WISEParks Nottingham

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Executive Summary

The WISEParks project was a one year long project which aimed to develop and test cost effective technology for counting park users using WiFi signals. The project was hosted at the University of Nottingham from September 2018 to December 2019. Working with partners at Nottingham City Council researchers at the University developed and tested technology in two destination parks in the city of Nottingham, UK.

Park user counts are often used to plan alterations to a park, evaluate the impact of changes or plan day-to-day maintenance. Currently these counts are usually manually performed by staff or volunteers physically located in the park. They are therefore expensive (financially and in goodwill) as well as being limited in spatial and temporal extent. Simple technological solutions such as gate counters offer better extent but are vulnerable to errors, vandalism and require physical changes to the park environment.

In this project visitor counts were obtained using signals routinely emitted from devices carried by visitors. The sensing technology is low cost, requires no interaction from the park visitor and can be discretely deployed.

This report describes the technology itself, how to deploy it, some failure modes, practical considerations when deploying sensors and gives some sample count results from the WISEParks Study.

- Routinely emitted WiFi signals from devices such as smartphones can be sensed and used to estimate visitor numbers.
- Suitable sensors can be built using £100 of hardware and can be mains or battery powered.
- The technology is capable of tracking visitors as they move around a park but data collection in this way without explicit user consent is likely to be very unpopular and may be against ePrivacy law.
- Consideration must be given to park informing park users and addressing misconceptions.
- Some advanced technical knowledge is required to build sensors, collect data and interpret the results.

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Contents

1 Introduction

The WISEParks project was a one year long project which aimed to develop and test cost effective technology for counting park users using WiFi signals. The project was hosted at the University of Nottingham from September 2018 to December 2019. Working with partners at Nottingham City Council researchers at the University developed and tested technology in two destination parks in the city of Nottingham, UK.

The technology developed in the WISEParks project receives signals routinely sent from WiFi enabled devices and uses them to count the number of devices passing within range over time. Devices counted will include smartphones, tablets, laptops and some wearable technology. No intervention is needed on behalf of the person carrying the device and internet connectivity of the device is not affected.

Counting park users using WiFi signals offers the potential to assess the 'busyness' of an area for a relatively small financial outlay. Each sensor used in the WISEParks project cost around £100 to build, including a battery. By using WiFi signals the need for a physical barrier (e.g. gate counters) or visible installed technology (e.g. light gates) is removed. Wifi sensing can cover a large area, up to 200 m radius, using a single sensor. Unlike manual counting using human observers WiFi based counting can produce results on a 24hr basis and data can be nearly instantly sent to park managers.

Public acceptance of any technology is key if it to be successfully deployed. Engagement with park users during the WISEParks project revealed a poor understanding of WiFi (and WiFi based counting) technology in the general public which resulted in some unfounded concerns. Concerns about 'monitoring' of visits, 'big brother' surveillance and unauthorised use of personal data were apparent. Indeed the use of WiFi signals without explicit user consent, while legal, does pose ethical challenges. The technology must be used with caution since personally identifiable data will be handled at some level in the system. The key distinction between 'counting' at one sensor and 'tracking' between multiple sensors is important if the technology is to be acceptable to the public.

This report describes the technology, processes and lessons arising from the research undertaken during the WISEParks project and includes guides for replicating the work. One aim of the project was to produce replicable, cost effective technology and methods. Using this report along with the associated technical resources and videos it should be possible to replicate the WISEParks studies in any location and understand the technical, ethical and practical issues involved.

2 Example Use Cases & Alternative Methods

In this section we discuss the motivation to build and deploy WiFi based counting technology in a park setting. Despite being a relatively cheap and deployable technology an investment of time and money is still required. In order to illustrate some potential uses of the technology we will introduce three potential deployment styles which became apparent during the WISEParks project.

2.1 Short Term Deployment

Deploying user counting devices for set periods to investigate pre- and post-intervention user numbers is the most common reason for requiring such data. This information provides an **objective evaluation of the impact of investment** or change in visitor numbers.

Example: Highfields Park

Highfields park is a 121 acre park in the west of Nottingham. It is adjacent to the University of Nottingham and busy commuter routes into the city. The park surrounds a boating lake and contains a cafe, playground and other concessions. As such it is both a destination park and a pleasant space used by people travelling to and from work.

At Highfields manual visitor counts were carried out before and after a £4.8m Lottery-funded restoration project that completed in 2018. Staff and volunteers carried these observations out in person with 24 hours' worth of counting data then used to estimate annual visitor numbers. When undertaking similar projects in the future we plan to use WISEParks monitoring to both establish baselines of park usage before works as well as changes to these numbers throughout and post-restoration.

A project planned in Highfields for 2020 will create a new memorial garden at the less visited Western end of the site and we use WISEParks methods to report to the funders how this has impacted on site usage, including visitor numbers. On a part of the site where carrying out visitor observations in-person would be impractical, WISEParks monitoring will allow us to establish whether our aim to bring more visitors to this end of the park is actually successful.

2.2 Long Term Deployment

For most park improvement projects, capital funding must be sought from external sources who require evidence of the impact the development will have and the benefits it will bring – including the potential number of people positively affected. For commercial projects, these numbers are essential to make business cases stand up.

Using WISEParks monitoring to gain a better understanding of park user numbers will help **build these business cases for further investment** – either by showing the existing potential audience for a new attraction or by illustrating the potential that a site has to increase the existing visitor numbers. A good understanding of visitor patterns for this type of application can only be achieved through a long term deployment of person counting - covering variable weather, seasons, festivals and holidays. This data can also help operations flex their opening hours and availability to meet times of greatest demand and avoid times when sites are quiet and facilities won't be needed or won't be profitable.

Example: Colwick Country Park

Colwick Country Park in Nottingham is a 250 acre park on the east side of the city. The park is a destination for many activities including open water swimming, parkrun and a children's playground. The park is used to access a private marina and an activity centre. The park is situated away from major commuter routes and has a 'country feel' despite being a short journey from Nottingham City Centre.

An opportunity to improve the cafe provision at Colwick has been identified & long term visitor counts are being used to both support the business plan and inform the placement of a new facility. Few visitors traverse the entire park on each visit since the park is very large, the placement of a new cafe will therefore need to be accessible to the majority of visitors and could be used to deliberately influence visitor flow within the park.

2.3 Live Data

In the future, there is potential to extend the WISEParks counting method to give 'live' data from parks, perhaps via a public facing web dashboard. This data could offer park services real-time information on when is best to carry out opportunistic basic maintenance on the park; for example, arranging litter collection and bin emptying to take place after peak visit times or ensuring that grass cutting isn't scheduled for when the park is at its busiest and covered in people enjoying the space. At Highfields Park, for example, we have learnt through WISEParks about the weekday usage peaks which take place every two hours in-between student lectures; we also know that in peak season, the areas around the play area, boat hire launch and adventure golf can become very busy and put strains on park cleanliness and litter bin emptying; if able to monitor usage in real-time, park maintenance could be tailored to better meet visitors' needs.

Public facing live data could also act as a communication tool for the parks service - making data visible and perhaps even available to the public could act as a conduit for people to **engage with and understand the work being done**. The perception of a threat to privacy could be alleviated by making data visible and accessible.

2.4 Alternative Methods

Capturing data on the number of users visiting parks and other green spaces has been an ambition for Parks Services for many years but with no single agreed best method of doing so.

Manual counting wherein a staff member or volunteer records visitors using on site survey method is perhaps the most obvious. Whilst this provides reliable, first-hand data, this method is time consuming and relies on both staff and volunteers to contribute large amounts of time. This method also naturally restricts counts to times when observers can be safely deployed. Data is unlikely to be collected after dark and it is unpleasant work in poor weather.

Technological solutions such as pressure pads or gate counters can give an accurate count of footfall at one location. Their counts however can be of limited use due to the permeable nature of many sites which don't have defined boundaries or have numerous informal entry points. These methods also require visible deployment of technology and power sources; they are therefore vulnerable to vandalism, weather damage and theft.

WiFi derived counts used in this project can be used to device counts at all times of day and night. The sensors can be deployed out of sight of the public and near to mains power supplies. They can be used to provide near 'live' data and are low cost to obtain and setup. Conversely these devices deliver counts from an area which can be difficult to define, they only count visitors carrying technology and their ability to function while hidden from sight using a technology which may not be well understood may lead to poor public perceptions. In this report we describe how some of these concerns were addressed during the WISEParks project but it is likely that the most reliable results will always be obtained using a combination of methods.

3 Understanding the Technology

In this chapter we discuss the technical issues involved in building a system to perform WiFi counting and the concepts behind the technology. Detailed guides for building sensors are included in chapter **??** and the appendices.

3.1 System Overview

The system for counting park users using WiFi developed during WISEParks was formed of five main components:

1. The device owner (or park visitor).
    - May be carrying no device or multiple devices.
    - Assumed to 'own' devices so that device identity is closely related to the owners identity.
    - Informed that signals from their devices may be used, should know that opt out is possible through disabling WiFi or turning off device.
2. The WiFi enabled device.
    - For these purposes 'WiFi enabled' means that the device is capable of communication using WiFi and this this capability is switched on.
    - While a device is 'WiFi Enabled' and not connected to a network it will periodically 'probe' for new networks and be visible for counting. If it connects to a network these probes may slow or cease completely making it invisible to counting. It is assumed to be unlikely that a device will be connected to a WiFi network while in a park.
3. The sensor (or 'counter').
    - Some WiFi enabled device which has been switched to 'Monitor' mode in order to listen for probes from WiFi enabled devices.
    - This device is a passive 'listen only' device. It will be invisible to WiFi enabled devices.
    - The process of transforming data from received & identified signals to 'counts' is assumed to happen at the sensor. Device identity does not pass further than the sensor.
4. The data handling system.
    - Transports counts from the sensor to the park manager.
    - Produces data summaries (plots, statistics).
    - Only has sight of device counts, no personally identifiable information.

5. The park manager.

    - Takes ownership of the data collection process & sensors.
    - Creates actions from the count data.
    - Liaises with the park users to inform and reassure. Association with 'non-profit' park service can be an asset when discussing collection and use of data.

3.1.1 A Brief Introduction to WiFi

The name 'WiFi' is a trademark of the WiFi Alliance, it was coined to replace the less catchy 'IEEE 802.11 Direct Sequence'. WiFi is a family of technologies used for the radio based networking of devices. It is commonly used to provide internet access to WiFi enabled devices via some 'access point' - a hub which relays data between the devices and a wired internet connection.

A detailed description of the WiFi communications protocol is beyond this report but a brief description is included so that the signals being counted can be understood. the process of interest to use is the process of connecting a device to an 'access point'. It is signals sent in this process which we intercept and make use of.

When a WiFi enabled device is not connected to a network it sends a 'probe request'. These signals give the identity of the device (aka the MAC address), any networks it has previously connected to, and the type of networks it's capably of connecting to. These probe requests can routinely travel up to 200m from a device. The 'probe request' can be sent on any one of 14 channels used in WiFi (assuming the more common 2.4GHz frequency, some devices also operate on 5GHz).

When an 'access point' receives a 'probe request' and sees that it has some network which the sender might be able to connect to then it replies with it's capabilities and the connection process can begin. However this is where the interest stops when performing WiFi counting. A WiFi counter is simply an access point which never replies to probe requests. It receives the information from the device looking for a connection and quietly logs it. The sending device does not know that it's probe has been received.

Counting vs Tracking

If multiple sensors are deployed, each looking out for and recording probe requests, then a device & its owner may be tracked between the sensors. Tracking means that the data contains a record of where and when an individual device was seen. Tracking allows us to infer the route taken by a park visitor, the time spent in each location and even the method of transport used. Tracking users allows us to monitor repeat visits and associate park visitors with events or habits. Naturally tracking is a very invasive process, without user consent it is ethically dubious and may well become illegal in the UK in the near future. In Europe the use of received MAC addresses is covered by the ePrivacy Directive, it remains unclear what is allowable despite numerous test cases but unlimited tracking with no time boundaries and no user consent has been deemed not permissible in several test cases.

The alternative to tracking used in the WISEParks project is 'counting'. When counting we record the number of unique devices seen by a sensor in a set period, usually 5mins. The [hashed, see section 3.5] MAC addresses are stored only for the duration of the counting window then can be discarded. No sharing of data between sensors is performed and so no information about dwell times, routes or revisits is available. The count data has been deemed to not be personal data since identifying individuals from the data is close to impossible and usually meaningless. Count data gives us information about the 'busyness' of a single area around a single sensor. Multiple sensors can give us 'relative business' between two places or information about busyness peak times in different sections of the park.

Why a Probe Request May Not be Received

There are a number of reasons why a probe request may not be received by the access point or WiFi counter:

- The sending device may not have been in range of may not have sent a probe request while in range. Devices which send probe requests more often are more likely to be seen by a sensors, as are devices which spend longer in range. *This leads to a bias in the data collection - cyclists pass by a sensor faster than pedestrians and are therefore less likely to be counted*.
- The probe request may have been sent on a different channel / frequency than the listening device is using. The sensors used in the WISEParks project only listen on one channel, one frequency. This is common for lower cost technology. The listening channel could rotated but then a collision between the receive channel and transmit channel would have to occur for a probe to be received. *During WISEParks a decision was made to listen on one commonly used channel (2.4GHz, ch1)*.
- Somewhat less likely is a collision between one probe request and another. If two devices send a probe on the same channel at the same time then they may 'collide' or interfere with each other and prevent reception by the sensor. This will happen more in busy spaces with a high density of devices *leading to a bias in the count in busy spaces*. We anticipate that this will not happen often in parks but needs to be taken into account if performing counts at busy events.

3.2 The Raspberry Pi and WiFi adaptors

The WISEParks project team developed sensor technology based on the Raspberry Pi single board computer . This device is relatively inexpensive, widely available and requires limited technical knowledge to access.Specifically the 'Raspberry Pi Zero' was used which is the smallest version of the Raspberry Pi (pictured in figure 3.1). It it designed for applications where low power consumption and small size is more important than processing power or connectivity. Power consuption and power supplies are discussed later in this section

The Pi Zero has an onboard WiFi capability. this means that a 'WiFi dongle' does not need to be purchased separately. Using onboard WiFi or an external dongle it is important that the WiFi adaptor is capable of being put into 'monitor mode'. In this mode it is in listening mode, listening for WiFi signals. we can then filter received signals to analyse only 'probe requests' which contain the information we need.

The SD card image provided with the WISEParks toolkit transforms a Pi Zero into a WiFi counter and puts its onboard WiFi adaptor into monitor mode. Note that this means that the WiFi antenna is on the Pi Zero - if it is shielded by a metal casing then reception of probe requests will be impeded.

3.3 Data SIMs

One downside to the Rapsberry Pi is that it lacks an onboard clock which operates when the device is powered down. When the Pi is turned off it loses track of the time and needs to learn the time again on startup. For this reason we need to provide either an internet connection to the Pi so that

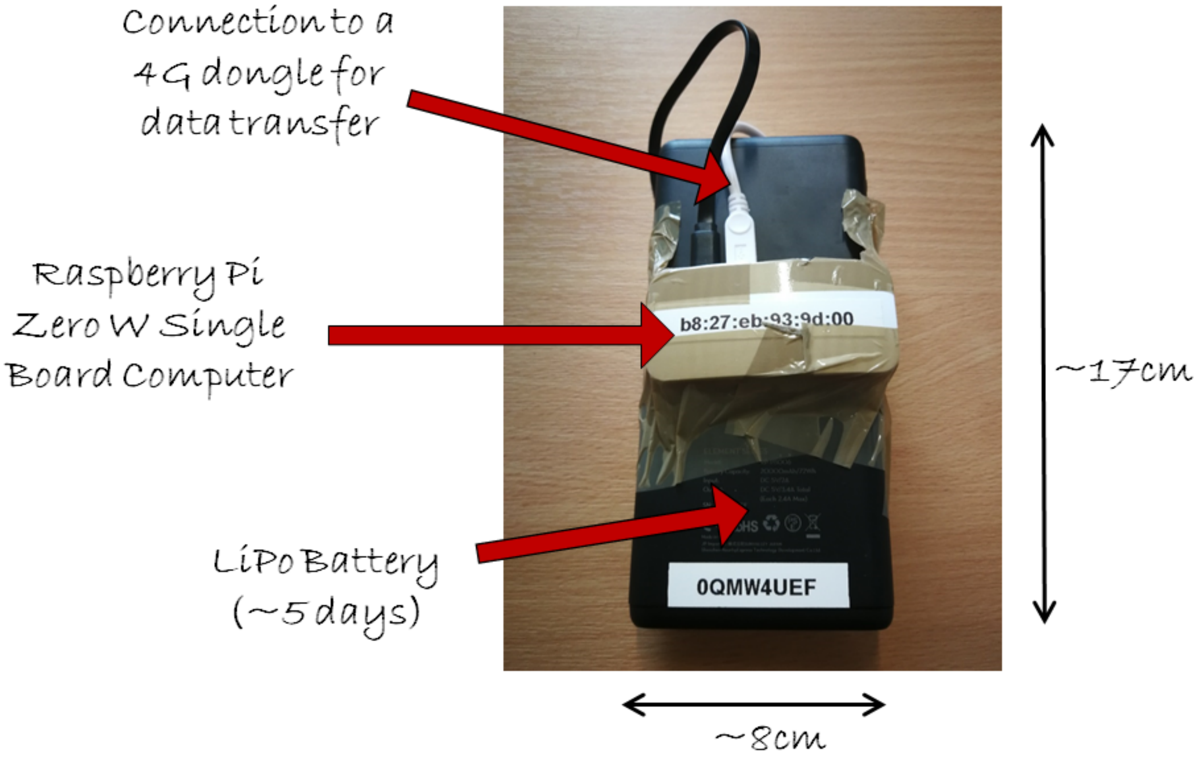

Figure 3.1: A single battery powered sensor used in the WISEParks project

it can connect to a timeserver and regularly update it's clock or we need to add a 'real time clock' module to the Pi. These clock modules are inexpensive (£4), small and readily available.

During the WISEParks project we achieved connectivity by providing each Pi Zero with a 3G or 4G data dongle (readily available from many suppliers, Specifications in appendix **??**). These dongles require a SIM card to connect to a mobile network and use 3G or 4G data. For a short term study a 'pay as you go' (PAYG) type SIM card may be appropriate, for longer studies a contract may be worthwhile. During the project it was found that sufficient data was available on a PAYG basis for around £5 a month.

If data is to be sent to a server for analysis (see section 3.5) then the mobile network connection will also be used to transfer this data. We found that less than ≈200 MB per month was typically used by each sensor.

3.4 Power Supplies

The Raspberry Pi Zero can be powered from a mains outlet or a battery providing 5V (USB) power. For long term studies a mains based power supply is preferred although this will naturally limit the deployment locations available.

A Raspberry Pi Zero setup with a 4G dongle and the WISEParks SD card image will use around a current of around 150 mA. With a typical 20000 mAh battery* (pictured in figure 3.1) this equates to a battery life of around 5.5 days. In order to maintain continuous data the battery would therefore need changing at least every five days if the batteries maintain performance over time. The need for two sets of batteries (one live, one charging) and time to exchange them should be accounted for when budgeting for equipment and maintenance.

*The specifications of the batteries used during WISEParks are given in section **??**.

3.5 The Data Pathway

The path which data takes in the WiFi counting system will depend somewhat on the purpose and setup of the study. For a short term study setup where real time analysis is not required it may be appropriate to leave data on the sensors and retrieve it when the study is over. This approach is relatively simple and requires little technology to be setup beyond the sensors. For longer term studies, those in which analysis is required in (near) real time or where security of the sensors is a concern, it may be appropriate to send the counts to a server for storage and processing. This was the approach taken during the WISEParks project during which technical expertise was readily available. In this section we describe the path taken by data in the WiFi counting system for both approaches.

In the Sensor

Personally identifiable data is recorded by the sensor in the form of device identity (MAC address). The WISEParks approach has been to hash (scramble) that as soon as possible. The hashed device identities then need to be stored for as long as the count duration to enable the count of unique devices to take place. By default this period is 5 minutes. After this even the hashed device identities can be safely discarded.

This process addresses some of the privacy concerns expressed by park users (no tracking or monitoring of individuals is taking place). the cost however is that we limit the questions which can be asked of the system - we can say nothing about repeat visitors, visit duration or the path taken between devices. If a sensor were stolen and 'hacked', at most 5 minutes of hashed identities would be stored on the device.

Download from the Sensor

If the study were to be short term or a technically simplified approach is desired then log files can be taken straight from the sensor to be analysed with the tools made available in the WISEParks toolkit. In this case data, in the form of time windows and device counts, is transferred directly from the sensor to some other PC to be processed.

Using a Server

If the study were to be longer term or loss of the sensors (and hence data) is a concern then an alternative approach is to setup a server and use the data connection provided to the Pi Zeros to send data directly to a server.

The setup of a server is discussed in detail in section **??**, for now it is worth noting the cost involved in this process. Access to the server or server hardware must be paid for and there is a time cost associated with setup and testing. The reward for this expenditure however is potentially greater data security, less staff intervention (especially for mains powered devices) and potentially near instant access to data.

During the WISEParks project data was transferred to a server on a 6 hourly basis and local data copies were taken for use in developing analysis methods. During development the hashed device identities were recorded and so the data quantities were significant (75k probes recorded per month at each sensor). By recording only counts of devices seen this data quantity is greatly reduced; 200MB per month per sensor will be plenty for most setups.

3.6 Equipment You Will Need

The process of planning a deployment is discussed further in section 4.4, however a brief list of items to consider is given here for each of the three deployment scenarios.

Per Park Site	▪ Information Signage ▪ Staff Training
One-off	▪ PC for Analysis ▪ (AND) Server for data storage
Per Sensing Location	▪ Raspberry Pi Zero ▪ 2GB Micro SD Card ▪ 4G Dongle. ▪ Data SIM Card. ▪ 'Do not touch' & information signage and/or switch blockers. ▪ (Casing for the system.) *For Battery Powered Devices* ▪ Battery. ▪ If the battery does not have USB (5V & 2A output) then a converter will be needed. ▪ Micro USB Cable ▪ Battery Charging Equipment ▪ Spare Batteries *For Mains Powered Devices* ▪ Mains to Micro-USB power supply.

4 Planning a Deployment

In this chapter we discuss some of the factors which must be considered when planning the deployment of WiFi technology. We have tried to present generic factors applicable to every park, the balance of concerns will vary between parks - for example security may be an issue in some parks more than others.

4.1 Location

Deciding the location of the sensors is of utmost importance when planning a deployment. Potential locations may be limited by practical issues like security and power supply. However a badly placed sensor will deliver bad data. The idea placement may be in the middle of an open space, away from non-park users, with a mains power supply and on a path which every park user must traverse. These places rarely exist and some compromise must be made.

4.1.1 Power supply & access to a cellular data service

As described in chapter 3 sensors may be run with mains or battery power supplies. For ease of maintenance mains power is obviously preferable. If a battery is to be used the the sensor must be readily accessible to staff trained to maintain it.

As the sensors were deployed during the WISEParks project access to a cellular data signal is essential. If this is not possible at a desired sensor location then some other arrangement must be made - a clock add-on for the Raspberry Pi or a bespoke wireless data connection (e.g. WiFi or a 433 MHz solution).

4.1.2 Housing & security

The sensor as built for WISEParks is not inherently weatherproof. It must therefore be provided with some casing / housing. A solution as simple as a ‘clingfilm’ wrap may work, especially for devices are housed in some other way, for example in a bin or tree box.

It is worth bearing in mind that any housing will reduce the strength of the signal received by the sensor. Completely enclosing the sensor in a metal housing may mean that no signals make it to the sensor to be counted.

4.1.3 The Immediate Environment

If the sensor is placed in an area where people will dwell for longer periods (car park, cafés, playgrounds) it will be more likely to receive a beacon from every device in the area. If however it is placed on a thoroughfare there will be a bias in data as faster moving travellers will be less likely to be counted.

Not all areas of a park are equally visited - indeed understanding this imbalance this may be the purpose of a study. If the purpose of a study is to answer the question "How many people visited the park this year?" then placing the sensor at a location which most park users must pass through will be important. A more readily answered question may be "is this area busier than that area?" or "is today busier than yesterday?".

4.2 Informing Park Users

This section is expanded since acceptability to the park-using public and park service staff is very likely to affect the viability of a study. Naturally park users should be informed about the type of research being undertaken in their park and how it may affect them.

Figure 4.1: The symbol used to alert park users to data collection during the WISEParks project.

4.2.1 Acceptability

Acceptability of the research will be somewhat dependent upon how it is understood by others. The research needs to be acceptable to the public using the space as well as the employees working in the park. Clear explanations are required for staff working in the area and information for the public also needs to be available and understandable. If properly understood, individuals will be better informed, hopefully more willing to support the project, and more likely to participate in it.

4.2.2 Signage

Signs may be the only thing to alert someone that data is being collected for the project. Signs in the park need to be visible with a clear message that is easily understood. This is both in terms of visual impact as well as the information conveyed. There is a risk that the research will not be sufficiently obvious if the signage is not eye-catching or informative.

4.2.3 Education

The aim and nature of the project may not be immediately understood by those not involved in it. Project information should be immediately accessible to all and details relating to the projects' methods and rationale need to be made available to those who want to know more about the project. Providing educational materials about the project and how technologies are being used will help to clarify the meaning behind what is advertised on signs. A web presence is a good way of making information widely available to the population likely to be counted. The WISEParks toolkit includes a video 'explainer' of the technology which can be use dtom compliment a description of the study itself.

4.2.4 Data Governance & Ethics

Currently no explicit consent is required from users in order to use signals emitted from their devices. This situation is likely to change although at the time of writing it is likely that using such signals for counting purposes will remain legally acceptable. A useful analogy might be the use of CCTV - the (UK) law in this area is far more advanced. When using CCTV, personally identifiable is usually deliberately collected (a.k.a images) although a distinction is drawn between images and data derived from images (e.g. number plates, automated facial recognition). Data handling processes for non-private CCTV deployments are clearly laid out and it is likely that similar process will exist for radio based counting methods in the future.

Despite the legality of collecting signals from WiFi enabled devices the [lack of] acceptability (section 4.2.1) to the public and implied duty to handle data with due care remains. Clearly the data collected must be kept safe and in accordance with local data protection arrangements. Once transformed to 'counts' the WiFi derived and manual count data may be considered no-longer personal. At this point it may be appropriate to use it to reassure park users of the nature and intent of any study (section 2.3).

Personally identifiable data from manual counts or surveys must be transferred to secure electronic folders as soon as is feasibly possible. Any audio recordings need to be transcribed and the transcriptions must be safely stored as soon as possible so the audio files may then be deleted.

4.3 The Data

The WISEParks method collects signals from WiFi-enabled devices using WiFi sensors, numbers of people seen by human researchers placed at designated positions in the park as well as survey, interview and focus group responses. As far as people-counting is concerned it is not feasible to easily recover personal identities from the data. Exceptions to this may exist in very quiet periods at the park when very few devices will be observed. If only one device is present the identity of the owner may be simple to ascribe using other data, e.g. CCTV.

Further details about group sizes and activities being undertaken may be collected and recorded by the researchers. Surveys need not collect personal identifiers from participants if completed on paper or online. However, if interviews or focus groups are undertaken to gather information about park users, any audio-recordings of such activities will need to be treated as identifiable information.

4.3.1 Counting biases

If the question asked of a WiFi counting system is one of "how many people" then some conversion must be done from device count to person count. This isn't always an easy conversion to do and can be dependent on the park, or even area within the park. Factors which affect the translation from device count to person count include:

- Propensity of the park user population to carry a WiFi enabled devices (e.g. children are less likely to be counted than adults).
- Park users owning and carrying more than one WiFi enabled device.
- Park user activity (walking / cycling / swimming etc).
- Park busyness - are beacons being missed due to collisions? (Section 3.1.1).
- Location of the sensor - are devices from outside the area of interest being counted?

If we assume that many of these factors are constant in the park user population and sensor location then 'relative busyness' may be a better number to use i.e. asking is one area or time busier than another.

4.4 The study planning process

The following list is intended to illustrate some of the questions which must be answered and activities which must be undertaken to achieve a successful study;

Planning Stage

- Motivation - why is the data being collected, where will it be used and which decisions will it influence?
- What is the budget available?
- Timescale - which events are motivating this study or for a long term study are there events which might be desirable to record soon?
- Specific locations - which areas in each park are of interest? Where is power available? Where is ranger support easily available? Where can a device be securely placed?

Development Stage

- Who will setup and test the technology? Will this be done 'in house' or outsourced?
- Do we need a server or data storage facility?
- Do we need live data or data transmitted to a server?
- How many sensors do we need and how many of each component (including batteries)?
- How will the sensors be maintained? Do we need ranger support & training?
- Undertake Hardware Purchasing.
- How will we publicise this deployment?
- Who will have access to the data, will it be public data? How will we achieve this?
- Will we perform manual counts or park user engagement to compliment the technology deployment?
- Sensor build and test.

Deployment Stage

- Begin & monitor study publicity.
- Deploy sensors and regularly revisit to check power, collect data etc.
- Park user engagement activities if applicable.
- Maintain deployment throughout park improvement if applicable.
- Retrieve and Redeploy if applicable.

Analysis Stage & Complimentary Activities

- Will analysis take place once all data has been collected or will it be a rolling process?
- Will we perform manual counts to compare to the WiFi derived counts?
- Who will receive the results?
- What format should they take?
- Who has the understanding and skills to aggregate, interpret and present the count data?

7

5 Nottingham Deployment Case Studies

In this section we present some illustrative results obtained at two Nottingham parks in 2019. Data collection and analysis is ongoing at both parks at the time of writing.

5.1 Highfields Park

Figure 5.1: The boating ticket office at Highfields park. In this view the WISEParks sensor was located inside this building in the far left corner.

Highfields park is a 121 acre park in the west of Nottingham. It is adjacent to the University of Nottingham and busy commuter routes into the city. The park surrounds a boating lake and contains a cafe, playground and other concessions. As such it is both a destination park and a pleasant space used by people travelling to and from work. Highfields is a long narrow park crossed by pedestrian and cycle paths. Being close to a major workplace it is used as a destination for short breaks as well as a destination for longer family visits.

Highfields was chosen as a test site for this study since it provided a straightforward location for sensor deployment, easy access for project staff and is undergoing a series of improvement projects.

Two sensors were deployed in the park, one at the busy east end of the park and one at the quieter west end. In the east end of the park a cafe and numerous activity concessions can be found. An adjacent car park and tram stop make this end of the park easy to access and a large playground is the sole destination for many families. In the west end of the park there are no activity concessions and the main activity is exercise; walking, running or cycling. The west end of the park features a newly restored waterfall and stepping stone feature.

The sensor at the east end of the park was deployed in a brick built ticket office close to a main path through the park. The ticket office sells tickets for boat rental and has mains power which was used to power the sensor. This sensor was placed in the heart of a busy area but separated from most passing devices by a single skin brick wall. At the west end of the park a sensor was placed near the water pump for the newly restored waterfall. A pair of 240V sockets were installed with the water pump and were used to power the sensor here. This sensor was further from major thoroughfares and was placed in a stone stairwell slightly below ground level for security.

In figure 5.2 results obtained using the sensor at the east end of Highfields park are shown. The number of unique devices ‘seen’ by the sensor at each 5min interval during the day are shown as blue dots while the black line is the mean of these for each 5min interval. The data are split between weekend and weekdays, naturally therefore the number of days represented in each plot varies but both plots depict data collected over three months.

Two features of interest were identified when this data was viewed by park managers. Firstly the hourly ‘peaks’ in the weekday data. This is caused by the commuter users of the park; students passing the sensor on their way to lectures which begin at regular intervals during the day. Commuters combined with lunchtime exercisers cause the biggest peak in this data, weekday lunchtimes are the busiest time in this park. Unsurprisingly mornings are generally quieter than afternoons at this sensor with weekends being slower to get busy than weekdays. Weekends at this park are generally quieter than weekdays.

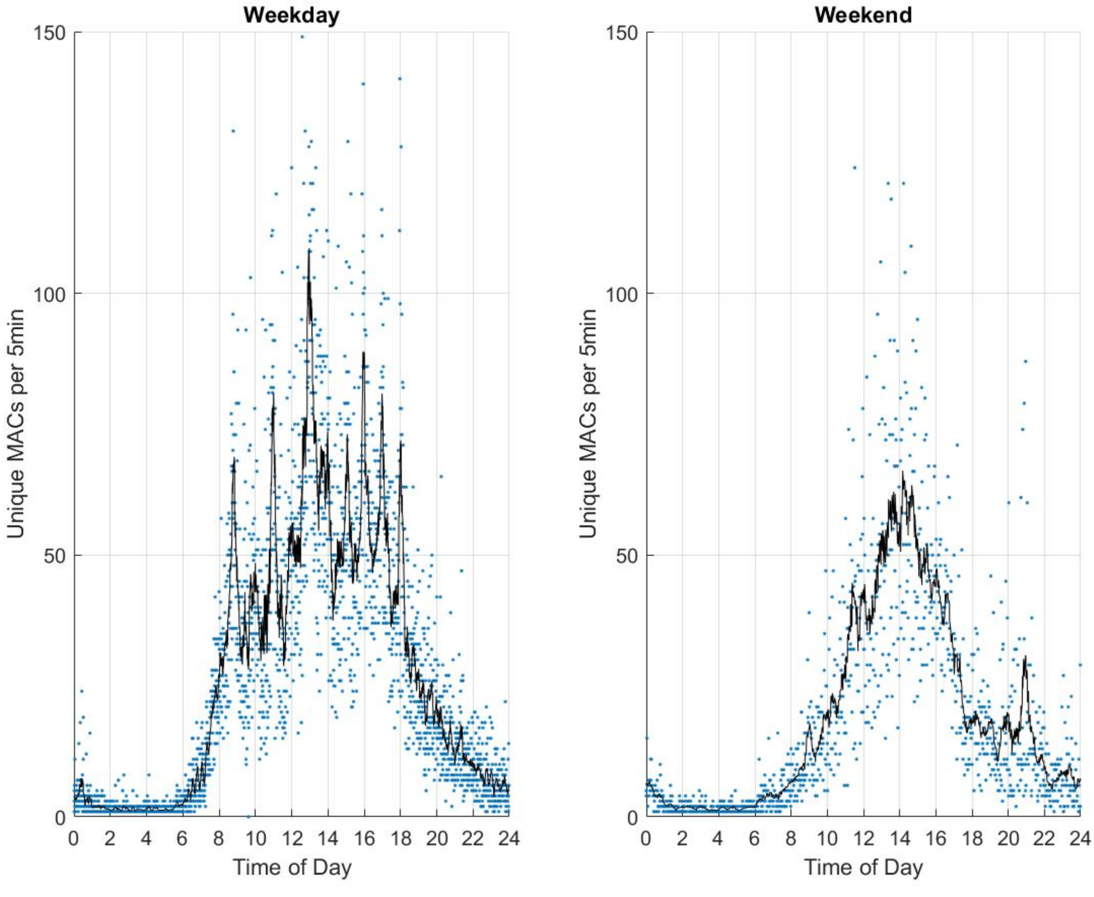

Figure 5.2: Device Counts per 5 minutes at the east end of Highfields park, spring 2019

Long term data collection is ongoing at Highfields at the time of writing, comparisons of data collected at each end of the park and analysis of seasonal variations will be published by the project team and may be obtained using the contacts on the rear cover of this report.

Figure 5.3: The kiosk at Colwick Park (center image). In this view the WISEParks sensor was located inside this building in the center of the near wall.

5.2 Colwick Country Park

Colwick Country Park is a 250 acre park on the east side of the city. The park is a destination for many activities including open water swimming, parkrun and a children's playground. The park is used to access a private marina and an activity centre. The park is situated away from major commuter routes and has a 'country feel' despite being a short journey from Nottingham City Centre. Colwick park has two main entrance and exit routes but is a porous site despite being bordered on one side by the Trent river. Colwick was chosen for this study since it is a larger 'destination' park with multiple well-distributed attractions. The potential for future development of Colwick makes it an attractive candidate for long term data collection.

Multiple sensors have been deployed at Colwick park for long term and short term studies, analysis of which is ongoing. In this report we illustrate some of the results obtained using data from a long term sensor at the main road entrance to the park. Park staff estimate that 80% of the park visitors enter the park using this road and so will pass this sensor on foot or by car. Adjacent to the entrance is a kiosk in a metal cabin. This kiosk has mains power and so was selected as a site for long-term data collection. Since the sensor was deployed inside the metal cabin we can expect to see lower strength signals being received but the expectation was that this is offset by the proximity to the major paths into the park.

Figure 5.4 depicts the data collected by this sensor in the spring of 2019. The plot area is broken up into rectangles, each representing a 5min counting window (y-axis) and one day (x-axis). The box is shaded to indicate the relative business of that interval compared to the other 5min intervals. A black box indicates the park was at its busiest while a lightly shaded gray (weekday) or green (weekend) box indicates a quiet period.

At Colwick Park we do see a level of business associated with the morning (9am) commute and lunchtime exercising. This can be seen in the row of dark shaded boxes near the top of the plot and around the middle (1pm). However the biggest determinant of how busy this park will be is the weather. In February 2019 we had a period of unseasonably good weather which lead to the busiest periods observed in Colwick Park. Both weekdays and the weekend of the 23rd/24th February were busy. Conversely the first weeks of April that year saw poor weather and the park busyness was at its lowest. We noted both here and at Highfields park that the busiest times in the park were not at weekends, weekdays were often busier.

One expected feature is absent in this data - 9am each Saturday sees a Parkrun event with 300 runners at Colwick park. This event is not apparent in this data suggesting that either the runners are not carrying WiFi enabled devices, not detected as they drive past the sensor or they use a second entrance near to the start of the Parkrun. The answer probably lies in a combination of all of these

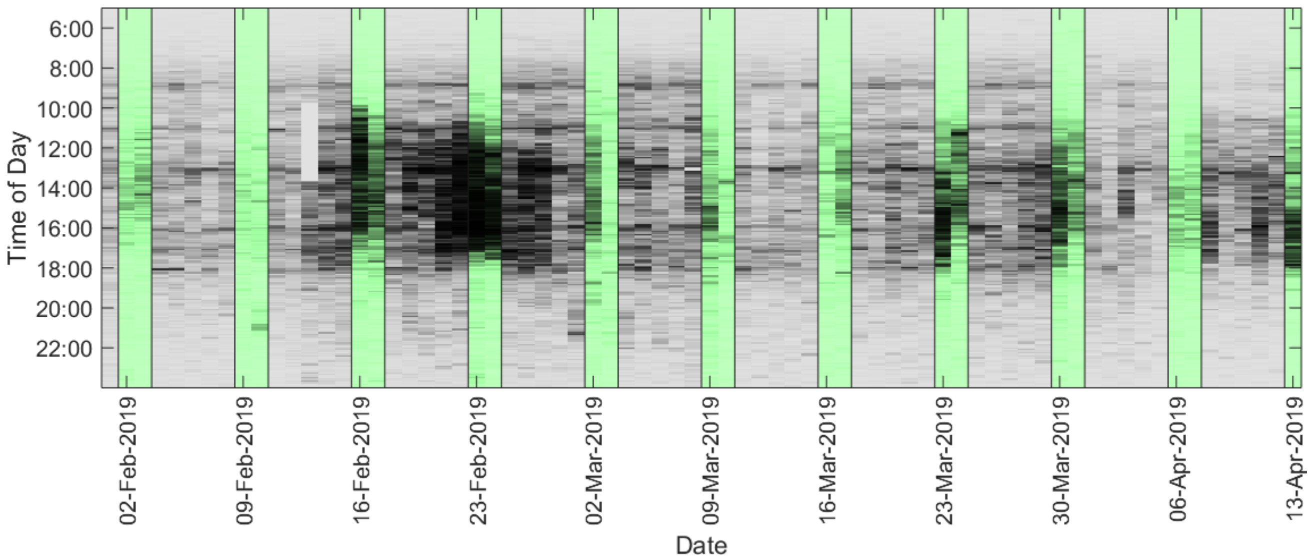

Figure 5.4: Device Counts per 5 minutes at the entrance of Colwick park, spring 2019

factors. The porous nature of nearly all parks means that park business will never be measure by a single device, only the business in one part of the park.

5.3 Park User Engagement Study

During the WISEParks study a pilot survey was undertaken to gather further information about park use and the signs that were used to inform park users about the data collection being undertaken. The data presented here concern the understanding of the technology being used and views about the poster used to inform park users about the study.

5.3.1 Method

The survey was advertised by email, twitter and local newsletters, including the local council's. It was made available online and in a paper-based format. It may be administered from a kiosk, on location, as well as remotely to a wider sample of the population. Information notices about the WISEParks Project were posted in a number of locations around the park.

When administered in-person, the study design allows for participants to consent to having their comments audio recorded for transcription later. Other than what is recorded on the consent form and the voice of participants who choose to be audio-recorded, no other identifiable data will be captured for the survey.

The quantitative data was analysed with descriptive statistics and the qualitative data was processed manually and with NVIVO software.

5.3.2 Results

The summary results presented here represents analysis of both the quantitative and qualitative survey data. There were 107 responses to the survey. Full results are presented in appendix **??**.

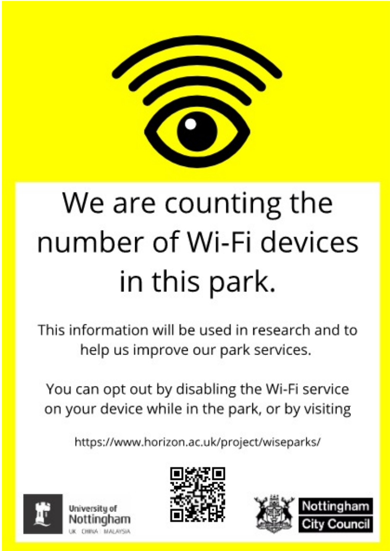

Figure 5.5: Poster used to advertise the presence of sensors

5.3.3 Device Ownership

All 107 respondents were asked how many phones were carried by them and their companions when in a park. 87.8% of respondents thought that they would typically have 1 or 2 phones in their group, when visiting a park with the 2 phone option being most frequently selected.

- 2 phones = 54 (50.5%)
- 1 phone = 40 (37.4%)
- 4 phones = 6 (5.6%)
- No phones = 3 (2.8%)
- 3 phones = 2 (1.9%)
- 5 phones = 2 (1.9%)
- Other = 0 (0%)

Of the respondents 31.8 % reported that they usually visit alone. A further 62.6 % reported that they usually visit in a group of 2-4 people.

Of the respondents 97% said that the only WiFi enabled device they (or their group) carried was a smartphone.

5.3.4 Project Understanding

When asked if they had seen the WISEParks poster before (figure 5.5) 99 (92.5%) of the respondents indicated that they hadn't. Since the survey included users of parks not included in the WISEParks study this figure is perhaps not indicative of the effectiveness of the poster.

When presented with the poster and asked what they thought it meant, 99 (92.5%) of the survey participants gave a free text answer. Their responses were analysed to identify statements that essentially indicated correct understanding, incorrect understanding or those that appeared to be unclear or ambiguous in their expression of understanding. Of those 99 responses 32 were classified as a correct understanding of the WISEParks project from the poster image. 38 responses indicated an incorrect understanding of the poster and 29 responses were ambiguous or unclear.

Some statements contained fragments that were correct, as well as incorrect or ambiguous, therefore further thematic analysis was undertaken where chunks of data (words or phrases) were identified as 'indicators' of correct, incorrect or ambiguous/unclear understanding within each response. Themes emerging from 'misunderstood' responses are given below. They are listed in order with those containing the most number of indicators listed first.

Themes for indicators of incorrect understanding are listed below:

1. Privacy
   - Monitoring, Tracking, Big Brother
   - Other specific privacy concerns
2. Connecting to WiFi
3. Free WiFi
4. Miscellaneous

Many park users were concerned about the effect of technology on their visit, either through visible devices in a 'natural' environment or through their needing to interact with technology somehow during their visit. Both of these are unnecessary but are a concern which should be taken into account when planning a study and the opt-out options.

5.3.5 Discussion

Despite information presented on posters (during the survey) 67% of respondents exhibited some lack of understanding of the study when asked to describe it. This lack of understanding lead to concerns which might be alleviated with a little communication - for example some park users expected that their ability to access the internet would be affected (untrue), others worried that their personal data, for example website viewed could be accessed (untrue) and others were worried about the use to which the data would be put. As part of the WISEParks project we produced a video explainer to address these concerns. This video is publically available and links can be provided on request from the authors.

6 Summary and Key Learning

6.1 Report Summary

The WISEParks project was a one year long project which aimed to develop and test cost effective technology for counting park users using WiFi signals. The project was hosted at the University of Nottingham from September 2018 to December 2019. Working with partners at Nottingham City Council researchers at the University developed and tested technology in two destination parks in the city of Nottingham, UK.

Park user counts are often used to plan alterations to a park, evaluate the impact of changes or plan day-to-day maintenance. Currently these counts are usually manually performed by staff or volunteers physically located in the park. They are therefore expensive (financially and in goodwill) as well as being limited in spatial and temporal extent. Simple technological solutions such as gate counters offer better extent but are vulnerable to errors, vandalism and require physical changes to the park environment.

In this project visitor counts were obtained using signals routinely emitted from devices carried by visitors. The sensing technology is low cost, requires no interaction from the park visitor and can be discretely deployed. Data from this technology can be collected at all times of day and night and in all weather.

This report describes the technology itself, how to deploy it, some failure modes, practical considerations when deploying sensors and gives some sample count results from the WISEParks Study. During this project we have demonstrated that useful results can be produced using sensors which can be built using £100 of hardware. Key lessons learnt from our experience on the the WISEParks project are listed below along with hyperlinks to the relevant sections in the report.

The authors contact details may be found on the final page of this report and we welcome contact from interested parties.

6.2 Key Learning Points

- Results from our park user engagement survey suggest that public understanding of the technology which underpins WiFi counting is poor and some effort will be required to address misconceptions and lack of trust. This may be achieved through public information campaigns and perhaps making the data and results visible to concerned park visitors. Opening the data may increase trust in the data collection process and lead to collaborative innovation (Section 5.3, page 19).
- Determining the best location for a sensor is not an easy task. Power supplies and security may be the deciding factors but those interpreting the data should appreciate that parks are very porous spaces and that the results probably do not represent all visitors to a park (Section 5.2, page 18).

- Using low cost technology limits scans to one channel at a time. Probe requests will be missed if they are not broadcast on the channel used by the sensor at the time of broadcast. This limitation may be overcome with more powerful hardware (Section 3.1, page 5).

- Those planning a study using park visitor counting data should have a clear idea where the data will be used within their organisation. Which decisions will it affect, who needs to see and make sense of the data? (Section 4.4, page 15).

- The technical capability to build, maintain and interpret date from sensors must be available to anyone planning a study of this kind. The WISEParks toolkit aims to ease the building of sensors but technical knowledge will still be required, especially as technology moves on. (Section

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