travelled, and air pollution monitoring.

In a study, (Lewis et al., 2018) investigated the social and behavioral drivers and effects of air quality sensor use. They found that the developers of low cost sensors are varied, including traditional air measurement technology companies but also crowd-funded start-ups and community organizations. However the research to inform the translation of air sensor data into information that might guide an individual's decisions about daily activities remains limited. “*The adoption of low-cost air quality sensors by both public and private sectors, for a diverse set of applications, portends expansive use and widespread circulation of sensor-based air quality data. Further research is needed to elucidate how air quality sensors and their data are being used and to better understand the groups and individuals who use them*”. They identify this as a great opportunity for interdisciplinary research that could bring together social scientists and air quality researchers involved in developing, testing, and deploying sensors in communities.

Through IoT and the usage of low cost sensors, it is now possible to deploy large scale sensors over a city monitoring various aspects of the air quality. Experiments and trends from the scientific literature show that such deployment can be made through citizen and community involvement. On the next section, we present our own initiative, to monitor mobility and air quality at the Australian city of Liverpool.

5. The Liverpool Smart Pedestrian Project

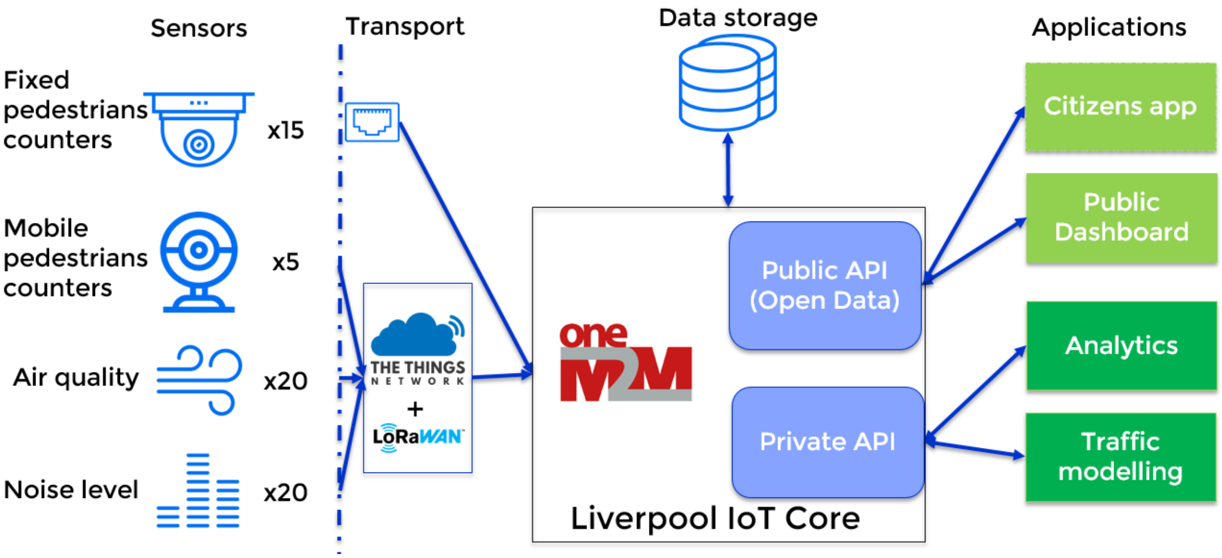


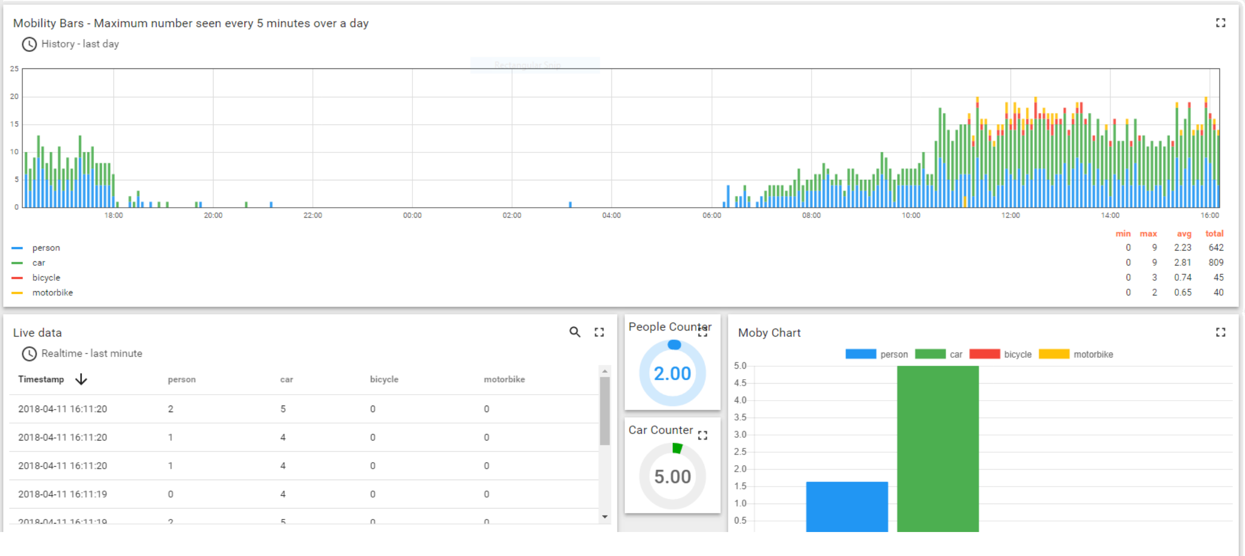
Figure 1- The architecture of the project. Sensors are sending data through LoRaWan and Ethernet networks to OM2M. Applications uses APIs to access to live and historical data.

The Smart Pedestrian Project is funded under the Australian Government Smart Cities and Suburbs Program. It is a collaboration between the Liverpool city council, the University of Wollongong and the IT integration company Meshed. The Smart Pedestrian Project aims to design innovative solutions for the collection of data in a non-intrusive ways to help inform urban planning in the city of Liverpool. Liverpool is a suburb of Sydney, in the state of New South Wales, Australia. It is located in Greater Western Sydney 32 kilometers south-west of the Sydney central business district. It has an estimated population of 27,084 citizens. The attractiveness of the city has led to make it growing, with more housing, offices and educational facilities. The council's Civic Place redevelopment on Scott St is expected to result in 30,000 additional pedestrian movements per day, making of the city a good area of experimentation to monitor the effect of this redevelopment on flows of both pedestrians and traffic.

5.1. Project objectives

- The deployment of a free to use Internet of Things network architecture based on LoRaWAN technology and *The Things Network* (*https://www.thethingsnetwork.org/*).
- The real-time monitoring of urban mobility within the city.
- The real-time monitoring of air quality (particulate matter and carbon monoxide) and noise to assess the impact of mobility on the urban environment.
- Citizen and community involvement in the project.

The whole solution is designed to produce and consume data to inform the planning for future pedestrian and vehicle movements throughout the city to ease congestion, provide better transport options and improve health and safety.



	min	max	avg	total
person	0	9	2.23	642
car	0	9	2.81	809
bicycle	0	3	0.74	45
motorbike	0	2	0.65	40

Live data

Realtime - last minute

Timestamp ↓	person	car	bicycle	motorbike
2018-04-11 16:11:20	2	5	0	0
2018-04-11 16:11:20	1	4	0	0
2018-04-11 16:11:20	1	4	0	0
2018-04-11 16:11:19	0	4	0	0
2018-04-11 16:11:19	2	5	0	0

Figure 2 - A dashboard enables to visualize the mobility data coming from our prototype.

5.2. Architecture

The infrastructure being developed for this project is described in figure 1. 20 visual sensors (15 using fixed CCTV cameras and 5 using mobile cameras) are deployed to monitor pedestrians, vehicles and cyclists, as well as 20 environmental sensors monitoring air quality. Data transport is enabled by the use of a LoRaWAN network using *The Things Network* and a classical internet network connected to the CCTV camera feeds. To collect data from those sensors, the Eclipse OM2M (http://www.eclipse.org/om2m/) implementation of the oneM2M standard is used in order to allow inter-operability between the devices. Specific APIs allows either a public access (Open data) to the meta-data extracted by the sensors, or a private access to all the data. Data storage is enabling historization of data. Dashboards (figures 2) and specific applications will visualization and exploitation of the generated data.

The behavior of the sensors is briefly described below.

5.2.1. Network

In order to support the deployment of IoT sensors into the city, a LoRaWAN network is being deployed. LoRaWAN is a patented wireless data communication technology that has been developed by Cycleo of Grenoble, France, and acquired by Semtech. This technology relies on the usage of license-free sub-gigahertz radio frequency bands. LoRa enables long range transmissions (more than 10km in rural areas) with a low power consumption (with devices that can last for decades). 4 LoRaWAN gateways are going to be installed within the city offering a free-to-use IoT network covering the whole city. This network relies on *The Things Network*, an open source and free to use global LoRaWAN network. One of the specificity of this network is that it can be easily expanded by any of its users.

5.2.2. Mobility

For the purpose of monitoring the mobility, smart visual sensors has been designed (figure 4) whose operation is briefly detailed below.

The camera is capturing a live feed of a street. Each frame of the feed is then going through two steps:

1- The frame is firstly analyzed by YOLO v3 (Redmon and Farhadi, 2018), a specific neural network architecture performing object detection using deep artificial neural network. The output consists of a list of detected object with their category (pedestrian, car, bus ...) and coordinates.

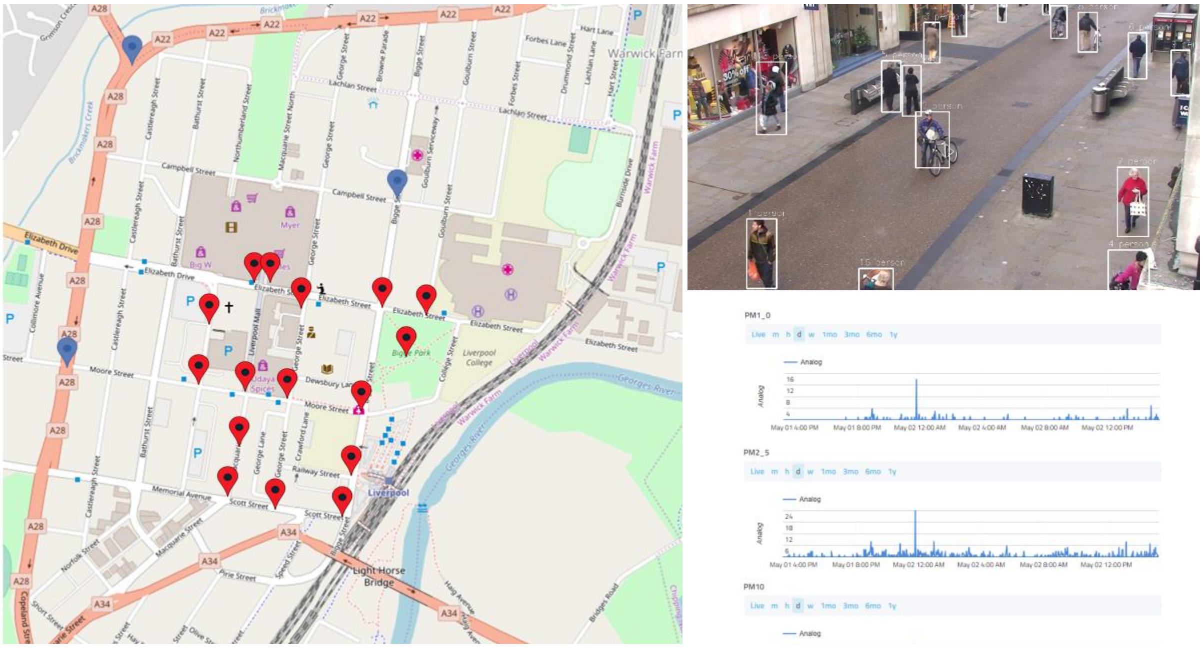


Figure 3 - On the left, a map of the city town centre displaying sensors location. On the top right, results of our tracking algorithm applied the the Oxford Town Center classification data set (Benfold and Reid, 2011). On the bottom right, a chart displaying results from pm sensing.

2- The Frame and the list generated in the previous step are then passed to standard Kalman tracking algorithm (Bewley et al., 2016). This allows our sensor to perform real-time multiple objects tracking, i.e. it associates each tracked pedestrian and vehicle with a specific id.

An example of the output of these two steps is shown in figure 3. Following the edge computing paradigm, once the frame has been processed, it is discarded and only the necessary indicators are sent over a network, for instance to a dashboard such as the one illustrated in figure 2.

The current implementation runs at 6 frame per seconds on an NVidia Jetson TX2 platform, a high performance embedded computing device. This prototype is performing edge computing, which means that every computation is done on the chip and no images are shared, limiting privacy issues. The smart camera only outputs aggregated indicators (numbers of pedestrians, cars, etc...). The raw data that was processed is directly discarded. This ensure the strict privacy of data.

5.2.3. Air Quality

To monitor air quality, a low cost LoRaWAN sensor (figure 4) has been developed. This prototype is based on a Lopy which is a triple bearer MicroPython enabled microcontroller (LoRa, Wifi, Bluetooth) produced by Pycom. The air quality sensor is a laser dust sensor (SEN0177) that can be used to monitor the number of suspended particulate matter in a unit volume of air within 0.3 to 10 microns. This sensor enables to monitor PM10 and PM2.5. The microcontroller and the sensor are contained in a waterproof casing protecting the equipment from water while allowing the air to flow. The unit is powered through an usb connector. With this configuration, the device can monitor PM10 and PM2.5 and push data through LoRaWAN. The figure 3 shows results obtained after one day of outdoor measurement with data gathered every minutes. In the current milestone, results obtained with our prototype are compared to results from an outdoor air quality station to assess quality of the measurement.

5.2.4. Deployment and perspectives

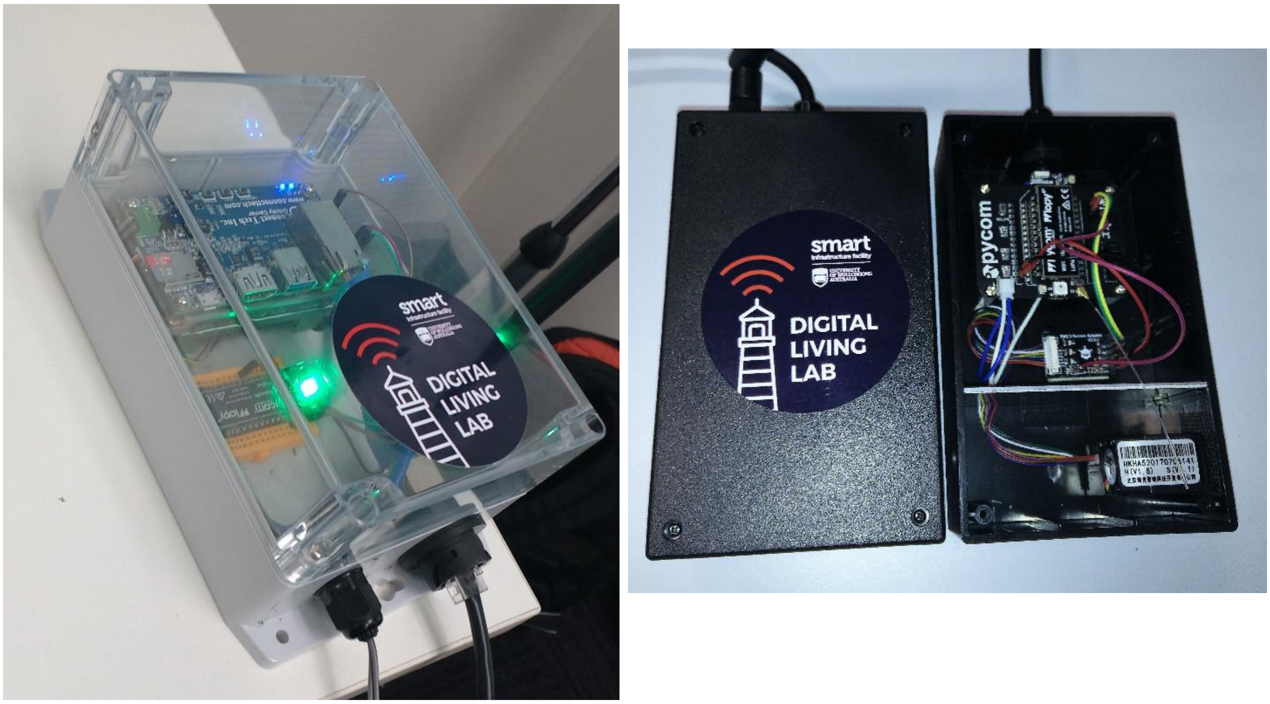


Figure 4 – On the left, the prototype of visual sensor, combining a JetsonTX2 with a LoPy for LoRaWAN connectivity. On the right, the prototype of the air quality sensor.

20 mobility sensors and 20 air quality sensors are being deployed over the city according the map in figure 3. The data gathered will made available through maps and dashboard and accessible to city stakeholders and citizens. In order to select the devices location, a community workshop has been organized in which citizens where invited to play to a serious game. This has enable to identify which are the traffic problems within the city and to identify possible spots for the sensors. Also, in order to make the most of the existing infrastructure, the mobility sensor will use the images from the existing CCTV camera network.

6. Conclusion & Perspectives

This paper details the early stage of the Liverpool Smart Pedestrian project aiming at assessing the effects of mobility on air quality using IoT sensors. The project involves the deployment of a free-to-use IoT network, and the development of new type of mobility and air quality sensors. In order to monitor mobility, CCTVs have been transformed into smart sensors using edge computing, whereas specific sensors has been designed to look at air quality. First prototypes has been built and are currently installed within the city.

As data are currently being collected, the next step of the project involve the design of dashboards for data visualization and the development of mobility models using agent-based modelling. We also want to investigate the usage of sound sensors as a proxy for traffic and air quality monitoring.

The organization of a workshop at the very beginning of the project has enable to involve citizens in the process of selecting sensors location according to the real problematic risen by the citizens. Citizen involvement is also made possible by the deployment of *The Things Network* in Australia. Indeed, as this global LoRaWAN network is open-source and free to use, Liverpool and its community can freely use it to develop new applications. This pilot project will enable to evaluate how the data is used by citizens and how this information will help to reduce pollution and traffic jam.

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