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2017-02-02

ChildFinder

Finding the Child that walked away playing

Acknowledgement

This project is my last as a Creative Technology student. There are a lot of people whom I want to thank for their support not only during this project, but during my entire time as a bachelor student. However, some people stand out and I would like to thank them in this paper.

First of all, I could not have done this without my project supervisor, Robin Aly. While he was mainly there to be as a guide, his investment during meeting made it feel more like project partners. His main focus to train me into having a more academic mind set has helped tremendously in developing a system with the many different aspects the system affects in mind.

Secondly I would like to thank Edwin Dertien for halting me during this project when my focus got too technical and I almost forgot the human element in this project. While it was only one instance, the project took quite a different turn when I listened to his advice. This turn in focus has eventually led this project in how it is today. And I would like to thank him for it.

I also would like to thank Erik Faber, not for the support during this project, but for the support during the entire bachelor study. As a study Coordinator, he has an enormous insight in what people bring can become and he makes it his mission to get those people where belong, but he makes them do it on their own accord, making them grow mentally.

Lastly, I wish to thank all of my family, friends, and my significant other, Rozemarijn Seijdel, for their overwhelming support during all stages of my studies. With them, I have discussed many projects, problems and challenges I have faced along the way. Discussing these things caused me to get different insights into these subjects which helped me to improve not only what I did. But also myself.

Abstract

In public spaces, children sometimes get separated from their parents. In this paper, a possible solution for this problem is explored. The question is raised about what is necessary to locate children via technical means in a public space while maintaining low maintenance costs. To answer this questions in steps, four sub questions are formulated.

- *What are similar solutions and how do they compare with the proposed solution?*
- *How do outdoor and indoor public space differ and what impact does it have on the solution?*
- *What are points of interest in public spaces that can assist in location tracking?*
- *How are ethical values ensured in this context?*

To answer these questions, a system was developed. The system is a network of smartphones scanning for Bluetooth addresses that are tagged as missing, these Bluetooth addresses correspond with the addresses of Bluetooth tags the children carry on their wrist.

After the development, both the accuracy and the decrease in time when trying to find the child again were measured. This was done via two kinds of experiments. One by walking a predetermined path and measuring the deviation from said path. The other was by measuring the time difference between users of the system and non-users of the system. The solution has a room level accuracy with an average of 3.9 meter deviation from the path, which should be enough to find a child again in a closed public space. However, when testing for a decrease in speed of the system, an unexpected change of behaviour emerged. Users of the system didn't ask around about the location of the child anymore whereas non-users did. This drastically changed the expected outcome in that the time difference in finding the child back again between users and non-users was quite small.

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1 Introduction

In public spaces, it is not unheard of for children to walk away from their parents, exploring the things they see in moments of curiosity or parents not noticing that their child is not walking with them while they move throughout the park. These kind of situations gets children lost, often resulting in parents worrying about the location of their child or children worrying about being lost which can lead to a ruined day at the zoo, museum or amusement park. Public spaces often have protocols for this, but more often than not, the only protocol in place is notifying the staff to keep an eye out for a child that appears lost. These methods appear to be inefficient due to their lack of direct contact with the child.

Currently, location devices can be used for such problems. However, many parents wish for a solution that does not interfere with the child's privacy, while the owners of these public spaces wish for a low maintenance cost solution. When looking for solutions, another facet to keep in mind is that the layout of indoor and outdoor public spaces is different which needs to be accounted for if the same solution for both places is needed. Further research is necessary to evaluate if these wishes are compatible with one another.

In order to better understand the situation. Some scenarios that may happen at public space should be addressed. This also shows the current non-tech solutions to the problem. Two scenarios are described below.

Billy and his parents go to the zoo. Billy is four years old and his parents know he tends to walk away. To make sure he doesn't this time, they tell him the dangers of the animals and that he must stay close to his parents. This however makes Billy all the more interested in what would happen if he were to walk away. When he eventually wanders off exploring, his parents are getting very worried he might have gone to the safari zone where the animals walk freely and immediately contact one of the workers in the park. The park announces that a boy of four years old needs to be found over the public announcement system and the other visitors should be on the lookout. Thanks to this announcement, Billy is found and the day is continued.

Cynthia and her father are going to a museum. Cynthia is eight years and she always agrees with her father to meet at a place every hour. This time at the museum however, she can't find the place back. Her father is waiting for her and is slowly getting anxious. Usually, she is on time. When her father finally goes to find an employee for help, Cynthia finds the meeting spot. Only this time, her father is missing. Cynthia panics and starts to cry, thinking her father may have forgotten her. When they are finally back together the harm has already been done, and the day is partly ruined.

As can be seen in the examples above, the current solutions are often social in their nature. Other people are alerted to the situation and assist in reuniting the family. This however disrupts the flow of work of employees and parents can only relax when their child is found again. Technology can reduce the stress parents may experience and increase the effectiveness of employees.

1.1 Problem Statement

The problem statement is as follows:

Developing a technological way to find lost children of young ages who don't always have a smartphone again in public spaces.

1.2 Research Question

In order to delve into this subject in an orderly fashion, a research question should be proposed:

What is necessary to locate children via technical means in a public space while maintaining low maintenance costs?

This question is supported by the following three sub questions:

- *What are similar solutions and how do they compare with the proposed solution?*
- *How do outdoor and indoor public space differ and what impact does it have on the solution?*
- *What are points of interest in public spaces that can assist in location tracking?*
- *How are ethical values ensured in this context?*

The scope of this project is focussed on the technological aspect of the solution. Although the social side of this solution is not to be ignored, it will have a lower priority in this research project since this project is an exploration of possible solutions to indoor and outdoor tracking.

To test whether the research question has been answered, certain criteria must be met. These criteria are directly related to how the research question will be answered. During the design phase, these criteria will play a significant role in the specification of the proposed solution.

- The literature study must show related solutions that can improve upon the proposed solution. The proposed solution should also show at least one improvement due to this literature research.
- The proposed solution should aim for functioning in both indoor and outdoor situations and this research paper should answer whether it is practical to cover both situations.
- The proposed solution must serve its intended function. If not, this paper should answer how the proposed solution fails to deliver and how it can be adapted to accomplish this.
- Public spaces should be researched and the outcome should be adopted in the design of the proposed solution
- Ethical constrains should be addressed in this paper.

2 State of the Art

In order to design a proper solution, research towards other products is required. In this chapter, an analysis is made for every product. After each description, the advantages and disadvantages will be reconsidered to better design the solution to the problem. This will ultimately help during the design of the product later on in this paper.

Before delving into the technology, there also are methods which don't require any technology at all. Examples of this are mainly communicative in nature such as whistling or agreeing upon a meetup point in case somebody gets lost. This often is an agreement between the parent and the child. If these agreements fail, parents or children can ask around for their respective counterpart.

There are multiple technologies available to create a location tracking environment. Some examples include Wi-Fi, GPS and Bluetooth. However, some are more suitable for certain tasks than others. As such, each technology will be briefly discussed here with its corresponding products outlined thereafter.

2.1 Bluetooth Based Products

Bluetooth is a short range communication method that uses little energy. In the current market, Bluetooth low energy (BLE) tags are often cheaply acquired (Cheung, Intille, & Larson, 2006). The range is typically from 10 meters to 100 meters, depending on the build quality of both the transmitter as well as the receiver. Most of these devices use the short range of Bluetooth to limit the range of where the target could be. This is especially useful in indoor locations.

2.1.1 My Buddy Tag

My Buddy Tag uses Bluetooth to monitor a child's location within certain specified boundaries. It alerts the parent if the child goes outside these boundaries. Additionally, it alerts parents if the device is submerged under water for 5 seconds to lower the chance of the child drowning. The armband is locked with a coin screw fastener to avoid easy removal of the armband

This solution is quite cheap and requires little resources. However, the armband only alerts the parents when the child is already lost. The coin screw fastener is quite useful to ensure the child cannot remove the device easily. While the underwater sensor is irrelevant for answering the research question and building a prototype, it can help in child safety, which could be another concern for parents and may be included into non-prototype versions of the product, may it be implemented.

2.1.2 Lineable

Lineable is a Bluetooth location device that uses the Bluetooth range of other smartphones which have the accessory app installed. The location of the child can thusly only be known if other app-users are in the vicinity of the child. The effectiveness of this solution is therefore based on number of users within the area. This can be quite effective in public spaces if the application proves to be popular, if not, this solution is too inaccurate for the parent to find their child.

2.2 GPS Based Products

Global Positioning System (GPS) is a system that work via a satellite connection. Its range is, as the name implies, global with an outdoor average accuracy of 3 meters, depending on the receiving device (Zandbergen & Barbeau, 2011). However, the accuracy strongly declines in indoor situations. Rendering the technique not suitable for indoor practices. GPS is often improved by including cellular towers in the area.

2.2.1 Google Location sharing.

Google has a feature for sharing your location to other people on Google Plus. This technique uses Wi-Fi, GPS, Bluetooth or the cellular network to determine the location of users. This location sharing is not perfect however, and often has small deviations of 10 meters. This makes it mostly useful to determine location in open areas and single floored indoor places. However, this requires a smartphone, which most children of the target group don’t have.

2.2.2 AngelSense

AngelSense is a wearable GPS design for children with special needs. In addition to the GPS functionality, AngelSense also allows the parent to use a microphone located on the tracker to listen to the surroundings of the child. It also is able to set perimeters where the child is supposed to go and alerts the parent if the child moves outside these set boundaries.

AngelSense is mainly focussed on children with mental disabilities and is more a supporting device for the parents than it is a monitoring device. However, the GPS makes it less practical for indoor situations than it currently is for outdoor situations. It also is less practical that it is not a bracelet, but a device that needs to go into pockets or backpacks, making it less practical to carry. The use of boundaries is quite useful to add since it helps to prevent the child from walking away instead of finding the child again.

2.2.3 FiLIP 2

The FiLIP 2 is a wearable smartphonewith limited capabilities. It can store 5 contacts and share the location of the child. Parents can find the location of the child based on GPS, cellular towers and Bluetooth via an app on their phone. Additionally, there is a panic button on the device which will call the favourite contact and produce an audio log until the function is cancelled.

The calling concept is a feature that can prove to be useful when the child is lost. This may however make the device unnecessarily complex and also influence the battery life of the device. A panic button can be useful to include to signal the parents in case of emergency.

2.2.4 PocketFinder

PocketFinder uses the cellular network and GPS to locate a child. This device is made to be sturdier than other solutions to prevent accidental breaking or loss of the device. It is only for monitoring the location of the child and does not offer additional features.

This device is very clear in its functionality although it only measures the location accurately when the child is outside, it is a very clear solution that matches with the scope of the project as far as outdoor localization is concerned. But ergonomically, the device needs to be attached to the backpack, clothing or shoes instead or a bracelet.

2.3 RFID Based Products

Radio Frequency Identification (RFID) is a technique used for short range communication. There are two kinds of RFID tags, Passive and active. Passive tags are powered by the radio energy of the transmitter whereas active tags are powered by an internal power source (Tesoriero, Gallud, Lozano, & Penichet, 2008).

An advantage of RFID is that the tags are cheaper than most other solutions, the reader however is often very expensive. One major ergonomical advantage is that the tags are usually small and can be placed almost anywhere on the body. A problem however is that using this technology requires a network which most likely needs building which can be quite expensive.

2.3.1 Anti-Shoplifting Gates

Most shops are outfitted with anti-shoplifting gates at the exit. These gates detect when an item that isn’t paid for gets through the exit, setting off an alarm. These gates can also be used for localizing techniques with room accuracy by placing them at the exits of rooms, corridors or areas.

This technique is quite difficult to implement in outdoor situations due to the fact that exits of these areas can be quite broad, making it impractical for the gates to be able to detect the child when it manoeuvres through the gates due to signal strength.

2.3.2 RFID mats

During races, sometimes the sportsmen are timed based on an RFID system in which the antennae is located within a mat. The passive tags are then recorded as the athletes step on or cycle over the mat as their tag has been read.

This system can provide a similar solution as the anti-shoplifting gates. Whereas the anti-shoplifting gates are better suitable for indoor solutions, these RFID mats can be used in indoor as well as outdoor solutions.

2.4 Wi-Fi Based Products

Wi-Fi is a communication standard which is mainly used for networking applications. However, when the network is large enough, Wi-Fi can also be used as a means for positioning applications. An advantage is that Wi-Fi provides additional features like an internet connection for uploading data other than the location of the child (e.g. photos made at the park to social media). A downside however is a lack of accuracy, most networks have an accuracy of about 5 meters. Which can just be the difference between a hallway and the room next to it.

2.4.1 Accuware Whereabouts

Accuware Whereabouts is an indoor location system for companies that localizes employees through means of Wi-Fi signal and camera images via their smartphone. By combining the images from the camera with the location of the device, a more accurate location can be given. However, this accuracy is dependent on the quality of the pictures of the location during setup.

This is a very accurate indoor solution. Using a smartphone’s camera is an efficient way of determining the location, but it requires a phone that the children of the targeted age group probably do not have. It also requires the device to have a camera facing the room it is in. This causes a need for a holder for the phone so it does not go into the pocket of the user. Also, the fact that a camera is used may cause privacy issues to arise.

2.4.2 Child position monitoring and locating device (US 5289163 A)

This patent shows child position monitoring device that detects the signal strength of a radio frequency and the angle it is coming from. When the signal gets out of reach, the device for

the parents will vibrate or beep to signal the parents. It then shows the direction the parent has to walk to find the child through 8 LEDs positioned in a circle.

This patent is quite different than the usual localizing techniques in the way that it does not show the exact location of the child, but more its general direction. It also works more intuitive due to its likeness to a compass which in itself can offer gamification possibilities. It does however require a strong signal from the device the child wears which may be heavier than the usual bracelet or other wearable device.

3 Current technologies and methods

To properly address the solution to the before mentioned problem, similar solutions need to be explored. While technologies differ, the methods used by these technologies do not. Therefore distinctions will be made based on the method of localising the target as well as the technologies used.

Currently most location technologies use methods such as triangulation, trilateration, multilateration and cell based methods.

3.1 Localising Techniques

3.1.1 Triangulation

Triangulation is a localising technique that measures the angles between two beacons and the line of sight towards the target at the beacons (beacons have to be able to distinguish different angles) as shown in Figure 3.1. This method of triangulation is called angle of arrival. (Golden & Bateman, 2007)

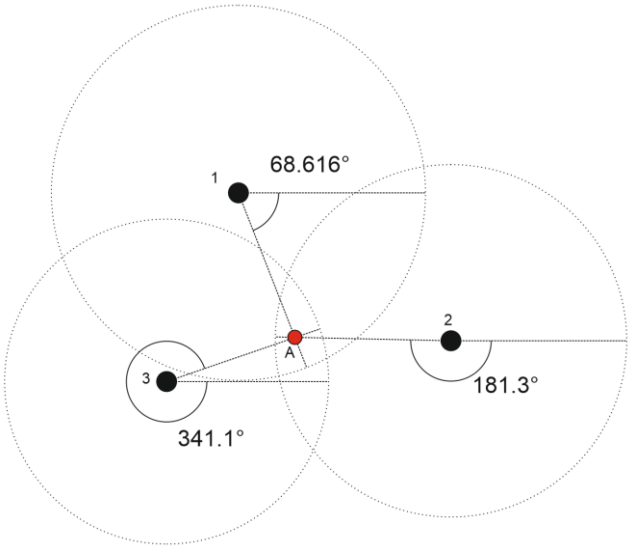


Figure 3.1 Triangulation technique

3.1.2 Trilateration

Trilateration is often confused with triangulation. Where triangulation uses the angles towards the target, trilateration uses the distance to the target. Because the location of the beacons is known, the target can be found by combining the overlapping parts of the circles as shown in Figure 3.2. This system is also known for supporting fingerprinting, a method where are matched to signal strengths of different Wi-Fi access points (Navarro, Peuker, & Quan, 2010).

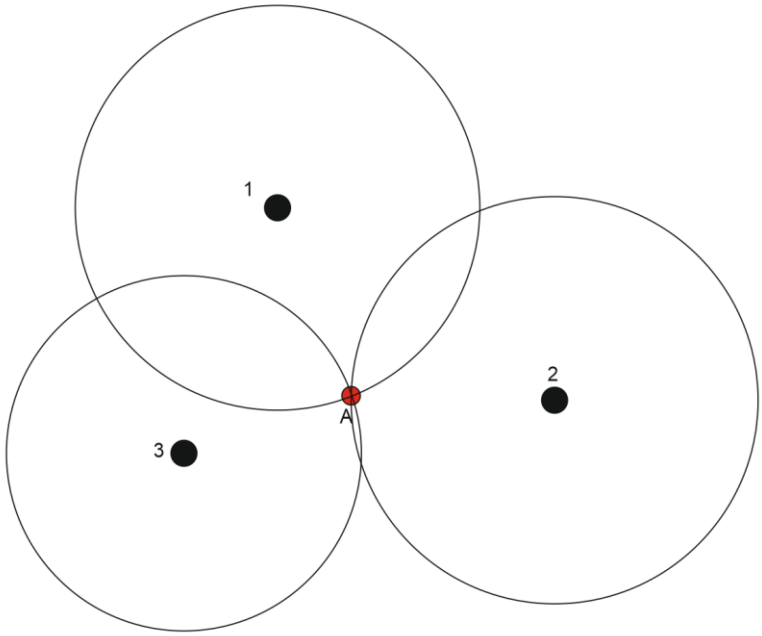


Figure 3.2 Trilateration technique

3.1.3 Cell based method

The cell based method is a low cost technique to locate a target through means of exclusion (Chawathe, 2008). Not unlike trilateration, this method utilizes the radius of the beacons to roughly estimate the location of the target. The main difference being the fact that the distance between the target and the beacons is not measured, but if the target is in range of a beacon.

In figure 3.4, the target can be located very precisely because it falls within the range of each beacon. Therefore the target can be determined to be in cell G.

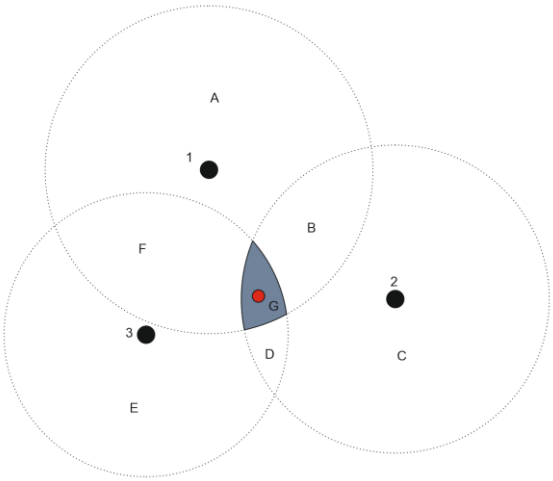


Figure 3.3 Cell Based Methood

3.1.1 LANDMARC

LANDMARC (Ni, Liu, Lau, & Patil, 2004) is less an actual system but more a methodology for tactical beacon placement. It uses multiple scanners with two different ranges for location tracking optimization. By having the beacon with the larger range cover most of the smaller ranges, the smaller ranges increase the accuracy of the larger range. This method creates multiple cells in which the location can be more easily determined. While it is not a system of its own, it should be mentioned here since is provides insight in localisation techniques.

4 Design Process

After delving into the state of the art, possible solutions need to be explored. In order to do this, a design process is employed. This design process is mainly to create a basis for the specification and evaluation later described in this document.

4.1 Methods and Techniques

The design method is mainly focussed on how on this project the transition from idea to product is reached. First an analysis of the problem is conducted via a small research of the current situation. The current situation has 3 main parties involved, namely the children, the parents and the public spaces.

To analyse the frequency of lost children and the amount of time needed to find them again, 10 Dutch public spaces where asked for their data regarding this subject. The public spaces where also asked if there was some form of network available. This was to see if there were networks that could be used as part of the solution.

Most public spaces did not save the frequency of lost children. However what was notable was that most estimates of indoor public spaces was much higher than the estimates of outdoor public spaces.

Parallel to the research conducted with public spaces, a survey for parents was published to www.reddit.com/r/samplesize, a subreddit for increasing survey response, to learn more about the opinion of parents regarding location techniques to find their children again and their attitude towards technology and privacy. The amount of participants was however less than expected. There were only 7 responses to the survey, the results of which can be found in appendix A.

According to the data provided by the public spaces, the current solution to the problem is in most public spaces a low tech solution. More often than not, the personnel is alerted to look out for a lost child with characteristics described by the parents. When the child is sighted by one of the personnel, the child is escorted to a predetermined location where the family can be reunited. If the park has one, an announcement is made over the PA system, alerting other visitors to the lost child. The frequency of lost children in indoor public spaces is 0-10 times per day, depending on the density of visitors within the public space. Outdoors, this number decreases to 0-5 per day. According to one indoor space, walls and the density of objects indoor can make the parent lose their child while they are just around the corner. More often than not, the child was nearby when their parent were looking for them. Parents mostly did not find children because some children were not paying attention.

5 Ideation

During the first step of the ideation phase, a brainstorm session has been executed for the divergence of ideas. This brainstorm session has been with fellow students of Creative Technology as well as students from different studies. During this brainstorm session, the

main focus was to think of ways for relocating children in public spaces. The goal of this brainstorm session was to supply as many ideas as possible, of which some would be selected during the convergence step of the ideation phase for more thorough research. During this step, one idea would be specified and eventually realized.

During the brainstorm session, four dominant ways of locating persons could be formulated. These ways include Beacon solutions, Gated solution, Virtual leash solutions and Camera analysing solutions. These four methods will be discussed briefly in order to create a framework which will later help to select the method of choice during this project.

5.1 Beacon Solution

Beacon solutions are systems that use access points of a network to find the location of the device. These often use an already existing network as beacons since building a new network is often costly.

5.2 Gated Solution

Gated solutions are system that use gates to determine where a specified border has been crossed. This system is currently being used for anti-shoplifting gates and likewise solutions that have few points of interest.

5.3 Virtual Leash

Virtual leashes are a pair between two devices that alerts the users if the distance between both devices increases by too much. This technique is very cheap and is easily expandable.

5.4 Camera Analysing

Camera analysing is a technique that uses a camera to determine the exact location of a person. This can be done by having the camera check for certain markers, such as LEDs. This technique is mostly useful for indoor solutions that have higher than usual ceilings in order to have the greatest area one camera can monitor.

5.5 Trace Tracking

All of these solutions can also be combined with trace tracking. By analysing certain behaviour of children, a possible path the child will take can be determined. This approach can however only be combined with other techniques after enough data has been gathered.

During the second part of the ideation phase, the opinion of the relevant parties will also be taken into account. For this, a survey for parents that may use the system is made to delve

into the specific needs a parent may have that have not been mentioned in earlier stages of the project.

6 Specification

In order to further specify the product, different levels of requirements will need to be addressed. In this document, we use 4 levels of requirements in order to specify the project. These levels are respectively; the goal level, where the main goal of the project is underlined; the domain level, where the goal is translated into the user's perspective of the product; the product level, where the functions of the system are stated; the design level, where details of the system are discussed.

6.1 Goal Level Requirements

As specified in the introduction of this paper, the main goal of the project is that parents and children will be able to find each other again if they are separated inside public spaces. It would be even better if separation is avoided altogether. For the public spaces' perspective, the main goal of the project is reducing stress in parents and children alike to create a better visiting experience.

From this perspective, the domain level requirements are formed.

6.2 Domain Level Requirements

From a domain perspective, the product needs to alert the parent whenever the child gets outside a certain radius of the parent. If somehow this fails to prevent the loss of the child, the product should locate children and parents alike to be able to show the parents the location of their child. Additionally the device should be understandable for the user and not be accidentally removable. The system should also function if parents have multiple children they wish to track. Finally, the system should function both indoor as well as outdoor.

From the domain level requirements, the product level requirements are formed.

6.3 Product Level Requirements

The product level requirements of the project are that the device should use a virtual leash as explained in the ideation section of this paper to prevent children going astray. If this fails, the device should use a network to locate children and parents. In order to send the respective coordinates, the device should communicate with this network. To ensure parents with multiple children can use the system on all of their children, the device needs to be able to be paired and unpaired with other devices.

In order to describe the product fully, the design level requirements are used.

6.4 Design Level Requirements

The design requirements are that the device should use GPS to locate itself and an internet connection to upload its location to a database. The device should also use a Bluetooth connection in order to determine whether the child is inside the virtual leash. To make it so that the device is not easily removed accidentally, the system should use a coin screw lock.

7 Realization

7.1 Realization

For the implementation, a smartphone application is built that uses Bluetooth to sense the tags the children around the phone wear as stated in the specification. Whenever a tag is scanned, the current location of the phone is saved for 15 minutes. If the child is reported missing during this time, the phone will send the location with a timestamp to a server, which will relay this information to the parents.

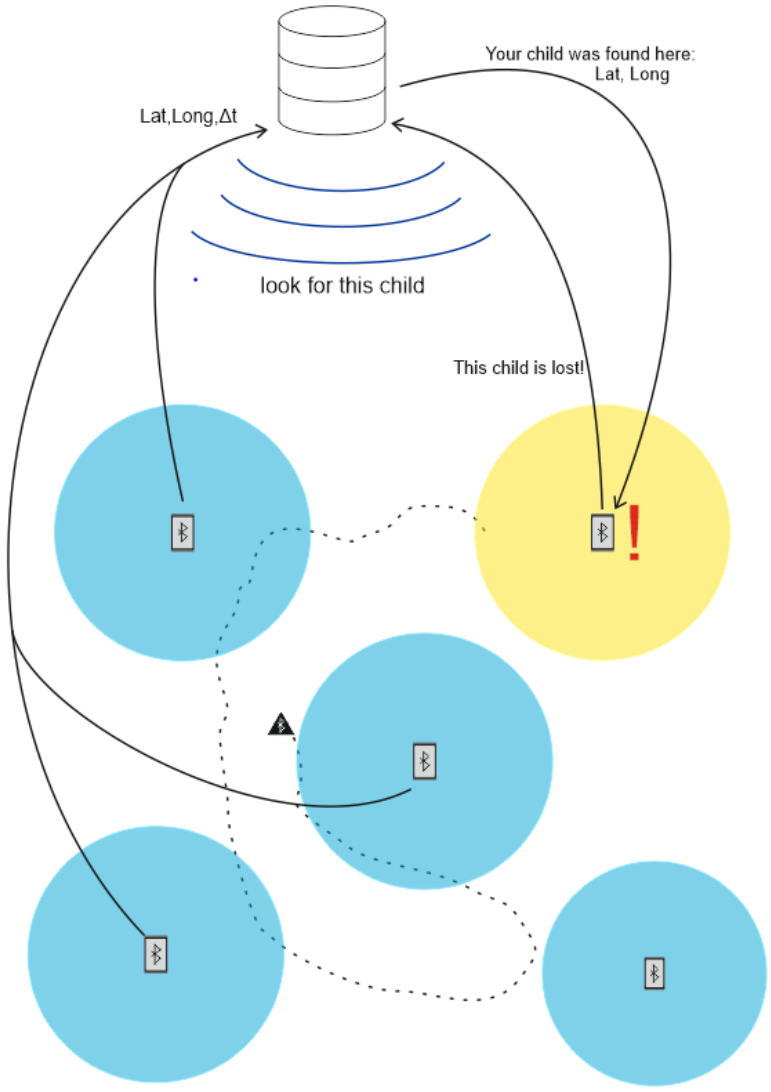


Figure 7.1 The system works as follows. Once the child (triangle) moves outside the perimeter and the parents press the "lost!" button. The database sends out a command to all phones to search for the child. If they found it 15 minutes prior, they also send when they found it. The parents will get notified of the location of their child as soon as data is available.

Smartphones have all the necessary features embedded to facilitate Bluetooth scanning, location sharing and accessing the internet to reach the server. Also, most people have a

smartphone which would cut costs for the organization that wants to implement a child location service because there is no need to build a beacon network.

To explain the system from a scenario standpoint, the following possible scenario is used in combination with Figure 7.1:

Billy the child (black triangle) wanders off from his parents (phone with exclamation mark next to it). While wandering off, the Bluetooth address from his bracelet gets recorded along with a timestamp and location by other smartphones with the app installed in range (blue areas Billy wanders through). After a while, Billy's parents notice that Billy is gone and press a button on their phone. This phone sends Billy's address to a database (cylinder at the top), where it is tagged as 'lost'. The other phones ask the database for lost addresses and sift through their own registry for any matches. When there is a match, that recorded data is sent to the database which the parent's phone can read. This phone then shows the locations after one another to show the parent the path Billy has followed and the last point where he has been seen. They can then go straight to Billy and be reunited.

As can be seen in the scenario above the only information shared that is child specific is the Bluetooth address of the child. This is done so that the database contains no information about the child such as their name or age. Only users with the correct address can request data about the specific child and only if it is reported missing. Abuse of the system is therefore limited to a minimum.

7.2 Implementation

During the realization process, the prototype app was made within Automate, an automation app for android devices which employs a flowchart like system to structure apps made in it. This decision was made to help visualise the logic within the program which ensured rapid prototyping.

The background part app works as follows:

1. It determines a unique address for the parent to be able to inquire the location of the child for when it is lost.
2. It scans for Bluetooth addresses and the phones' location. It saves all these addresses for 15 minutes.
3. It checks a Google sheet called 'lost' for any Bluetooth addresses that match with the saved Bluetooth addresses. When there are matches, it continues with step 4, otherwise it returns to step 2.
4. It stores all matches in another Google sheet called 'found' and returns to step 2.

In the foreground, the app uses these steps which it runs through with the user.

1. It asks the user how many children he has.

2 It then asks for the addresses located on the wristband of one of the children and their name. It repeats this process until all children have been recorded.
3 A menu appears where the parent can select their children.
4 Once one of the buttons has been pressed. The app adds the corresponding address to the Google sheet called ‘lost’. And shows a button with the text ‘I found my child’
5 When the child is found again, the parent can press the ‘I found my child’ button which will add the same line as before on the Google sheet called ‘lost’ and the app will return to step 3. [1]

As mentioned before, there are two Google sheets included in this project. These have some filtering of their own to limit excessive data. The ‘lost’ sheet counts the amount of times a Bluetooth address is added to it and removes all addresses which have been added an even number of times.

The ‘found’ sheet filters by removing all entries older than 15 minutes. This is to avoid privacy issues regarding the child where the parent can push the ‘lost’ button on the app and make the system a monitoring technique instead of a searching tool.

8 Evaluation Phase

To test if the system is useful for answering the research question an evaluation plan is to be proposed. This phase comprises of two main components. One of the components should answer if the system is working properly while the other should answer if the system helps in answering the research question as mentioned in the introduction. To avoid misinterpretations, the first component will be called the ‘accuracy experiment’ while the second will be referred to as the ‘user experiments’, for the rest of this paper.

8.1 Accuracy Experiment

To make sure the system functions properly, the system will be subjected to a couple of tests which will determine the accuracy and reliability of the system. All tests will happen at the University of Twente where volunteers will install the application on their smartphone while a child-tag will be moved along a predetermined path. The measurements of the system will be weighed against the actual path. This will eventually create and accuracy factor, which can determine if the system proves effective for locating in general. Since the time interval between each scan is roughly 10 seconds, the chance of missed tags is very well present, especially if the child is moving fast like running. It is therefore also important to

[1] During the evaluating part of this app, another step before step 5 was added. This step included the portrayal of a map which showed the last seen locations by other phones of the lost child. This was however not planned to be the case due to an overlapping project which was delayed.

check for any false negatives within the system. In indoor situations, the height accuracy should also be tested. A multitude of tags to be scanned should not have a serious impact on the effectiveness of the system.

Hypothesis:

From this testing proposal, it is expected that the system will have a maximum location deviation of 10 meters. Deviations above this expected threshold will indicate that the system is not exact enough for implementation into a real world scenario.

8.2 Accuracy Experiment Results

For the analysis, a total of 10 people were asked to participate in the searching part of experiment. While another group of 6 different people installed the scanning app on their phones. The path taken during the testing phase and corresponding locations are located in appendix B

During the experiments, the system worked as expected. Several outliers were present in the test result that exceeded the accuracy threshold, these were limited to 9,76%. During the predetermined walks, the scan time of the system proved to be one of the mayor problems and contributed to high percentage of false negatives. While it is difficult to say anything meaningful about not collected data, the estimate of false negatives lays at approximately 40%. This estimate results from the fact that during the test, the approximate locations of the scanning devices were known and a prediction on the amount of scans could be made. An average of 3.9 meter deviation from the path was measured.

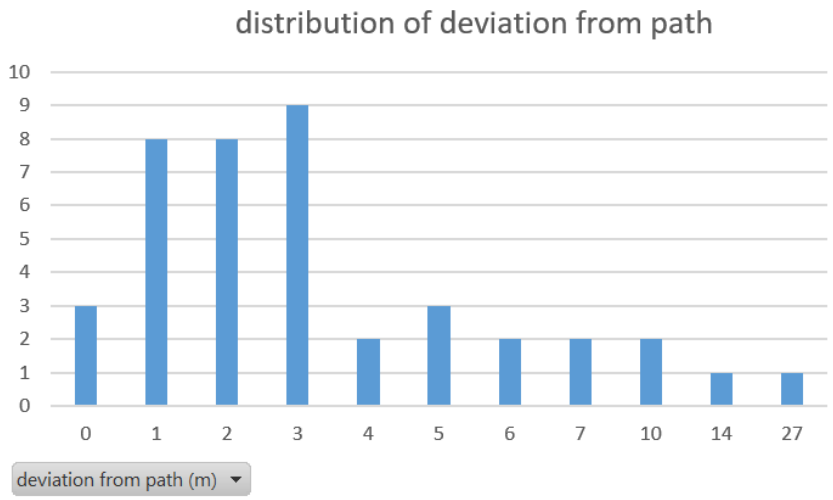


Figure 8.1: The distribution of the path error. As visible from the graph, there are 4 instances where the system deviated 10 meters or more from the path.

8.3 User Experiment

For evaluating the system on its ability to answer the research questions, the system needs to be evaluated on multiple facets. Most of these facets are based on the behavioural change of the users. This evaluation includes the reaction to the child and the parent to the new technology and the change in their behaviour. But also evaluate the effectiveness of the system in terms of search time decrease and the minimum density of the users for the system to be effective.

This evaluation requires a small amount of participants to install the app and run it in the background of their phones while they are around the Smart Xp of the Zilverling at the University of Twente[2]. This is needed to create a network to evaluate and test with. For evaluating the effectiveness of the system, a doll is placed in this area. One at a time, Participants are asked to locate a doll carrying the prototype tag. The searching time will be matched against the searching time without the system. Also, their behaviour will be studied. After the experiment, the users are asked some questions regarding their motive for their behaviour.

Hypothesis:

The hypothesis in this evaluation is that the participant using the system will be faster in locating the doll than participants without the system because they have access to an approximate location of the doll. The hypothesis will be accepted if the average searching time is decreased by 25%.

[2] The testing area is approximately 520 m^2. A few rooms next to the SmartXp are also included to increase the chance of being in the wrong room, which could happen when looking for a child.

8.4 User Experiment Results

During the Evaluation phase, users of the system were not measurably faster in finding the doll again than non-users.

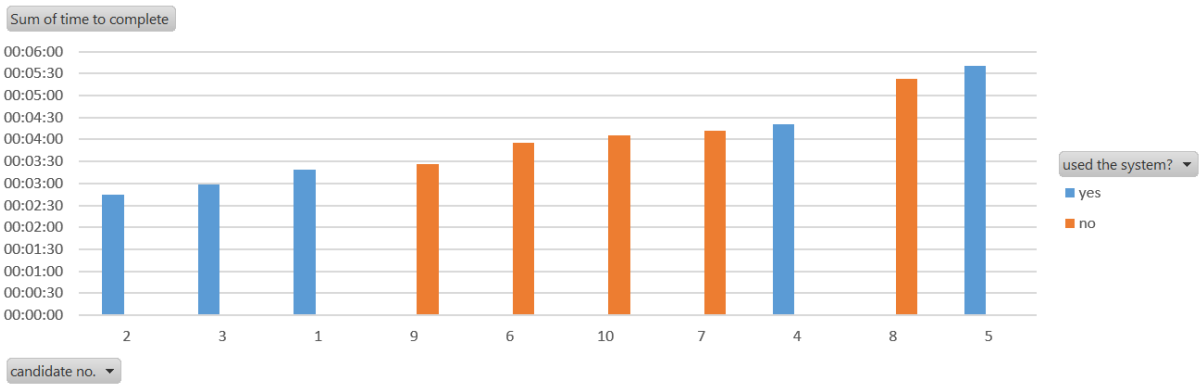
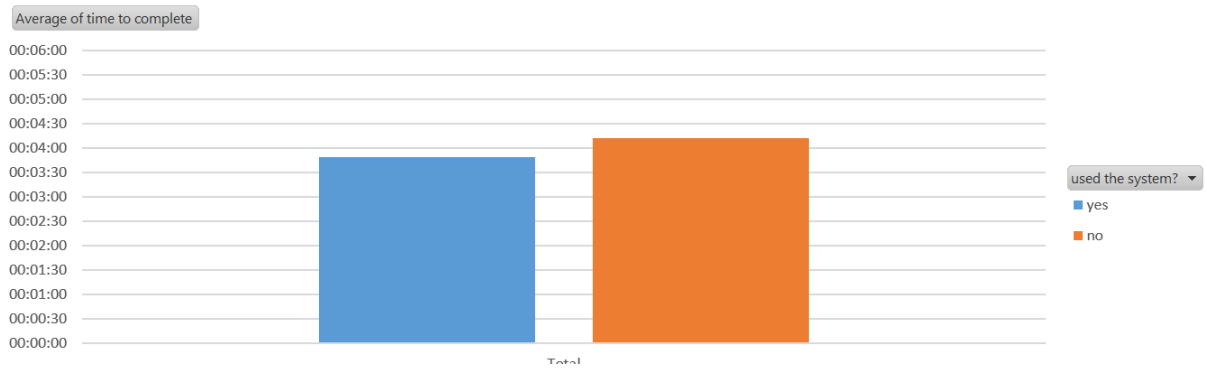


Figure 8.2: the time it took participants to complete assignment, ordered by speed. In blue, the users of the system are highlighted. Orange are the users without access to the system.



Some remarkable results were that the behaviour of people changed depending on if they used the system or not. Participants with the app followed the path of the child, rather than going to the last point the child was located. This caused them to walk for longer than necessary. People that didn't use the system also asked other people if they had seen the doll whereas participants with the system did not ask around. This decreased their searching time when the participant was already in the correct room. If not, it increased the searching time by a minute because the participants sometimes spend longer than necessary in the same room. When asked why they stayed longer in a certain room, 2 participants responded that they wanted to make sure they did not have to search a room twice. The full results can be found in appendix C

9 Analysis

According to the research data. It seems that the system does not significantly increase the finding speed of the user. In fact, it appears as if use of the system makes participants less likely to ask others which appears to be as effective as the system. The main feature of the system appears to be that users can start looking for their child in the right room. While the combination of using the proposed system and asking other people if they have seen the child seems to be the most effective approach, using technological means seems to decrease the use of this social equivalent. However, with a small test group, it can be hard to determine if the results are actually significant. The testing area was also quite small (~520m^2), which makes it difficult to simulate an actual public space, which is often much larger. It is expected that if this space was increased, the performance system users would increase in comparison to non-users.

The deviation of the location of the child given by the system and the actual location shows that a network of smart devices is quite capable of determining the location of a child at room accuracy. However, such networks are heavily dependent on the quality of data produced by the individual nodes. Because of this, these systems will probably be less accurate than other, more expensive, locating systems. The proposed system is cheap by design because the network is built by the collective user base instead of the system owner. It provides an easy way for public spaces to evaluate the need for a locating system. If there is a need, they may invest in more robust solutions.

10 Discussion

During this research project, the question was raised about what is necessary to locate children via technical means in a public space while maintaining low maintenance costs. To answer this questions in steps, four sub questions were formulated.

- *What are similar solutions and how do they compare with the proposed solution?*
- *How do outdoor and indoor public space differ and what impact does it have on the solution?*
- *What are points of interest in public spaces that can assist in location tracking?*
- *How are ethical values ensured in this context?*

Similar solutions are in the many, but there is a common denominator in all locating techniques which is that they all rely on some form of network. Some are very accurate but expensive, while others are cheap but less accurate. The cost is heavily dependent on the cost per node and the workings of the network itself. The stronger the signal needs to be, the

more expensive both the tag and the node will become. To cut costs, either existing nodes needs to be repurposed or the accuracy of the system must be downscaled. In this project, the use of phones as nodes has been proposed to cut costs while sacrificing as little as possible in the accuracy of the system. The accuracy of the network is variable depending on the amount of users which is useful in a closed context such as public spaces due to the user density those areas provide. Outside of these areas, it becomes vastly less accurate because of the lower density.

Out- and indoor areas vary in which location techniques are most accurate. Outdoors, GPS and cellular towers are most effective since they have a very large coverage. Indoors, the density of Wi-Fi access points make it more effective as a means of localization. Bluetooth can also be effective, although these beacons often have to be installed, whereas Wi-Fi is often already available. To ensure the highest accuracy, smartphones can be used since they have access to all of these techniques and can combine them to provide higher accuracy.

With location monitoring, privacy concerns are often expressed. To ensure the freedom of space for children, systems made for helping find children should not become a means to inhibit their privacy. This should be done by design. Examples of such design decisions are making continuous monitoring impossible or giving children the ability to hide their location when they do not wish to be found.

The proposed system scans only for Bluetooth addresses. There is no communication with other devices besides the database. The exchange of addresses and the signal strength does not provide any useful information for people who do not know what they should be looking for. While this discussion is quite complex and will not be solved within this document. Removal of data after a short amount of time and providing data only on a need-to-know basis should decrease if not invalidate most of the concerns expressed. Encryption of this data would further decrease the ethical concerns with localization techniques.

11 Future Work

Overall, the research on this topic is far from over. While this research shows promise for a cheap and fast network building method, some aspects could not be explored due to time constraints. In future research, these aspects should be researched in depth.

One of the major points that should get attention in future research is how maps of a public space could help to locate children. For example, since it is not possible to instantly move to another floor when there are no stairs or elevators nearby, a location system could make

assumptions about where the child should be and eliminate certain rooms accordingly. This would require tests about how fast children can walk and how this elimination of areas would work in detail.

To ensure an actual implementation of a system like the one described in this paper, the effectiveness of the proposed system versus other means of localization should be explored. This could be measured over both performance and cost efficiency.

During the evaluating phase it was noted that users actually followed the path the child walked. This may have been impacted by the way the path was presented. To make sure that this is the case, there should be research about the best way to present this information. This could make the system more effective or maybe improve insight about the behaviour of the users.

One unexpected finding was that the use of technology seems to decrease the likelihood that people will ask for assistance. This change of behaviour could be researched to establish if this is only dependent on the use of localisation techniques or if it is applicable in a broader sense such as technology as a whole.

All in all, most research in this area should mainly be focussed on the human factor and how the system should adapt to that. A small research could be to include a text to remind the user that asking for help is still possible when using technology and see if results differ from the result presented in this paper.

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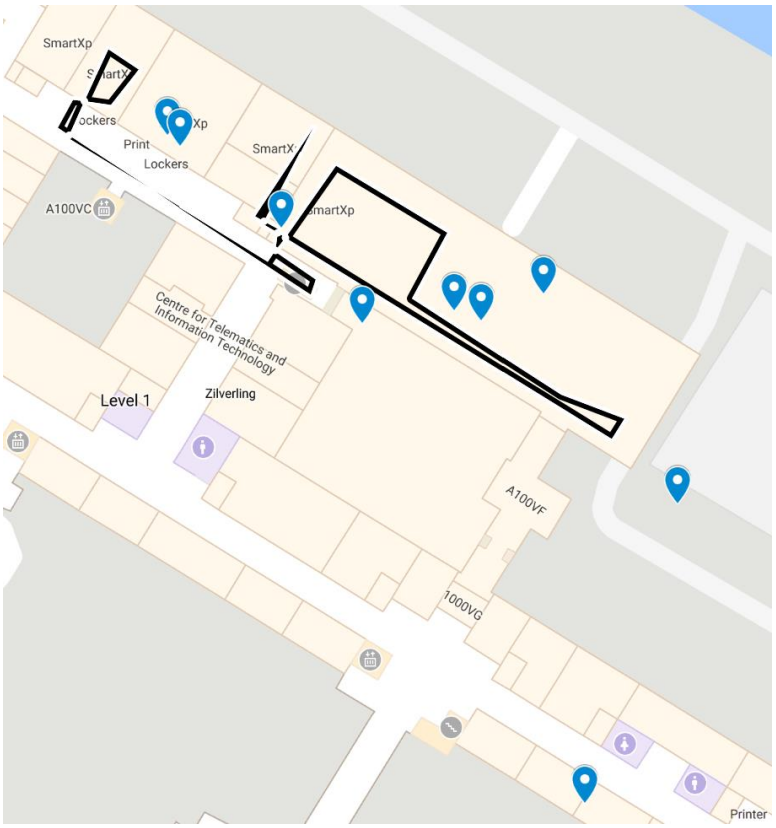
Appendix A: Childfinder Internet Survey Results

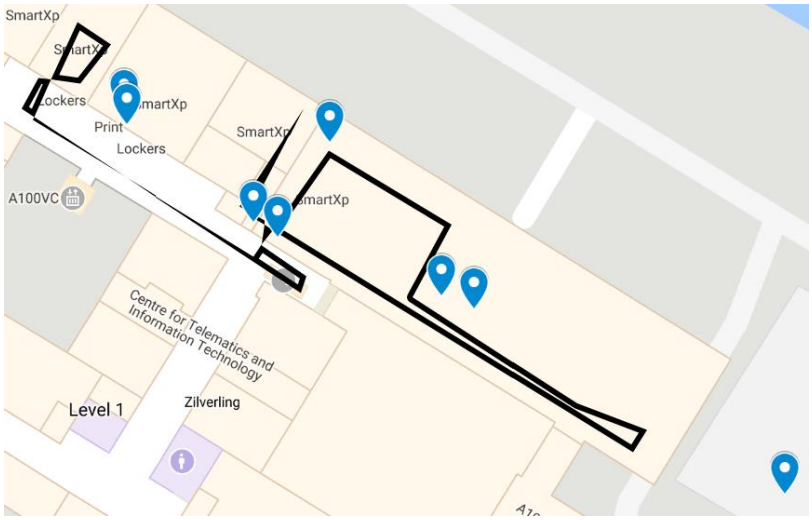
Appendix B: Testing Phase Path Deviation Visualized.

This Appendix represents the test results accuracy of the system. Below are screenshots from the location Google maps interpreted from the coordinate as well as the corresponding tables which were saved during the tests.



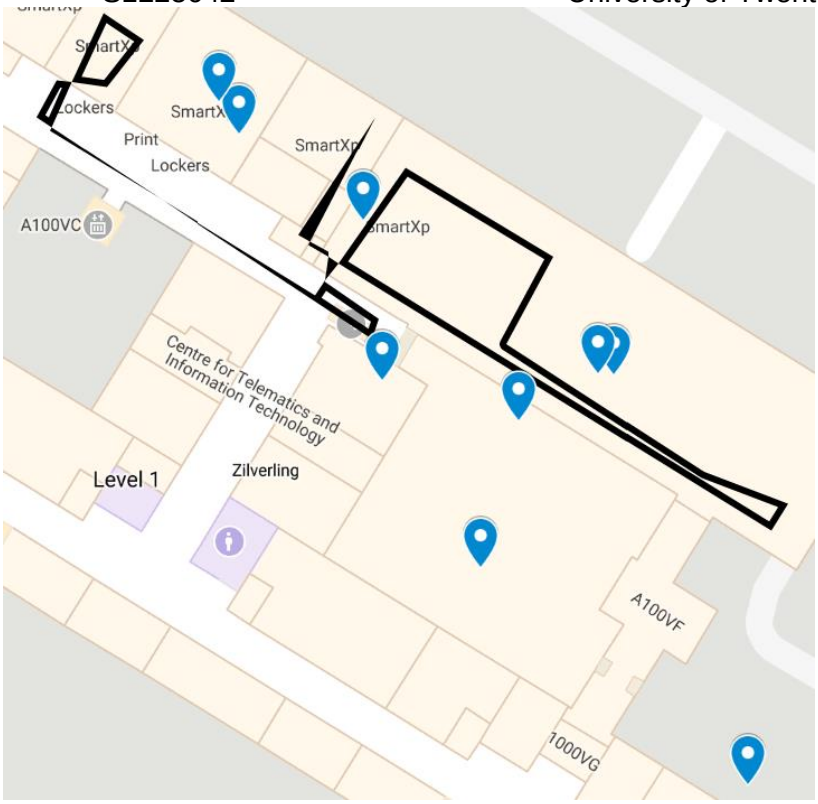
Test 1:

Location	deviation from path (m)
52.23925,6.85703	2
52.23894,6.85727	27
52.23926,6.85713	1
52.23914,6.85737	7
52.23931,6.85695	0
52.23927,6.85723	5
52.23937,6.85683	4
52.23925,6.85716	1
52.23937,6.85684	3



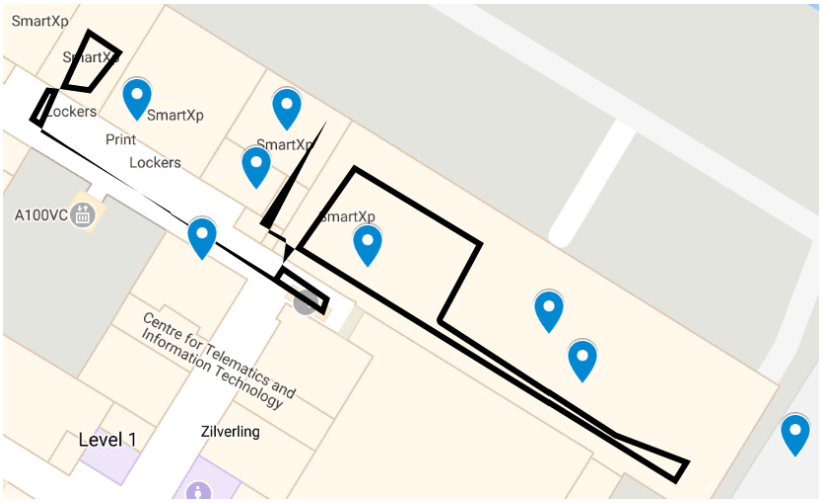
Test 2:

Location	deviation from path (m)
52.23935, 6.85700	3
52.23931, 6.85693	0
52.23937, 6.85680	3
52.23937, 6.85681	3
52.23913, 6.85695	1
52.23926, 6.85711	2
52.23926, 6.85714	3
52.23915, 6.85744	10



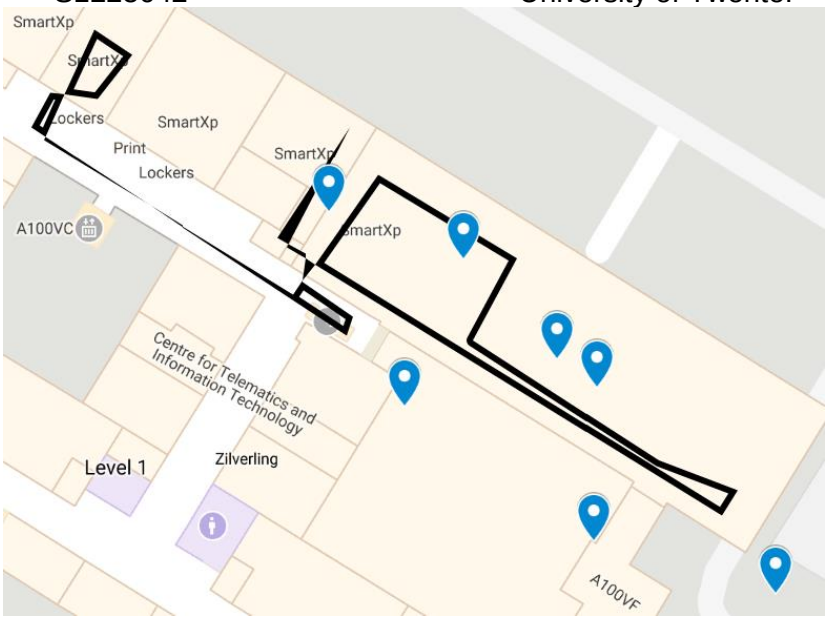
Test 3:

Location	deviation from path (m)
52.23925, 6.85698	3
52.23915, 6.85706	10
52.23923, 6.85709	2
52.23905, 6.85728	14
52.23932, 6.85697	0
52.23925, 6.85717	2
52.23937, 6.85687	5
52.23925, 6.85716	1
52.23938, 6.85685	6



Test 4:

Location	deviation from path (m)
52.23937, 6.85694	2
52.23937, 6.85680	3
52.23929, 6.85701	1
52.23923, 6.85721	1
52.23919, 6.8574	7
52.23926, 6.85718	3
52.23934, 6.85691	1
52.2393, 6.85686	2



Test 5:

Location	deviation from path (m)
52.23923, 6.85702	4
52.23916, 6.85718	5
52.23925, 6.85715	2
52.23913, 6.85734	6
52.23933, 6.85696	1
52.23931, 6.85707	2
52.23924, 6.85719	3

Appendix C: Evaluating Phase, Searching Time of Users

Candidate no.	**Time to complete**	**Used the system?**	**Remarks**
1	00:03:19	yes	Did not like the look of the app
2	00:02:45	yes	
3	00:02:58	yes	Loses a lot of stuff, said she was experienced
4	00:04:20	yes	
5	00:05:40	yes	Followed the path because he thought that was the assignment
6	00:03:55	no	Asked around immediately
7	00:04:12	no	Did not want to search the room twice
8	00:05:22	no	Wanted to know for sure he did not overlook the doll
9	00:03:26	no	
10	00:04:05	no	