A project completed as part of the requirements for the BSc (Hons) Information Technology

Entitled
Can Location Services be trusted in our Smart Devices?

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Abstract

This study has researched into the accuracy of smart devices that use Location Services, and if the data received can be trusted.

The research conducted will also be observing to see how much difference indoor and outdoor environments effect the results, and to what the accuracy levels are for certain locations within Derbyshire.

Firstly this study will be reviewing previous studies and research that were conducted about Location Services, and looking at what should be expected from this study’s results. The next stage is to explore into how the data will be collected, and by what means.

This study has collected 200 photographs, with Location Services activated, and the EXIF data will be extracted from them in order to receive the latitude and longitude.

When the data has been collected, analysing and reviewing the data will be completed with the guidance of Statistical Analysis Software (SAS). This software will use the latitude and longitude that was collected from the EXIF data, and will calculate what the error of accuracy is from the true location.

With the statistics being viewed in tables and graphs, the discussion about what the results have shown will be completed, with comparisons to the previous studies in the Literature Review.

The study will conclude that with the indoor and outdoor data producing a variety of results, the Location Services used in smart phones could not be trusted for its accuracy readings, and that further research should be conducted.
Acknowledgements

I would just like to firstly thank Richard Self for the time and effort he has spent helping me. This year he has been a great influence in my studies, and I cannot thank him enough.

Secondly I would like to thank my good friend Benjamin Wilson. Benjamin assisted me on my travels for when I was collecting location data, and for that I thank him.

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1. Introduction

1.1. Project Rationale

Technology use is growing at an extraordinary speed, and has become highly popular within the population. It is believed that 6% of the global population own a tablet, and that 20% own a smartphone (Heggestuen, 2013). Smart devices have become an important part in everyday lives, and are used to help make life simpler and easier to handle. The use of a smart device varies from using it as a regular phone, to using it to access the Internet and to use it for navigational reasons. Using a smart device for navigational reasons uses many features of the phone, including Location Services.

It has been stated that nearly 80% of all Big Data and the Internet of Things can be questionable with regard to its reliability and certainty (Easton, 2012). With this in mind, it raises questions to just how accurate Location Services are.

With smart devices being used by 36 million people in the UK (Curtis, 2014), it would seem reasonable for these people to expect accuracy from these devices. The users know that these devices can give directions to locations, and that they can Geotag their current locations, but how reliable can this service be?

Smart devices have the ability to produce errors and miscalculations, and if produced then consequences from these problems could emerge. This could greatly impact the trust that is given to these devices, and it is said that a user’s trust is an important factor for the interactive relationship between themselves and the system (Phillips, 2011).

Location data from a smart device using Location Services is an area that always represents uncertainty. People know that GPS devices have a fairly accurate reading, but do these people also believe that the same quality and accuracy is received from their smart device? It would be interesting to see how a smart device using Location Services compares to a GPS device, and to know just how accurate these devices can be.
1.2. **Project Aim**

The aim of this project is to discover how accurate Location Services are in smart devices. The project will be researching previously measured studies of accuracy for Location Services, while then producing its own results to compare with. The data collected will vary for location and indoor/outdoor, and will help define how accurate the device can be under these conditions. It is important to acquire this data under those conditions, as smart devices are mobile and are taken to most places and locations with its user.

1.3. **Objectives**

The objectives for this project are:

- To research and understand what Location Services are, how they work, and what the predicted accuracy is
- To understand the consequences of incorrect location data
- To collect and measure various location data from a smart device, and to see what accuracy levels are achieved
- Analyse the results and to see what factors have taken place to produce the readings
- Compare the project’s results with the previously researched results, and to discuss the findings
2. Literature Review

2.1. Introduction

Technology is constantly advancing in both the amount of devices created, and with what each device is capable of. It is believed that 4.9 billion smart devices are currently connected to the Internet, with that number increasing to 25 billion by 2020 (Gartner, 2014). With smart devices now being a common item for the member of public, do they completely understand what their device is capable of, and how accurate their device is?

Smart devices have the ability to track your location for your personal uses, or for 3rd party companies, but it is believed that by 2015 80% of all Big Data would become questionable and uncertain (Easton, 2012). If this is correct, then it would interesting to see just how accurate Location Services are for smart devices, and what the consequences would be if it is incorrect.

To be able to fully understand Location Services in smart devices, research into Global Positioning Systems (GPS) and Location Services is required. Research into what Location Services provides smart devices and why they are used will also be an area that will be covered in this literature review.

This literature review will first be discussing GPS, how a GPS operates, and what is believed to be the accuracy of this. The second part of this literature review will be researching what Location Services are, how they work within smart devices, and how correct the accuracy can be. The final topic that will be discussed for this chapter will be on smart devices. This will involve reviewing why Location Services are important to a smart device, and what would be the implications and consequences of inaccurate data.

2.2. Understanding Global Positioning System (GPS)

2.2.1. GPS Defined

The Global Positioning System (GPS) is navigation system that has a minimum of 24 satellites orbiting the globe that can establish your geographical location. GPS is said to be able to function anywhere in the world, at any time of the day, and in any weather condition (Lee, 2015). The GPS was created and is owned by the United States Government, was originally created for military use (GPS.gov, 2014), and it is now used by various businesses and many different countries around the world. With GPS now deemed affordable and easily operated, it can be found in numerous devices, including laptop computers and smart devices such as smartphones.
2.2.2. How GPS Works

As mentioned earlier, the GPS system is operated by a minimum of 24 satellites that orbit the earth and can determine the location and time of the object using the system. The satellites that orbit the earth broadcast three signals that measure the time of the information that was sent by the receiver, the orbital information, and the status of the system that includes the current positioning of satellites in orbit (Rose India, 2012).

The GPS navigational system involves a constellation of satellites that have been arranged into six orbital planes that have four slots in them (as illustrated in figure 1). Each slot has a baseline satellite within it and with this constellation and four satellites in each plane, it allows for the users to view a minimum of four satellites from anywhere on earth (GPS.gov, 2014).

![Figure 1: Constellation Arrangement (GPS.gov, 2014)](image)

In order for the GPS navigational system to locate the user, the satellites transmit signals to data receivers on the ground that will calculate the latitude, longitude, altitude, and the time. With all this data used, the GPS should be able to accurately record your location, what time this encounter happened, and how fast the user is travelling if moving (Haung, 2013).
2.2.3. GPS Accuracy

With the knowledge of what GPS is and how it operates, the next stage would be to research into how accurate GPS is. With the minimum of 24 satellites orbiting the earth and four satellites constantly in view for the user, the signals are said to provide a “worst case” pseudo-range accuracy 7.8 meters for 95% of the time (All Things Nav, 2012). With data 95% correct it may seem that this would ensure the results you get from your GPS are rather accurate, but that 5% could in fact be 10 or more meters incorrect.

For a GPS transceiver to measure how correct the position is the accuracy and precision of the data should be used. There is a difference between these two terms, and Ogaja describes them as the “Accuracy is the degree of closeness of an estimate to its true, but unknown value and the precision is the degree of closeness of observations to their means” (Ogaja, 2010). As shown in figure 2.1, these are the relationships that can occur from these two parameters. The true value is shown as the centre of the crossing between the two lines, the middle of the shaded area is the area of the mean estimate, and the radius of that area shows us the measurement of how uncertain the estimate is (Ogaja, 2010).

![Accuracy vs Precision Diagram](image)

Figure 2.1: Accuracy versus Precision (Ogaja, 2010)

With GPS data using accuracy and precision to calculate the true location of the user, the next step would be to see how they use it. With data being collected for a determined amount of time, the measurement errors that occur will cause them to be scattered over the given area. This information is then used in a scatter plot (See figure 2.2), which is what is used to identify the equipment’s accuracy. Using the area
within from either the measurements or the predicted parameters creates the confidence region. With the confidence region, they can then analyse the data to quantify the performance of the GPS. In order to locate where the GPS receiver is, the confidence region would create a radius that would determine the probability of how accurate the solution is (Ogaja, 2010).

Figure 2.2: The accuracy of the data collected from a GPS (Coyle, 2012)

The results shown in Figure 2.2 show the positional points for where the device believes it is, and how they fall into the 50% and 95% radiuses. The Circular Error Probable (CEP) was calculated at 6.06 meters, with the 2DRMS being calculated at 14.86 meters. The results given from this study do not correspond with what was predicted from a GPS from previously of 7.8 meters. While the result is almost double what was predicted, the accuracy from a GPS device is still shown to be fairly accurate for determining a users location. When calculating the accuracy for a GPS device, you might encounter a variation of results depending on the device that is used. Having two devices from two different companies could result in a variation of data. This is something that could be considered when collecting data.
2.3. Understanding Location Services

2.3.1. What are Location Services?

Location Services are increasingly becoming more common in new and modern devices. Location Services are used to help the device determine its location for either the user or a 3rd party. Apple explains, “Location Services allows location-based apps and websites to use information from cellular, Wi-Fi, and, GPS networks to determine your approximate location” (Apple, 2014). With Location Services using numerous methods to help the user define their location, it can help provide more accurate data than a standard GPS device. A GPS device alone can provide the user with highly accurate location data, but with the other options available to use too, should not be the only method of data collection. This is because if the GPS function fails, either by signal blockage or multiple path errors, the device can carry on with retrieving the location through the other methods mentioned (Ogle, 2007).

Location Services can be found in the devices Options or Settings, and must be activated for it to be able to function correctly (See figure 3).

![Figure 3: A screenshot of where Location Services is found on an Apple Device](image)

Location Services can be used for a variety of applications that might require your location. Map applications would benefit from using Location Services, along with other applications such as the Camera or even social media applications. By allowing the application permission to use Location Services on the device, the user would be having their location tracked at most times, and which could produce a privacy concern for that person (Roberts, 2010).
2.3.2. How do they work?

Location services have numerous methods in order to track your given location. The first method that shall be reviewed is the Wi-Fi function that operates with Location Services. A Wi-Fi system usually involves having fixed access points that can be installed in many locations, such as the workplace, in your home, or public transport. A Wi-Fi system can be practically installed anywhere, and is used to help the users with convenience for their computers or other devices (Karimi, 2013). By having the device connect to a Wi-Fi access point, Location Services can use this to be able to give a more accurate reading than it could without. If cellular signal and GPS signals are poor then the chance of an inaccurate reading is possible, but with those two methods unavailable and the device is connect to a Wi-Fi access point with a strong signal, then the probability of accurately finding the location is extremely higher (Burton, 2013).

Another method Location Services use to retrieve the devices location is by using the signal received from its cellular network. This can be an effective way, but can also be inaccurate. The way this method works is by detecting the signal from several cellular towers, and then to triangulate by using the signal’s strength (As illustrated in figure 4). If there are not enough towers available, then the accuracy could be several hundred meters incorrect. If only one tower is available to be used, then the angle of the arrival from the device’s signal, collected with the strength of the signal, can be used to give a measure of distance (Thornycroft, 2012).

![Figure 4: Showing a Device being located by Cell Tower Triangulation (Locke, 2012)](image-url)
The last method to review is the use of GPS within Location Services. As mentioned previously in this chapter, GPS uses four satellites that orbit the earth to help calculate your current location. The GPS inside of a device using Location Services is the Assisted GPS (A-GPS), and can be as accurate as a regular GPS device if the right criteria are met. A-GPS requires the connection of Wi-Fi and a cellular network to be able to work correctly, without it the given location could be incorrect. By having these both connected, initial location information can be provided and they will both help with assisting the A-GPS in locating visible GPS satellites faster (Apple, 2014).

2.3.3. The accuracy of Location Services

This next section will be researching into the accuracy of Location Services. From reviewing what Location Services are and how they work, we can now research into what the accuracy levels are for this service. With Location Services using A-GPS with the help from cellular and Wi-Fi connections, the accuracy of Location Services should be as accurate as a stand alone GPS. While some stand alone GPSs might not be as accurate because the device itself is poor or not maintained well, it is safe to presume with a branded and well-known product the device should work accurately (Anton, 2010).

When researching into various articles, there have been some interesting results found for the accuracy of Location Services. Firstly the study conducted by Paul Zandbergen, and his comparison of GPS and A-GPS, interestingly shows what results he has encountered when measuring the their accuracy. Figure 5.1 shows the accuracy between an iPhone using A-GPS and a Garmin autonomous using GPS through a scatterplot, with some varied results. The Garmin device is shown to have a high level of accuracy with a collection of position fixes close to the benchmark with a maximum horizontal error of 1.4 meters, and a Root Mean Square Error (RMSE) of 1 meter. Unlike the Garmin, the iPhone’s results were not as accurate. The iPhone device showed a more spread reading with a maximum horizontal error of 18.5 meters, and a RMSE of 8.3 meters (Zandbergen, 2009).

Through the same study conducted by Paul Zandbergen, the collection of his ten tests were summarised into Table 1. This table shows the median and RSME for both vertical and horizontal errors for both devices. From examining this table you can see the average of all ten tests at the bottom. For horizontal errors the iPhone did not improve with an average RSME of 9 meters, and an average median of 7.7 meters. Compared to the Garmin’s averages for RSME with 1.6 meters and its median 1.4 meters, the iPhone is proven to be not as accurate as the stand-alone GPS device. The results for the vertical errors also prove the inaccuracy of the iPhone, with the Garmin device having significantly lower errors in meters than the iPhone.

As you can see with these results, the A-GPS that is used in Location Services does not seem to have the equivalent accuracy levels as a standard GPS. This is deemed surprising as the A-GPS not only has access to the GPS function, but also has the support from cellular networks and Wi-Fi.
Figure 5.1: Horizontal accuracy of iPhone A-GPS and Garmin autonomous GPS locations (Zandbergen, 2009)

Table 1: The Summary of the Horizontal and Vertical Errors Reported as the Median and RMSE (Zandbergen, 2009)

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Horizontal Error (m)</th>
<th></th>
<th></th>
<th></th>
<th>Vertical Error (m)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Garmin</td>
<td>Median</td>
<td>RMSE</td>
<td>iPhone</td>
<td>Median</td>
<td>RMSE</td>
<td>Garmin</td>
<td>Median</td>
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</tr>
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<td>9.0</td>
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<td>2.7</td>
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<td>4.3</td>
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<tr>
<td>#8</td>
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<td>7.7</td>
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<td>3.0</td>
<td>3.1</td>
<td>8.0</td>
<td>10.6</td>
</tr>
</tbody>
</table>
When researching into the accuracy of Location Services, a study conducted by Michael Coyle shows what results he encountered when using a Samsung Galaxy Nexus as his device. Coyle had lay down the smart device and let it retrieve the data needed for several hours. From looking at the scatter plot (Figure 5.2), the CEP was calculated at 14.6m and the 2DRMS was calculated at 35m. This shows that the 95% confidence interval of the Samsung device was 35m and not as accurate as a GPS device (Coyle, 2012).

![Smart Phone Position - 2 hours](image)

Figure 5.2: The accuracy of the data collected from a smart device (Coyle, 2012)

This conducted test is also showing several positioning points that fall outside of the 2DRMS. While this might only be a small number of positioning points compared to the total number, it is showing the maximum distance the device has placed itself. By having the device believe you are close to 60m away could cause some problems if presented.
2.4. **Smart Devices**

2.4.1. **Why do Smart Devices use Location Services?**

Location Services are used in smart devices for various reasons. Smart devices are a common piece of technology for the public, and in the last five years has moved from the fringe of computing to the mainstream. Users have seen the benefits that they can provide, such as seamless connectivity and simple easy to use interfaces (Benton et al. 2015). Smart devices using Location Services can achieve many objectives, such as giving you directions to a place from your current location, or to geo-tagging your location and inputting the data into a crowd sourced database (Apple, 2014).

One of the main features of using Location Services is for the user to use it for navigation. As previously mentioned, a smart device using Location Services can use GPS, Wi-Fi, and cellular data in order to retrieve the users location. With these features the smart devices is able to pick up on its location, and it can give directions to another location if needed. While a person still has the ability to read a map and determine their own directions, the ease and availability given through a smart phone allows them to effortlessly find what they are looking for (Kaasinen, 2003). By having the ability to use Location Services in their device, people can view the directions they need at anytime. There is not a need to read a map beforehand, or to memorise how to get to a place, as a simple search on their device would allow that person to look up where they want to go and how to get there, from wherever they are currently located. This can be seen as very convenient and help that person cut down their planning time (Wong, 2014).

Another feature that Location Services provide the user is the capability of Geo-tagging. Geo-tagging is the process of connecting a digital resource (such as a digital photo or video) with a physical location (Educause, 2008). Many users of smart devices use Geo-tagging for the social media applications that are present for their device. With the ability to Geo-tag, the user can share the photo of their current location and tag it appropriately on a map to share with other people (Wong, 2014). Geo-tagging can also be used on the smart device without the use of social media. A smart device taking photos with Location Services activated will allow the user to view where that photo was taken. The device has used Location Services to collect the relevant data and to present it on a digital map. Photos can be viewed at anytime again to show the user where they took that photo, or alternatively the user can access the map and see where they have taken many photos in one location (Valli and Hannay, 2010). The ability to use Geo-tagging can be something that few users realise they are doing. With Location Services activated, the photos that are taken with that device can produce Geo-tagged locations that the user might not be aware of, and a result of this would raise privacy concerns for the user.

Another reason why Location Services are used is for the company who created the device to collect crowd-sourced data from the user. This does not mean that the company is tracking the users every step, but more just collecting data at certain points to add to their secured encrypted database. The only way to ensure your data is not being used for crowdsourcing is that the user would need to turn Location Services off (Sui et al. 2013). The data collected from the devices can help with traffic management and could help the user in avoiding high-density traffic and dangerous
points. By allowing access to your location data, you would be providing your current whereabouts and speed. The speed aspect of the user could provide useful if the user is travelling in a vehicle. By reviewing current speeds of several users around the area, the map applications can be updated to show the user if there is any traffic congestion for their route, or if an accident has happened and they should choose another route (Ragia, 2007).

2.4.2. Implications and consequences of not getting accuracy

Location Services within a smart device retrieve a great deal of information from its user. With 80% of data predicted to being questionable and uncertain by 2015 (Easton, 2012), what would be the implications and consequences of a smart device being inaccurate?

Location Services in a smart device might not work correctly if it is not connected to Wi-Fi or to a cellular connection. If this is the case, then the user might have trouble in locating where they are if they are lost. With the accuracy of the device being incorrect, the user could find that they are heading in the wrong direction and getting even more lost. Not having the accuracy they needed might persuade the user to turn off the Location Services feature, as they feel they can no longer trust it anymore. With it being deactivated, the company who created the device would no longer be able to collect the data to include in their crowd-sourcing database.

By having inaccuracies from using Location Services, the ability to use it for tracking purposes could prove to be a problem. GPS tracking can be used for parents locating where their young child is, and to have general surveillance of them. The need for parents to know where their children are is growing, and by having this service parents are more relaxed and happier (Goggin and Hjorth, 2008). If this data becomes inaccurate then parents would become extremely concerned if it suddenly states that their child’s location is across town. This could prove to be dangerous if the parent left in order to find the child at the wrong location, but actually the child was a lot closer than originally thought.

With the potential for the accuracy in Location Services being incorrect, the chance for the law to use the data could prove to be a problem. Smart devices giving out incorrect accuracy data could potentially harm an innocent person, or prevent a dangerous person from being incarcerated. If the police were to look at a suspect’s device and see that they were geo-tagged at a certain location near a crime scene, then action may be taken. But if that data was incorrect, and in fact that person was at the other side of the city when the crime took place, then a problem has now occurred. By having inaccuracies in Location Services, the law will struggle to use it in court. If the accuracy of Location Services were highly accurate, then the use for it would greatly benefit the police force and the community.

The law currently use GPS for various reasons, and not just the potential for convicting criminals. The police have been using this for many years and are used to help manage the police force. By having this technology the police are able to identify which police vehicle is closest to a crime scene, and to ensure that police officers stay
in the areas given to them. GPS is also used for police officers to be given directions to their destination and current traffic updates (BrickHouse Security, 2015). If this data was inaccurate, the consequences could be extremely harmful to the police’s image and the public’s safety. If the police officer was given the wrong directions because of this inaccuracy, then call outs to a crime scene or an emergency would be longer than expected. The accuracy of this data would need to be very accurate for the police to use, and any inaccuracies would hinder them rather than support them.

2.5. Conclusions

2.5.1. Key Issues

Throughout researching Location Services this literature review has discovered some key issues involved. Firstly is that from the studies found in this literature review, the potential accuracy levels provided from Location Services do not seem to correspond to what is predicted. This could be for a number of reasons, such as bias data collection, certain locations, or device problems. But with this research, it would become interesting to see what accuracy levels this study could produce. It seems that a GPS device can fall into this predicted average of 7.8m, but the use of the A-GPS has not been getting the results of this average. It would be interesting to see just what the accuracy levels in meters would be from a smart device with numerous data retrieved. The information collected from these tests in this literature review also do not mention whether or not they were taken indoor or outdoor, but an educated guess would suggest outdoor. It is suspected that indoor GPS data would be more inaccurate, but it would be intriguing to see just how inaccurate this is with Location Services.

Another issue presented is the need for accurate GPS data. With the growing amount of the public now possessing a smart device in some form or another, the need for correct information is becoming more necessary. If the Location Services inside of a device does not provide the same accuracy as a stand-alone GPS device, how much trust can a user place into it? It would not benefit the user if the Location Services gave them wrong information, and could potentially halt any further interest for people to use them for different activities.

2.5.2. Refined Research Questions

After researching Location Services and what it can provide, it seems that there are a couple of questions that need answering. Just how accurate are Location Services in a smart device? What are the accuracy level differences between indoor and outdoor data? And does location matter when retrieving this data?
3. Research Methodology

3.1. Introduction

To be able to create a good standard of research for this study, a clear and justified research methodology is required (Jonker and Pennink, 2009). This dissertation hopes to achieve this with the use of the six given sections. This research methodology will help with defining what is needed from the data collected, how it was produced, and why. By there being an interest in the accuracy of Location Services, it would be essential to find out just what questions are needed, and why data was collected in this way.

3.2. Research Strategy

The research strategy for this study will involve collecting quantitative data through the use of a singular smart device. Quantitative data has been chosen due to that numerical data is being collected from the study, and this can be analysed by using statistics (Muijs, 2011). Quantitative data collected is ideal for this study, not only would it help concentrate on facts and figures, but this would allow for more data to be collected.

3.3. Data Generation Methods

The data for this study will be collected from an iPhone 5s. The iPhone 5s will be used to take digital photographs with Location Services activated. With this in place, the iPhone’s photos will generate a Geo-tag for each of the photos taken, and the information from this data will be extracted from the EXIF data. A total of 200 photos will be taken and used for this study, each from various locations in Derbyshire in England. Half the photos collected will be taken indoors, and the other half will be outdoors. When concerning locations, the amount of data from each area was decided randomly with some locations containing more data than others.

Also for this study, the iPhone 5s was not connected to a Wi-Fi connection for numerous reasons. Firstly it allows all the results to be fair and on the same level as each other. It would not be fair if data was collected outside of a house, but the Wi-Fi connected for that photo, and then for data to be collected further down the road and no Wi-Fi connection given. This would give uncertainty in the data collected. Another reason is to ensure location data was accurately collected. If the device got accidentally connected to an unknown Wi-Fi hotspot, then a Geo-tag would not be generated for that photo. This could have proved to be troublesome when analysing the photos with missing data.
3.4.  Data Analysis

The data from this study will be analysed through the help of Statistical Analysis Software (SAS). Firstly the data from each photo will be extracted and input into a Microsoft Excel spread sheet, and it will contain the relevant information needed, such as longitude and latitude. After the photos EXIF data has been added, the next stage is to include the photos true location so the data can be compared and analysed correctly. To find out the true location of the photos, the photos taken had landmarks or references to be able to locate where it was. Once the true location is found, Google Maps was used to find this location and then to retrieve the true location’s longitude and latitude. Once this has been done the spread sheet will be imported into SAS and used for analysis. The analysis will include presenting the information in an SGPLOT, and in other ways, which will help with finding answers for this study.

3.5.  Sampling

As previously mentioned the sampling for this data will consist of 100 indoor and 100 outdoor digital photographs. The selection for locations will be that they are not too far away from my home location, but far enough away to get some varied data. The amount of sampling for each location will be set at random, with no specific amount set for each location. Some of the locations will have more data collected than other locations.

The choice of which indoor data will be collected will decide on what places allow the public to enter, such as shops or pubs. Some of the data for indoors will also be collected inside homes that have a connection with the data collector. The amount of what data is collected, and where data will be collected, will be random and no specific place shall be chosen in advance. This is to ensure there are no bias results in this data collection.

3.6.  Ethics

All the data and information collected from this study will follow The University of Derby’s ethical guidelines. Photographs taken inside of a building will ensure to have permission from either an employee or the owner, and all photographs outside will also abide by the ethical guidelines. Any photographs in this study with a person present will ensure to have their permission to use it for this study. While the image on the photograph is not what this study is after, it is understandable if it raises concerns for anybody included in it.
3.7. **Limitations**

When researching into the accuracy of Location Services, a limitation given might be not retrieving enough data from more areas. This study will be limited to a certain county being Derbyshire, but if finances and time were not an issue, then a more varied collection of data could be gathered.

Another limitation this study provides is not having access to more than one smart device. With only one smart device being used, it would be interesting to see how varied the data could be through the use of several devices.

A limitation that could occur with this study would not being able to retrieve the data needed. If a photograph was required inside of a certain building, the employee or the owner might not be comfortable with it. Explanation of the project might help with persuasion, but it cannot be guaranteed.

3.8. **Conclusion**

In conclusion, the method for this study will involve collecting quantitative data with 200 sets of digital photographs with an iPhone 5s. This would be presented in an SGPLOT to show analysis of the data, and to show what the accuracy levels are like for both indoor and outdoor, and for certain locations. By collecting the data using this methodology it will help with gathering a large amount of data, and for collecting a wide and varied assort of data too.
4. **Findings and Analysis**

4.1. **Introduction**

The aim of this study is to discover how accurate Location Services in a smart device can be. With a collection of 200 pieces of data, both indoor and outdoor in various locations, we are able to analyse this data and determine just how accurate it is. This data will be presented in various graphs and tables to show its accuracy levels, and a description about them will also be included. It will become interesting to see what the accuracy levels are like around the Derbyshire area, and what the differences can be between indoor and outdoor readings.

4.2. **Analysis**

The analysis of this study will be broken down into several sections that will help differentiate between the data. They will be broken down into overall results, each locations results, each indoor and outdoor data, and shown with several graphs showing several findings. The SGPILOT will be showing the locations mean errors, as well as the errors in meters for the places in the locations. This study will also be looking into the quantiles of the research data, and just how accurate each place is. The accuracy difference between the indoor and outdoor data will be shown throughout this study, and shown in various graphs.
4.2.1. Overall Collected Data

The first analysis to be shown is the overall collection of data showing the difference between indoor and outdoor collected data.

![Indoor or Outdoor Error Results](image)

Figure 6.1: Accuracy levels for Indoor and Outdoor

The graph shown in figure 6.1 shows the error in meters from the total 200 sets of data that were collected, and displaying which had the worst accuracy. This graph is showing that from all the locations, outdoor data had the lowest error with 40.597m and indoor data was measured at 236.69m. Both indoor and outdoor had equal amounts of data, which were 100 each.
Figure 6.2 is a graph that shows all of the data's accuracy for each location used. A total of 11 locations were used for both indoor and outdoor. This graph is a combination of the indoor and outdoor data, and shows us that the worst location for accuracy for the smartphone was Ambergate, which has a mean error of 1054.5m. With many others also reporting very high numbers, the only location that falls into the 7.8m average rating is Duffield with a mean error of 7.494m.
<table>
<thead>
<tr>
<th>Indoor Or Outdoor</th>
<th>N</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Std Err</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor</td>
<td>100</td>
<td>236.7</td>
<td>593.1</td>
<td>59.314</td>
<td>2.1821</td>
<td>4762.3</td>
</tr>
<tr>
<td>Outdoor</td>
<td>100</td>
<td>40.5967</td>
<td>153.9</td>
<td>15.3852</td>
<td>0.5573</td>
<td>1184.6</td>
</tr>
<tr>
<td>Diff (1-2)</td>
<td></td>
<td>196.1</td>
<td>433.3</td>
<td>61.2744</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Method          | Variances | DF | t Value | Pr > |t| |
|-----------------|-----------|----|---------|-------|---|
| Pooled          | Equal     | 198| 3.20    | 0.0016|
| Satterthwaite   | Unequal   | 112.26| 3.20 | 0.0018|

Table 2.1: PROC TTEST results in meters for all the data

The results from this PROC TTEST show information regarding all 200 sets of data. By looking at table 2.1 you can see the mean for both the 100 indoor data, and the 100 outdoor data. There is a large difference between the two as the mean outdoor data is 40.5967m, while the mean indoor data is 236.7m. This is showing that the indoor data is far more inaccurate than the outdoor data, which was slightly expected. Surprisingly the minimum error reading for the indoor data was 2.1821m, but with the total mean being so high, assumptions can be made that not many sets of data was this low. A maximum of 4762.3m is extremely high for indoor data, but so is the highest outdoor of 1184.6m. With the mean for the outdoor data being 40.5967m, this is showing us that it is nowhere near the 7.8-meter average reading expected.
Figure 6.3: PROC TTEST procedure graphs for all the data

The graphs produced from a PROC TTEST in SAS are showing comparative histograms and a box plot of all the 200 sets of data for indoor and outdoor data. With this you can see just how more inaccurate the indoor data is to the outdoor data.

Figure 6.4: Q-Q Plots of error for indoor and outdoor

The graph in figure 6.4 is showing the number of errors given for each set of data and presented in a box plot. From this graph you can see the difference between both indoor and outdoor data.
### Table 2.2: PROC TTEST results in meters for Belper

<table>
<thead>
<tr>
<th>Indoor Or Outdoor</th>
<th>N</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Std Err</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor</td>
<td>25</td>
<td>247.2</td>
<td>486.8</td>
<td>97.3532</td>
<td>5.0717</td>
<td>2010.0</td>
</tr>
<tr>
<td>Outdoor</td>
<td>33</td>
<td>30.7</td>
<td>102.6</td>
<td>17.8677</td>
<td>0.5794</td>
<td>535.0</td>
</tr>
<tr>
<td>Diff (1-2)</td>
<td></td>
<td>216.5</td>
<td>328.0</td>
<td>86.9612</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Method            | Variances | DF   | t Value | Pr > |t| |
|-------------------|-----------|------|---------|-------|---|
| Pooled            | Equal     | 56   | 2.49    | 0.0158|
| Satterthwaite     | Unequal   | 25.622 | 2.19   | 0.0381|

The results from this PROC TTEST procedure (Table 2.2) show statistics concerning all of Belper’s 58 indoor and outdoor results. Belper’s indoor and outdoor data shows a significant difference when looking at the error mean. Belper’s indoor data has a mean of 247.2m, which is over 200 meters higher than the outdoor data of 30.7021m. The statistics of this are close to the studies overall mean of indoor and outdoor, and it is not surprising to see indoor struggling with accuracy. The minimum error for the indoor data being 5m is extremely different than its maximum of 2010m. The outdoor data’s minimum is 0.5m and has a maximum of 535m. With the mean error for the outdoor data being 30.7m, it would be assumed that the maximum data is not a common theme throughout. Overall the error mean presented in both indoor and outdoor data is not showing the 7.8-meter average reading expected.
Figure 6.5: PROC TTEST procedure graphs for Belper

The graphs shown here (Figure 6.5) are produced in SAS through the procedure of a PROC TTEST. These graphs are showing comparative histograms and a box plot of all the data collected in Belper. From observing these graphs you can see the great difference between the indoor and the outdoor data collected. The outdoor is shown to be vastly more accurate than that of the indoor data.
Table 2.3 is from the PROC TTEST procedure produced in SAS, and is showing all of the 32 indoor and outdoor data that was collected in Ripley. There is a large difference between the indoor and outdoor mean error data, with the outdoor data being below the expected average of 7.8m with a reading of 7.1669m. With collecting 25 results for outdoor data, to have an error mean of this is impressive. Its highest error was 77.0524m, which is small compared to some other locations. Ripley’s indoor data is not quite as impressive, with a maximum error of 840.1m and a mean error of 241.7m. The positive that indoor data has is that it has a minimum error of 7.8536m.
The graphs in figure 6.6 have been produced in SAS with the PROC TTEST procedure. The graphs here are comparing the indoor and outdoor data within Ripley. Ripley’s outdoor accuracy is extremely accurate and is shown in these graphs with the short measurements. The indoor data for Ripley is not as accurate and the graphs show this through the wide varied spacing for the error in meters.
4.2.2. Indoor Collected Data

![Indoor Location Error Results](image)

**Figure 7.1: Mean error in meters for all of the indoor data**

This graph for figure 7.1 shows all of the locations for indoor data, and what the mean error is for these locations. Again it shows Ambergate has the highest mean error with a reading of 1634.2m, while Milford is not too far behind with a mean error of 1394.8m. These results are extremely high and add a lot of value to this study.
Figure 7.2: Alfreton's indoor error results

Alfreton had a total of seven photographs taken for indoors. Figure 7.2 shows where the data was collected, and what the error in meters is for each place. It shows here that the data collected at KFC was an extremely high, with an error of 1378.2m. Argos was the lowest and closest to reaching the predicted 7.8m average reading, with the error being 8.9515m.
Figure 7.3: Ambergate’s indoor error results

For the graph shown in figure 7.3, there were a total of three indoor photographs taken for Ambergate. While none of the readings were below 7.8m, the lowest was at the BP Station with the error of 18.987m. Surprisingly the highest reading for Ambergate was at Springfield Farm House, with a reading of 4762.3m. This is unusually high and was not expected, even for a farmhouse.
For Belper a total of 25 sets of data were collected indoor. As figure 7.4 shows, there are a number of readings that have a high error in meters. The highest error reading is shown to be the Leisure Centre, with a reading of 2010m. This is an extremely high error, and just shows the extent it can be for the Belper area. The second highest recording was The Bungalow Lawn Farm, with the error being 1482.74m. The lowest error for Belper was at Lester & Nix and its error reading was 5.07m.
Figure 7.5 is a graph of the indoor data for Matlock Bath. Four pieces of data was collected from here, and all results show small error results compared to previous locations. The highest error in Matlock was in the Matlock Bath Aquarium, with a error of 26.064m. Only one place falls into the predicted reading of 7.8m, with that place being The Midland Pub with 6.2198m.
Ripley had varied results when comparing them to the places they were taken. Figure 7.6 shows that the Red Lion had an inaccuracy of 840.15m, and this was the highest for Ripley. Sainsbury’s was not too far away, with an error reading of 645.37m. Both these readings are high and are nowhere near the predicted accuracy average. The results for Ripley hospital were more encouraging, and that had a reading of 7.8536m.
Figure 7.7: Indoor error results for Derby

In the graph shown in figure 7.7 the indoor error results for Derby are shown, and in this there were 43 photographs taken for this data. The error mean indoor data for Derby was 149.58m, and the highest reading for this was Tenpin Bowling with the error of 1630m. Again, this is another high result that has affected the overall mean. The lowest indoor error for Derby was Dreams with 4.38m.
Table 3.1: A table showing the statistics from all the indoor data collected

<table>
<thead>
<tr>
<th>Moments</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>100</td>
<td>Sum Weights</td>
</tr>
<tr>
<td>Mean</td>
<td>236.6941</td>
<td>Sum Observations</td>
</tr>
<tr>
<td>Std Deviation</td>
<td>593.114049</td>
<td>Variance</td>
</tr>
<tr>
<td>Skewness</td>
<td>5.244784</td>
<td>Kurtosis</td>
</tr>
<tr>
<td>Uncorrected SS</td>
<td>40429052.9</td>
<td>Corrected SS</td>
</tr>
<tr>
<td>Coeff Variation</td>
<td>250.582524</td>
<td>Std Error Mean</td>
</tr>
</tbody>
</table>

Table 3.2: A table showing the quantiles of the indoor data

<table>
<thead>
<tr>
<th>Quantiles (Definition 5)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantile</td>
<td>Estimate</td>
</tr>
<tr>
<td>100% Max</td>
<td>4762.280</td>
</tr>
<tr>
<td>99%</td>
<td>3386.140</td>
</tr>
<tr>
<td>95%</td>
<td>1386.525</td>
</tr>
<tr>
<td>90%</td>
<td>658.470</td>
</tr>
<tr>
<td>75% Q3</td>
<td>126.820</td>
</tr>
<tr>
<td>50% Median</td>
<td>29.135</td>
</tr>
<tr>
<td>25% Q1</td>
<td>14.505</td>
</tr>
<tr>
<td>10%</td>
<td>8.000</td>
</tr>
<tr>
<td>5%</td>
<td>5.640</td>
</tr>
<tr>
<td>1%</td>
<td>3.280</td>
</tr>
<tr>
<td>0% Min</td>
<td>2.180</td>
</tr>
</tbody>
</table>

From looking at both table 3.1 and 3.2, you can see many interesting figures. With the mean of the indoor data being 236.6941m, this is not close to the previously mentioned before average of 7.8m. Even when viewing the quantile of 95%, the estimate of 1386.140m is extremely high. The only time you get close to the 7.8m is with the 10% quantile of 8m.
The graph shown in figure 7.8 is of the errors of the indoor data, against the percentage of it. With a mean average of the data being 236m, you can see the amount of data that gathered around that area. It also shows, as a tiny percentage, that the highest is near the 4500m. You can see the curves show the averages for this data, and how it matches with the bars.
4.2.3. **Outside Collect Data**

By looking at figure 8.1 you can see the mean error for all of the outdoor data. From looking at this you can see that Wirksworth is the worst with a mean error of 308.99m, and below that is Ambergate with a mean error reading of 184.89m. Both of these are considered high, especially considering they were taken outside. Two locations do fall in with the predicted average of 7.8m, and they are with Ripley and Duffield. Both of these are considered acceptable and fairly accurate.
The graph in figure 8.2 shows all of the outdoor data taken within Belper and what the error is in meters. From looking at this graph there are two outstanding bars that catch your eye. First one is Prospect Drive, and this has an error of 535m. The other one is Bottom of Mill Street, and this has an error of 283m. Both of these results are abnormally high and are surprising to see for outside data. The lowest outside error for Belper was Corner 1 of Rec, as this gave an error reading of 0.572m. Overall the general outside accuracy for Belper looks good, except for the two that are highly inaccurate.
Figure 8.3: Outdoor error results for Derby

Figure 8.3 shows the error of all the 25 sets of outside data collected for Derby. With a mean 43.26m you can see the result that has not helped. The place of Odeon Cinema had the highest given error for Derby with 754m and this is unusual for outside data in an urban area. The lowest error for Derby was 1.8m at Bow Boutique, and this is deemed highly accurate.
The graph in figure 8.4 shows the four sets of data collected for Duffield and what the error in meters is for each place. While only four photographs were taken for Duffield, the mean error was 6.9737. These results show each places error, with Nether Close getting the highest with 15.272m, and Castle Hill producing the lowest error score of 2.5728m.
Figure 8.5: The outdoor error results for Milford

Milford’s outdoor error results are very interesting. Seven pieces of data was collected for Milford, and when you look at the graph in figure 8.5 you can see all but one place has good accuracy. Chevin Road has an error of 125.09m and is nowhere close to the other error results from Milford. With this the mean is given as 21.745m, but without that one place the mean would be sufficiently lower and more than likely within the 7.8m predicted average.
Ripley’s outdoor error results included 25 sets of data and shown in the graph for figure 8.6. This graph shows that one result is far greater than the rest, with a reading of 77m from Wood Street. This result does not reflect what was found for the other places within Ripley, but with that result present the error mean is still at 7.1668m. If that result from Wood Street were not included, the mean would have been a lot smaller. The smallest error result for outdoor Ripley was Cemetery Lane with an error reading of 0.5m.
None of Wirksworth’s outdoor error results was below 7.8m (See figure 8.7), but one place’s result was highly inaccurate. Sough Lane’s error was 1184.6m, which is huge compared to the other results within that location. It is not unusual for rural areas to give out the odd result, and this graph shows that.
Table 4.1: A table showing the statistics from all the outdoor data collected

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Moments</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>100</td>
<td>Sum Weights</td>
</tr>
<tr>
<td>Mean</td>
<td>40.5968</td>
<td>Sum Observations</td>
</tr>
<tr>
<td>Std Deviation</td>
<td>153.852276</td>
<td>Variance</td>
</tr>
<tr>
<td>Skewness</td>
<td>5.73498048</td>
<td>Kurtosis</td>
</tr>
<tr>
<td>Uncorrected SS</td>
<td>2508191.78</td>
<td>Corrected SS</td>
</tr>
<tr>
<td>Coeff Variation</td>
<td>378.976363</td>
<td>Std Error Mean</td>
</tr>
</tbody>
</table>

Table 4.2: A table showing the quantiles of the outdoor data

<table>
<thead>
<tr>
<th>Quantiles (Definition 5)</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% Max</td>
<td>1184.650</td>
</tr>
<tr>
<td>99%</td>
<td>969.440</td>
</tr>
<tr>
<td>95%</td>
<td>203.970</td>
</tr>
<tr>
<td>90%</td>
<td>42.045</td>
</tr>
<tr>
<td>75% Q3</td>
<td>9.740</td>
</tr>
<tr>
<td>50% Median</td>
<td>5.890</td>
</tr>
<tr>
<td>25% Q1</td>
<td>2.810</td>
</tr>
<tr>
<td>10%</td>
<td>1.820</td>
</tr>
<tr>
<td>5%</td>
<td>1.270</td>
</tr>
<tr>
<td>1%</td>
<td>0.565</td>
</tr>
<tr>
<td>0% Min</td>
<td>0.560</td>
</tr>
</tbody>
</table>

When viewing both table 4.1 and table 4.2, you can see the statistics involved for the outdoor data. Firstly with the mean error showing the data to be 40.5968m, this does not match the 7.8m expected. Although the mean error for outdoor data is significantly less than that of the indoor data, it still falls behind of expectations. Another interesting statistic is that the 95% quantile is 203.970m, and to get close to the 7.8m’s, then the quantile of 75% at 9.740m or 50% at 5.890m is where we can see it.
This histogram graph (Figure 8.8) is showing the errors of the outdoor data, against the percentage of it. With the mean average of the outside data being 40.6m, you can see the number of data gathered around that area. Within the histogram graph you can see that curves given show the averages for this data, and how it is connected to the bars.

### 4.3. Conclusions

In conclusion to these findings, the 200 sets of data collected for this study have shown a great difference between both indoor and outdoor data, and with certain locations being a great part of that. The Indoor data is shown to be the least accurate in this study with a mean error of 236.7m, which is huge compared to that of the outdoor mean error data of 40.6m. This study has shown the comparative differences between indoor and outdoor data collection accuracies for an iPhone 5s, and just how inaccurate they can be in certain locations. Each location has been shown its accuracy readings for the combined indoor and outdoor data, and separately to allow the observation for which are the best areas to get accuracy. This study suggests that the best overall location for accuracy within a smart device is at Duffield with 7.5m, while the worst location is shown to be Ambergate with 1054.5m. These figures are remarkably different to each other, which can be seen surprising since they are both in Derbyshire.
5. Discussion

5.1. Introduction

This study has been about researching the accuracy for Location Services in smart devices. After the data collection and the data analysis, it would be interesting how these results compare to the previously studied research. This chapter will be comparing the accuracy of GPS devices with smart phones, and seeing just how different they are. This chapter will also be looking at difference between the study’s collected data and the previously researched data to see if there are any similarities in them. The accuracy levels of the study’s location data will also be reviewed, and seeing how they contrast with the predicted results.

5.2. Are Location Services as accurate as GPS

Location Services use a variety of methods to calculate your given location. With the use of cellular, Wi-Fi, and GPS networks to gain the relevant information, assumptions would be made that Location Services would fairly accurate (Warner, 2012). When reviewing previous accuracies for GPS, it was mentioned that it would provide a “worst case” pseudo-range accuracy 7.8 meters for 95% of the time (All Things Nav, 2012). This is what is widely believed for GPS accuracy, and does not reflect that of the accuracy for Location Services.

When analysing the data from this study, it has shown that the mean average of indoor data was at 236.7m, and the outdoor data was moderately better with 40.6m (Figure 6.1). But as previously mentioned, these accuracy readings do not meet the 7.8m expected. When looking at the quantiles to see what is the closest to the 7.8-meter mark, you can see that Indoor has the 10% quantile of 8m (Table 3.2). This shows just how inaccurate Location Services are for indoor data collection. For the outside data the quantile of 75% at 9.74m (Table 4.2) shows the inaccuracies created, but this is still a large improvement compared to the indoor data.

When comparing Location Services with GPS, its best to use previous research studies. Michael Coyle conducted a study measuring the accuracy of a GPS device in 2012. Coyle’s GPS accuracy results showed that the 2DRMS of his studied data was calculated at 14.85 meters (Figure 2.2). While this shows nearly twice as much then the 7.8m expected, it was still considerably less than what was achieved in this study. Coyle’s 14.85m is considerably lower than the error mean of 236.7m for the indoor data collected, and slightly lower than the error mean of 40.6m for the outdoor data.

Another study concerning GPS accuracy was by Paul Zandbergen. In 2009 he completed ten tests to measure how accurate his Garmin GPS device was. Through these tests (Figure 5.1) it shows that the GPS device had an error mean of 1.6m, which
is extremely good. With this information, you can clearly see that the readings for this study are nowhere near as accurate as Zandbergen’s tests.

Overall, when comparing the results of this study for the accuracy of Location Services with the previous researched GPS results, the difference is significantly higher. It is shown that Location Services in a smart device are not anywhere near as accurate as a stand-alone GPS device, even when comparing indoor and outdoor data. This is something that should be taken into consideration when deciding on which one to use, and how important accuracy is to that person.

5.3. How do these results compare to the other results for Location Services?

With discovering that Location Services are not as accurate as a GPS device, how accurate are the results collected in this study compared to the results found for Location Services? It will be interesting to compare these results to see if there is any difference between them. Theoretically as both are determining the devices location with the same methods, there should not be large difference between them.

The first sets of results that will be reviewed are from Zandbergen (2009). While Zandbergen collected results for a GPS device, he also collected data with a smart device. The results from his findings were interesting to receive, and show that the smart device had a higher accuracy of error than the GPS (Table 1). In this study he collected ten sets of location data and compared them against each other. From this you can see that the mean error the iPhone received was 9 meters. This result does not reflect this study’s results in the slightest, as the mean in error for the indoor data was 236.7m, and the mean in error for the outdoor data was 40.6m. The data accuracy from Zandbergen’s device might differ from the study’s data due to several reasons, such as a different methodology, different location, and that his data was collected from a single point location. The data collected for this study was wide and varied, and shows a diverse amount of data.

The next study this section will be reviewing is the study conducted by Coyle (2012). As previously mentioned, Coyle collected data concerning location accuracy on a GPS device, but he also collected data with a smart device too. For his study he used a Samsung Galaxy Nexus as his device, and collected the data needed. In his results it shows that the 2DRMS of his studied data was 35 meters (Figure 5.2). This shows that the confidence interval of the smart device was 35 meters, which is not far off from the outside data collected from this study. For 100 photographs taken for the outside data, and retrieving a mean error of 40.6m, the results compared are not identical, but are very close. However the data from Coyle’s results do not match with the indoor data from this study, but that is understandable since Coyle’s data was collected outside. But even with these two outdoor results being similar, they both do not match with the predicted 7.8m from GPS.

From these results the comparison between them and the data in this study was differential. The error of accuracy for Location Services from this study was higher than both previous research results. While Coyle’s results were not as different, the results from Zandbergen’s iPhone were, which was quite surprising since the data collection for this study used an iPhone too.
5.4. **Accuracy for Locations**

While collecting data for this study, the chance to find out how accurate certain locations are became available. While not all the data was collected evenly for locations, it was still an interesting topic to cover. During the collection process the locations that were used were chosen at random for both where the photographs were taken, and for how many were taken. In the findings and analysis chapter, there are numerous locations that show what the accuracy error was for these places, in both indoor and outdoor circumstance.

When reviewing the total collection of data accuracy, you can see that Ambergate has the worst error reading with 1054.5m (Figure 6.2). This location does not share any similarities with the previous results that were reviewed, and is extremely far off from meeting the mark of 7.8m. While it is understood that the 7.8-meter accuracy prediction is from data collected outdoor, the accuracy error for Ambergate outdoors was still 184.9m and is still considered very high (Figure 8.1). When looking at outdoor location errors, the highest location for this happens to be Wirksworth with an error reading of 309m. For outdoor data this is extremely high, and is still one of the highest locations compared to the locations for the indoor data.

From looking at figure 6.2 the location with the lowest accuracy error was Duffield, and this had a total score of 7.5m from both indoor and outdoor data. When examining Duffield, you can see that it has an error of accuracy of 9.57 for indoor, and 6.8m for outdoor. Overall this is an extremely good reading for the smart device, and it even matches the standards of a GPS device.

A location that had many photographs taken within it was Belper, and this location contained 58 sets of data from both indoor and outdoor. With such a high amount of data collected, the average mean error was 124m, which is an unacceptable reading. While the indoor error for Belper was 247.2m, a slightly better reading presented itself for its outdoor data, which contained a mean error of 30.7m. While this might not be close to what is expected from a GPS device, from looking at previous studies it seems that this results is what should be expected from Location Services in a smart device. With the mean error for all of the outdoor data being 40.6m, this shows Belper’s outdoor accuracy for Location Services is not as bad as some other locations.

5.5. **Conclusion**

In conclusion, the results presented from this study have shown that Location Services from a smart device are not as accurate as GPS devices, with GPS devices being vastly superior for this role. These results have also shown the large difference between indoor and outdoor data, and how it effects accuracy, and how certain locations in Derbyshire can differ for location accuracy for both indoor and outdoor results. Indoor is shown to be greatly worse for its accuracy abilities, while so does certain locations such as Ambergate or Wirksworth.
6. Conclusions and Recommendations

6.1. Conclusions

This study’s objectives were to identify how accurate Location Services are in smart devices, and whether they can be trusted. This study has displayed the accuracy levels of both indoor and outdoor readings, while simultaneously showing how accurate certain locations in Derbyshire can be. The information provided could be beneficial for both organisations and individuals who are interested in using Location Services, but are unsure about the quality of the accuracy they would receive.

The results collected from this study have shown just how inaccurate Location Services can be, and how one poor reading can be as far as 4762.3m (Table 2.1). The average mean error accuracy given from Indoor data at 236.7m is unacceptable, and should be taken into consideration when planning to use this technology. With GPS devices expected to give an average reading with 7.8-meter error, this was not the case for the smart devices using Location Services.

This study has shown that a mixed set of results in its findings. While the indoor data has produced results that show a high amount of inaccuracies, the outdoor data was slightly more positive. With this in mind, when asking about the trust a user places in their smart device, the outdoor data suggests that trust might not be an issue. The outdoor average error readings of 40.6m might be fine for a user to obtain, and as such they would trust that device.

Another key issue that this study produced is the accuracy of certain locations. As previously mentioned, not all of the locations produced the same results. Some indoor data produced lower accuracy error results than the outdoor data, while some outdoor data produced some higher accuracy error results than indoor data. This could be for a number of reasons, but it shows just how different these results are.

This project has shown what the accuracy levels are for a smart device using Location Services in Derbyshire, at various locations, for both indoor and outdoor data. With 200 sets of data compiled and analysed, it shows exactly what to expect from Location Services and what areas have been shown the worst for it.

It is interesting to observe these results and to see how different certain aspects are when retrieving your location from these devices.

Overall, given the amount of inaccuracies that has been produced from this study, it is shown that Location Services cannot be entirely trusted. They have shown that they can retrieve an error accuracy of 40.6m for location when outside, but the inside error accuracy of 236.7m is too high to be deemed trusted. With smart devices being carried on a person at most times, the ability to collect accurate indoor data should be improved to enable trust again.
6.2. Recommendations

6.2.1. Location Services Improvement

This study has shown just how inaccurate Location Services can be, what areas affected this, and at what locations. Smart devices that use Location Services have the potential to be very accurate, and have been shown in some cases to be just as accurate as a GPS device.

The first recommendation would be to improve and upgrade the hardware installed into the smart devices. For Location Services to work correctly, it will need better parts that would help in location detection. Whether this means upgrading the A-GPS chip installed in these devices, or replacing them with full GPS chips, something must be done to allow improvements. Certain brands of smart devices will have different qualities with A-GPS chips, but the companies that can afford it should consider implementing the stronger and higher quality ones.

Another alternative recommendation to upgrading the hardware would be to include more hardware. While currently Location Services use cellular, Wi-Fi, and GPS networks, if another method could be created and used so it would help the accuracy of the device, then it should be considered. By having more ways to retrieve the devices location, accuracy for them should improve greatly.

Another recommendation would be for more cellular towers in less populated areas. Since Location Services uses a cellular network in order to find the devices location, by installing more cellular towers the signal the device receives would be higher, and with that the location accuracy would be improved.

With creating more cellular towers in mind, the increase of Wi-Fi hotspots would also increase the accuracy of Location Services. If the user connects their device to a Wi-Fi connection, then the accuracy would improve greatly. By adding more Wi-Fi hotspots, the device would be able to improve its accuracy reading and find its location with no problems.

6.2.2. Further Research

Further research into the accuracy of Location Services is something that needs to be implemented. While this study used 200 sets of data to show the accuracy around Derbyshire, the need for more data and locations is a must. If these locations were used again, but on a different day with a different device, what would the difference be between them? More research could be conducted to see if the locations in this study produced the same inaccuracies again. By improving the research of Location Services, the potential to improve the accuracy could present itself too.

Since this study only collected readings within Derbyshire, researching what other areas of the UK produce for accuracy should be considered. The accuracy readings in other locations could be far worse or better than these results, or they could be similar. This would lead to interesting findings, and could help with improving Location Services.
7. Personal Reflection

After completing this project, I can firmly say I was pleased with what my data has produced, and what I have learnt through this process. I started this project with the basic understanding to what Location Services are, and now I can walk away with the knowledge and experience to research it more.

A challenge I encountered while completing this study was managing my time. With the project requiring a lot of research, I spent the first half of the semester meeting with Richard and asking him for advice and what direction I should be in. He helped me immensely with that, and gave me the advice of what I needed to have completed by the end of the Christmas break. With having other modules to submit assignments for, I used the spare time I had in between to research for the literature review.

During the Christmas break my phone became damaged and needed replacing. When replacing the phone I had lost the data that I had collected, and set me back slightly. The whole scenario was my own fault, as I should have backed up the photographs I had taken.

Before this project, I did not have a clue how incorrect Location Services could be. It was not something I really thought about before. But since starting, my friends and family have now become extremely curious to how inaccurate smart devices can be, and they are now more aware.

I have begin to notice now that whenever I am out with friends or family and I take a photograph, I instantly look to see where it believes I am. I have become more curious into what my phone can do now, and I am always showing people my phone if it is inaccurate. The downside of me doing this is that people are getting annoyed with me showing them all the time.

I believe this to be a fascinating subject to study. To be able to do a project on a device that is so common, and is used everyday, was an exciting experience. This is definitely a subject area that I would recommend an Information Technology student to do.

While I was happy with how this project went, I do feel that there were some things I would improve on if I had the chance to do it again. Firstly I would collect a lot more data. While 200 sets of data was ample enough for this project, it would have become very interesting to collect more data from more locations. Another thing I would do differently in this project would be to use more than one device. With not having the finance to obtain another device, it was not an option for this project. But if I had the time to prepare again, I would try and either buy another device or borrow one to use.

Overall I believe that this project was successful in finding out the location accuracy within Derbyshire, and I am happy with the results that I produced. This subject is definitely an area that needs to be looked into further, and I believe overtime more studies will be conducted about it.
8. Bibliography


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## 9. Appendices

### Examples Indoor Data

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